A RAND NOTE

Analyzing the Transitory Costs of Regulation with an Application to Toxic Chemicals

Frank Camm, Daniel F. Kohler

June 1987

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The research described in this report was funded at least in part with Federal funds from the U.S. Environmental Protection Agency under Cooperative Agreement No. CR-811034-03-0.
A RAND NOTE

N-2586-EPA

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Prepared for
The U.S. Environmental Protection Agency
PREFACE

This Note presents a methodology for evaluating the economic costs of regulation, particularly transitory costs. Even though transition costs may disappear after the regulation is imposed, they may nevertheless be large enough at the time of regulation to influence decisions on when and how to regulate.

The methodology developed should be of interest to those involved in regulation, particularly those charged with managing the transition to a new regulatory regime. Because the research was sponsored by the Office of Toxic Substances in the Environmental Protection Agency, it uses the prohibition of toxic chemicals to focus discussion. Hence, the methodology should be of special interest to analysts and decisionmakers charged with regulating toxic substances.

The research was performed under Cooperative Agreement CR-811034-03-0 between The RAND Corporation and the U.S. Environmental Protection Agency. Related RAND studies under the same agreement include:

SUMMARY

When the Environmental Protection Agency (EPA) determines that a chemical is hazardous, it can restrict, or possibly prohibit its manufacture and use. Whether and how EPA regulates a hazardous chemical will depend at least in part on whether the benefits of a particular regulation exceed its costs.

This Note reviews the factors that affect the costs of chemicals regulation, giving special attention to costs that might result from the transition to regulation. While these costs may not be present many years after a regulation is imposed, they can be large enough to affect the overall comparison of costs and benefits. If they fall on a well-defined group, like the owners of assets used to produce a prohibited chemical, transition costs can also create political barriers far out of proportion to their share in total social regulatory costs.

The policy used to impose regulation can significantly affect transition costs; when policy changes are announced in advance, or phased in over a period of time, transitory costs are likely to be lower. While this Note does not examine alternative policies for implementing regulation, the cost and measurement concepts presented here should prove helpful in comparing such policy alternatives.

To measure the costs of a regulation, we must understand how it affects various actors in the economy. Regulation of a hazardous chemical has immediate effects on producers and users. It also affects actors in related markets. For example, regulation will generally increase the cost of products made with the regulated chemical, encouraging consumers of these products to seek alternatives. This search will create a demand for other chemicals and for inputs used in the manufacture and application of these chemicals. Regulation will also reduce the wealth of some actors, particularly those holding assets specialized for use in the manufacture or application of the regulated chemical. Understanding how regulation affects these various actors provides the first step toward understanding its costs.
Using a simplified model of a regulated market and markets related to it, the Note explains how a new regulation changes the economic environment for these markets and thereby induces new investment in some assets, including new knowledge, and decumulation of other existing assets. Understanding the rate and effects of these changes in asset holding provides the basis for understanding transitional regulatory costs. Standard economic welfare measures can help us understand some of these costs. A welfare measure based on regulation-induced changes in the value of assets can prove useful when these measures fall short.

For simplicity, suppose the regulation in question takes the form of an absolute prohibition on a chemical's manufacture and use. This prohibition will have four major types of effects.

First, the regulation will eliminate the consumer surplus associated with products that employ the chemical, that is, the dollar value of these products to consumers over and above the amount they pay for them. This surplus is normally measured as the area between the demand curve for the regulated chemical and its preregulatory price.

The use of this measure raises three issues: (1) The measurement is correct only if the proper demand curve is used. The Note explains why a mutatis mutandis demand curve is required and what it means in this context. (2) This measure of consumer surplus reflects regulation-induced changes in rents other than those we can attribute to final consumers. The Note explains why this area also reflects regulatory effects on other factors of production that are used with the regulated chemical to provide products. (3) This change in consumer surplus is appropriate only for the period immediately following the imposition of the regulation. But we can expect regulation-induced innovations to offset at least a portion of this loss as they generate alternatives to the regulated chemical and the processes associated with it.

Second, the prohibition reduces the quasirents that accrue to assets associated with the regulated chemical. If the assets have other uses, the loss in quasirents is the difference in their earnings before and after regulation. If there are no alternative uses, this equals
their earnings prior to regulation. In measuring this loss, one should note that the assets associated with a regulated chemical would have depreciated over time even in the absence of a regulatory change so that their quasirents would also have fallen over time. Hence, regulation-induced losses associated with these assets fall over their expected lifetime, reaching zero when these assets would have been retired or converted to alternative use in the absence of regulation. Because regulation can eliminate the markets for such assets, we cannot use traditional methods based on market data to measure this effect.

The Note presents a method for measuring these costs based on the cash flows expected from these assets in the absence of regulation. It shows that these effects depend on the expected lives of existing assets, their rates of physical depreciation, and the vintage of existing assets when regulatory change is announced. Accelerating the date of announcement of any regulation, or otherwise lengthening the period between announcement and implementation, can reduce these costs.

Third, a prohibition on the use of a chemical induces investment in innovation and in new assets. The prohibition effectively induces technical change that would not have been profitable in the absence of regulatory change. Similarly, by increasing the demand for substitutes for the chemical and its products and new processes to provide those products, the prohibition induces a wide variety of investments. In measuring the costs of a regulation, one must understand that the regulation does not require these responses. It creates an economic environment in which these investments become profitable. That is, investors expect the returns from these new investments to exceed their costs. As a result, we should not count these "conversion" costs in the costs of regulation without seeking measures of the positive effects they generate, effects that are likely to dominate their investment costs.

Investments in innovation and tangible assets reflect a situation in which desired capital stocks exceed actual stocks. In a frictionless world, adjustment would occur instantly and the gains from this investment would immediately be competed away to consumers of the final
products affected. In fact, "adjustment costs" dictate that learning and net investment take time. The Note explains this phenomenon and shows how it translates into a series of investments that, over time, offset a portion of the initial negative effects of the regulation. The Note argues that methods normally used to measure the effects of technical change can be used to measure these effects over time. However, we should not expect the positive effects of these investments to offset all negative effects of regulation; otherwise, incentives would have existed in the preregulatory period to pursue these investments.

Fourth, a prohibition increases the rents earned by assets that exist when the regulation is imposed and thus increases their value. The resulting divergence between desired and actual stock increases the demand for new investment and offsets some of the negative effects of regulation on other parts of the economy. Ultimately this effect ends when rents earned by these assets are just sufficient to justify new investment. This occurs, of course, at the same time that the net investment in new assets, discussed above, ends.

The measurement techniques available to deal with all these effects generate annual data that must be aggregated over time. The standard method of aggregation involves the use of a social discount rate. The same discount rate should be applied to negative effects on existing assets and care should be taken to avoid double-counting when combining these effects with the others. The measures proposed here rely heavily on the expectation that, in the long run, the private benefits and costs of new investment typically just balance in competitive markets. As a result, we need not give these private costs and benefits much attention in the analysis. This approach can present a problem when private and social discount rates differ, a problem addressed in detail in the Note.

The Note demonstrates the proposed treatment of negative effects on existing assets with an analytic case study of the regulations that ended most aerosol application of chlorofluorocarbons (CFCs) in the United States in 1979. These regulations provide a useful case because the period between their first consideration and their effective
enactment illustrates a suitably complicated transition and because relevant data are available from earlier cost-benefit studies. Using a historical case of this kind allowed us to avoid many difficult problems of predicting responses to regulatory change.

The case study illustrates that, while the concept of measuring regulatory effects on asset values is simple, its implementation requires many subtle judgments. The conceptual discussion in the Note is designed to help analysts make these judgments in an informed way. The case study presents a sensitivity analysis to indicate how important the basic characteristics of existing assets are to the determination of regulatory effects. Even the highest estimates of cost in this analysis are only a fraction of earlier cost estimates. Without attempting a complete critique of earlier estimates, the case explains the differences in terms of important costs and benefits neglected in earlier work. Hence, in addition to providing a basis for estimating regulatory effects in future studies, the framework presented here should prove useful in interpreting the estimates in existing studies.
ACKNOWLEDGMENTS

Michael Shapiro of the Office of Toxic Substances of EPA provided helpful support and advice. At RAND, Timothy Quinn made important contributions to some basic ideas presented here. Christine Augustyniak and Stanley Besen provided careful reviews of earlier drafts. Nancy Rizor managed the manuscript through its various versions. We thank them all, but retain responsibility for any errors of fact or interpretation.
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I. INTRODUCTION

An important function of the Office of Toxic Substances (OTS) of the Environmental Protection Agency (EPA) is to determine whether specific chemicals are dangerous enough for their manufacture and use to be restricted or prohibited. OTS must develop a case for regulating a chemical; this process takes time and alerts the public to OTS intentions. Further, administrative law dictates a set of procedures that OTS must use to notify the public of a pending rulemaking. Once OTS has decided to regulate the manufacture and use of a chemical in any or all applications, however, it can impose a regulation immediately. Alternatively, it can adopt a policy that delays total regulation in any of a number of ways. Delaying implementation of regulation delays the date at which its benefits are realized. But it can also reduce the social costs of regulation and that may be enough to warrant delaying these benefits.

Specifically, delay can reduce the allocative or "deadweight" losses associated with a regulation. For example, the loss in value that a regulation imposes on existing assets is a social loss that is not fully offset by gains elsewhere in the economy. Further, rapid, unanticipated reaction to regulatory change generally requires greater use of socially valuable resources than phased, planned adjustment. The social costs associated with an immediate prohibition can exceed the social benefits from reducing the adverse health effects of a toxic chemical.

This Note argues that costs associated with the transition to regulation can be substantial relative to other costs and benefits. It proposes an approach to cost-benefit analysis that gives special attention to transitory costs associated with ownership of assets. In its analysis, the Note assumes that a regulatory change yields net social benefits, at least after some point. It does not question the methods used to quantify or monetize the benefit measure used to reach
this conclusion or attempt to specify what form these social benefits might take in any more than the broadest terms. Given that net social benefits can ultimately be expected to result, the Note focuses on the costs associated with moving to a new regulation.

Fig. 1.1 illustrates the basic logic underlying the paper. On the abscissa, we show the time elapsed between the announcement of a regulatory decision \( t_0 \) and its implementation. The curve \( B \) represents the real benefits of the regulation as a function of the time between \( t_0 \) and the effective date of the regulation, discounted to \( t_0 \). If one year elapses before the regulation becomes effective, the benefits that would have accrued during that year are forgone, and the total discounted benefits are smaller. Therefore \( B \) is a declining function of the time between announcement and effective date of the regulation.

![Diagram](image)

**Fig. 1.1—Benefits and costs of alternative transition policies**
In an analogous fashion, $C_{LR}$ represents the real long-run costs of the regulation, also discounted to $t_0$. By the same argument as above for $B$, $C_{LR}$ is also downward sloping.¹

The discounted transition costs $C$ have to be added to $C_{LR}$ to obtain the total costs of the regulation. If $C$ were independent of the time elapsed between the announcement and the effective date of the regulation, transition costs would simply represent a proportional upward shift of $C_{LR}$. However, as we argue above, a delay between the announcement and the effective date of the regulation can reduce these transition costs. Hence, $C$ is downward sloping not only because of discounting, but also because a longer delay offers the parties affected by regulation more flexibility in reducing their transition costs. Note that, despite the clear net benefit of a regulation in the long run, $C+C_{LR}$ can lie above $B$ for regulations imposed with little warning, because transition costs outweigh long-term net benefits.

Section II constructs a simple model of a market for which regulation is being considered and the markets related to it. The model allows us to examine the likely effects of a prohibition that are relevant to the issues above. Section III reviews the standard method for measuring the welfare implications of the regulatory effects discussed in Sec. II. It shows how to measure the initial negative effect of regulation and the partially offsetting positive effects that accompany adjustment to the regulation over time. It also emphasizes that effects on producer surplus are typically much smaller than standard analyses suggest because much of producer surplus is a quasirent that must be netted out against investment costs. Section IV provides an alternative way to measure effects on producer surplus based on policy-induced changes in the value of assets. It is particularly useful in evaluating effects of assets in existence when a regulation starts. Section V illustrates the measurement concepts developed in the

¹We have assumed that the annual benefits and the annual long-run costs of the regulation are constant in real terms, so that $C_{LR}$ is always proportional to $B$. 
Note for a particular case, the U.S. prohibition against using chlorofluorocarbons in most aerosol applications in 1979. Because this prohibition has likely had its full effects and is not open to current dispute in the U.S. policy arena, we hope that an illustration based on this case can focus on methodological issues.

Compared with the methodological treatment in the preceding sections, Sec. V makes a number of simplifying assumptions. These are conditioned in part by data limitations (no new information could be collected for this exercise), and in part reflect a desire to keep the illustration as simple as possible. The simplicity helps emphasize those aspects that are most likely to influence transition costs.

Section VI sums up the Note and suggests directions for future work.
II. BEHAVIORAL EFFECTS OF PROHIBITING THE MANUFACTURE AND USE OF A CHEMICAL

Regulating the manufacture and use of a chemical will directly affect the markets in which that chemical is manufactured and used as well as markets vertically and horizontally related to these markets. Any set of measures used to quantify the effects of regulation must reflect the effects that regulation might have in these related markets. This section presents a simplified model of these markets and the channels through which the effects of a regulation pass from one market to another. We use regulatory prohibition of the manufacture and use of a chemical to exercise and thereby explain the model.\(^1\) The section starts with an overview of the principal effects of a prohibition and a model we can use to explain these. It then uses the graphical tools of price theory to trace the effects of a prohibition through the model.

OVERVIEW AND MODEL

What markets would a prohibition be likely to affect? Effects start in the market where manufacturers first sell the chemical to users, who then use it as an input to produce other goods and services. The effects of a prohibition flow "backward," reducing demand for inputs used in producing the chemical. They flow "forward," forcing users of the chemical to find substitutes and raising the cost of continuing to produce the goods and services they produce. Users of the prohibited chemical may be able to turn to an alternative chemical as a substitute. Final consumers of the goods based on the prohibited chemical, reacting to the higher cost of these goods, will also seek substitutes. These

\(^1\)Prohibiting the manufacture and use of a chemical is obviously only one regulatory option available to EPA. EPA could instead decide to restrict the chemical to "essential" uses, require the use of protective clothing during its manufacture, or insist on other preventive measures. For analytical purposes, we can think of all regulation as increasing the cost of using the chemical. A prohibition simply raises costs high enough to drive use to zero.
shifts in demand increase the demand for other goods, possibly including basic chemicals that serve as direct or indirect substitutes for the prohibited chemical.

We must understand these effects and how they move over time from one market to another. We can use a simplified model of the affected markets to do this. Figure 2.1 provides a schematic diagram of the model we will use. We assume, first, that the prohibition comes with no warning and trace the effects of the prohibition. Then we consider the effects of announcing a prohibition in advance.

Prohibition without Advance Announcement

Consider first the market in which the chemical to be prohibited (chemical A) is manufactured (box 10). Prohibiting the chemical's manufacture will reduce demand for the inputs used in its manufacture. These include capital assets (box 14) and other inputs (box 15). Lower demand could potentially reduce the prices these inputs receive and reduce the utilization of affected assets in the short run. For simplicity, we will assume in this section that lower demand has no effects on the price for "other inputs," implying that we need not analyze welfare effects associated with these inputs. Effects on capital assets will depend on the structure and nature of existing assets used to produce the prohibited chemical (box 18). Assets that are fully specialized to the manufacture of the chemical will lose all of their productive value, potentially leaving only some value as scrap. Typically, assets will not be fully specialized and, at some cost, can be moved to lower-valued use elsewhere, limiting the effect of the prohibition on their values.

Chemicals are typically intermediate goods, used with other factors in the production of other goods and services (3A). Prohibiting the use

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2The supply elasticity in this market is therefore assumed to be infinitely elastic. No quasirents exist in the market to repay earlier investment costs. By implication, all costs are variable, and prices fully reflect these costs. There are no net social effects in this market. These assumptions are obviously oversimplified. In fact, we drop this assumption in the case study in Sec. V.
Fig. 2.1—Schematic view of markets affected by a prohibition on manufacturing and using chemical A
of a chemical forces the user to employ an alternative input mix in the production process or withdraw from markets dependent on the chemical. Assets that are fully specialized to use with the chemical (box 7) lose their full value (again, other than scrap value). How much value is actually lost depends on the structure and nature of these assets (box 6) relative to those of other assets used in the industry. Effects on the demand for other assets and inputs (box 8) depend on whether they are substitutes or complements for the regulated chemical and, where they are substitutes, whether they are close enough substitutes so that the positive effect on demand of changing the factor mix outweighs the negative effect of a reduction in the demand for the products of this industry. Again, for simplicity, we assume that the services of these other inputs, including nonspecialized assets, are provided in infinitely elastic supply. Because a prohibition cannot affect their prices, we can neglect welfare effects in box 8.

The unavailability of the prohibited chemical begins a diffuse process of substitution toward other parts of the economy. Where other chemicals (chemical B) are used directly as factors with the prohibited chemical, substitution may occur directly (box 3B). Substitution will start shortly after the prohibition on the basis of the substitution opportunities and the complementary assets available to facilitate substitution (box 2). Users of the prohibited and substitute chemicals will begin to invest to increase their understanding of substitution opportunities and to increase the availability of assets that increase substitution (box 1). Meanwhile, the loss of the prohibited chemical raises the cost of producing goods and services previously based on the chemical, forcing the industry to raise the prices of these goods and services. Final consumers react by substituting away from these goods to alternatives (box 3C). Immediately following price increases, they react on the basis of their existing knowledge and assets (box 2). Like the industrial users of the prohibited chemical, however, they invest in new knowledge and assets to facilitate further substitution (box 1). This process increases the demand for goods ultimately based on other
chemicals that can be thought of as indirect substitutes for the prohibited chemical (box 3B). Hence, even in the absence of a direct relationship between the industry using the prohibited chemical and other chemicals, we can expect to see substitution toward alternatives through less direct means. This substitution could easily proceed on a diffuse front through many input-output relationships in the economy. For simplicity, we focus these substitutions in a single chemical (B) and simple channels of influence presented in box 3.

Increased demand for this substitute chemical and products based on it increases demand for other goods as well. Demand rises for the services of capital assets used with the substitute chemical (box 4), raising their utilization rate and the quasirents they earn. The prospect of higher profitability encourages new investment at a rate determined by the costs of supplying new assets and how it responds to changes in the rate of investment (box 5). As new assets accumulate, the cost of producing these alternative goods falls. As producers pass these cost savings on to consumers through competitive markets, substitution away from goods based on the prohibited chemical accelerates. Demand also rises for other inputs employed with the substitute chemical (box 9). As elsewhere, we assume their services are supplied with infinite elasticity; changes in demand have no net welfare effects.

Increased demand for the substitute chemical also increases the demand for inputs used to produce it (box 13). Increased demand for existing assets increases utilization rates and quasirents earned by these assets (box 17); owners react by expanding investment (box 19). How fast investment occurs depends on how investment costs change when the rate of investment changes. Demand rises for other inputs. They are assumed to be supplied with infinite elasticity so that no welfare effects occur here (box 16).

The way the model in Fig 2.1 is constructed, the effects of the prohibition radiate away from the market for the prohibited chemical (box 12) toward places where capital divestment and accumulation occur (shaded boxes 1, 5, 6, 18, and 19). The prohibition changes current and
expected future prices, altering the incentives to invest, and thereby setting in motion changes in the capital stocks in affected markets. These changes affect prices in following periods, changing behavior, and creating incentives for future investment decisions. In sum, an unannounced prohibition creates a large initial shock in the markets affected. As we shall see in Section III, this shock carries a large social cost. It also changes the economic landscape, creating opportunities to profit from new investment in knowledge and production assets. To anticipate Sec. III, these investments create net social benefits that to some extent offset the initial social cost imposed by the prohibition. Net social benefits continue to accumulate as investment and behavioral response continue. While they may become substantial, these accumulating benefits fully offset the negative social effects of the initial shock only if investment in knowledge following a prohibition is more productive than could reasonably have been expected. Hence, analysts should not predict a complete offset.

Prohibition with Advance Announcement

If a prohibition is announced in advance, events will differ from those described above in several important ways. First, while an unannounced prohibition will initiate the events above as soon as the prohibition starts, a prohibition announced in advance can induce effects well before the prohibition takes effect. In particular, producers and users of the chemical to be banned will change their investment behavior, reducing the effect of the prohibition itself on the value of existing assets. They will also invest in planning before the prohibition to reduce the annual rate at which they react to the prohibition, thereby reducing the total cost of the reaction. More measured reaction in each year should moderate regulatory effects on prices faced by asset owners, other inputs, and final consumers.

When a future prohibition is announced, owners of assets used to produce the prohibited chemical will immediately begin to reassess their investment plans (boxes 14 and 18 of Fig. 2.1, above). They will no longer invest in assets that must earn quasirents beyond the date of
prohibition to repay investment costs. This will reduce production over time, forcing up the price of the regulated chemical.\textsuperscript{3} If the price rises enough before the prohibition, investors may package assets that can be converted to other uses when the prohibition starts; these must cost more per unit of output than the assets they would have bought in the absence of regulation. Owners of assets that are specialized to use as factors with the prohibited chemical will react in a similar way (boxes 6 and 7). In either case, these investors will lose a smaller share of the value of their assets when the prohibition takes effect than they would if the future prohibition had not been announced.

Users of the prohibited chemical will begin to seek alternative factor mixes as soon as the prohibition is announced (boxes 1 and 2). To the extent that they are aware of the coming ban, final consumers will react in a similar way. Producers of substitute goods based on alternative chemicals or of chemicals that can serve as direct substitutes will also begin to accumulate the capital required to produce more of these goods and chemicals (boxes 4, 5, 17, and 19). As new assets are employed, the cost of producing the alternative may fall. Coupled with higher prices for the prohibited chemical, this change in cost can encourage substitution away from the prohibited chemical to alternatives even before the prohibition is effective. This effect tells us that the benefits of a prohibition can begin to flow before the prohibition takes effect, reducing the effect of delay of the accrual of benefits. How fast this occurs depends on all of the factors shown in Fig. 2.1. Let us turn now to a more detailed discussion of the behavioral decisions that drive the effects shown there.

\textsuperscript{3}Anticipating a prohibition, users of the prohibited chemical might possibly substitute away from that chemical more rapidly than the capital stock depreciates, effectively reducing demand for the remaining capital and placing downward pressure on its price. By assumption in this section, however, the users' preferences are stable over the period of change. Unless the prices they face change, we should not expect them to change their use of a chemical until it is prohibited, forcing them to change. If regulation affects users' preferences themselves, substitution can occur more rapidly. This possibility arises in the case studied in Sec. V.
THE PRINCIPAL EFFECTS OF A PROHIBITION

To start, use the model in Fig. 2.1, above, to consider how the markets for A and B would behave over time in the absence of a prohibition. We can then consider how behavior in these markets would change as the result of regulation, assuming first that consumers and producers do not anticipate the regulation and then assuming that they do.

Market Behavior without Regulation

Analyzing the markets for the regulated chemical (A) and its substitute (B) is simple. We assume that both markets are competitive and that both chemicals are produced without the use of any unique or irreproducible inputs so that their marginal costs are infinitely elastic in the long run. We assume that both are "mature" chemicals for which price equals marginal cost and marginal cost does not change over time in response to learning by doing.4

Figure 2.2 shows the markets for these chemicals in the absence of any regulation. The market for chemical A is shown in panel (a); that for chemical B is in panel (b). In each panel, production and consumption are on the abscissa; own price and marginal cost are on the ordinate. \( D_A^0 \) and \( C_A^0 \) are demand and marginal cost schedules defined over a one-year horizon at the prevailing prices. Prices are \( P_A^0 \) and equilibrium levels of production and consumption, \( Q_A^0 \). In the absence of regulation, the prices and quantities will remain stable over time.

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4Chemical B may well be a "new" chemical subject to two important influences not considered here. First, if little production experience exists for chemical B, we can expect its production cost to drop over time as the production process is finely tuned. This is known as "learning by doing" in the economics literature. It implies that costs fall as production cumulates. See, for example, Asher (1956) or Alchian (1959). Second, with a new chemical, a few producers typically dominate its production. These firms can use their dominance to earn rents that allow them to recapture their development costs for the chemical. It is appropriate to consider such "transitory monopoly" pricing in a competitive analysis because rents need not be earned over the long run if the monopoly pricing just allows a producer to recover earlier costs. See, for example, Schumpeter (1950) or Nelson and Winter (1982). We plan to examine the implications of these considerations in the future.
Fig. 2.2—Chemical markets without regulation
Response to an Unanticipated Prohibition

How would a regulatory prohibition of A affect the circumstances in Fig. 2.2? We start by assuming that regulation is unanticipated. A prohibition has the same effects as an exogenous rise in the price of A high enough to drive demand to zero. Chemical A is an intermediate good used by its consumers along with other factors to produce other goods and services. A price increase large enough to drive demand to zero encourages users to find alternatives to using chemical A in the production process. Changing the factor mix must raise costs, encouraging further search for alternatives downstream. Prohibition, then, helps providers of other factors, including capital assets, that are substitutes for A and A-based products and hurts providers of factors that are complements--specialized to use with chemical A.

We assume that products based on B, and perhaps even B itself, behave like close substitutes, assuring that a prohibition of A raises demand for B to $D_B^1$ in Fig. 2.3. Since a rise in the price of B raises the price of A required to drive demand for A to zero, which in turn raises the demand for B and its price, $D_B^1$ must be drawn to be consistent with $P_A = P_A^1$ and $D_A^1$ must be drawn to be consistent with $P_B = P_B^1$. The extent of the rise in B, then, depends on the own and cross price elasticities of A and B and on the supply elasticity of B.

We should expect all of these elasticities to change as producers and consumers adjust to the new regime. For example, former users of A will invest in efforts to increase the substitutability of other inputs for A and invest in new assets that can provide substitute services. Normally, the marginal cost of accumulating new capital or knowledge rises with the rate of accumulation. Hence, it is not cost-effective to move to the new desired stock of capital immediately. Neoclassical investment theory tells us that the level of investment in any period is

In the terminology of Palmer and Kohler (1985), $D_i^0$ and $D_i^1$ are ceteris paribus demand schedules, defined for a fixed level of other prices and income and allowing only quantity to vary with own price. As Sec. III explains, we will use an alternative definition of demand schedules to measure welfare effects.
Fig. 2.3—Chemical markets with regulation
governed by factors like those shown in Fig. 2.4. The level of investment in any period is shown on the abscissa; the ratio of the marginal value of investment to its "normal" marginal cost appears on the ordinate. In steady state, the investor presumably invests just enough to cover depreciation in his existing stock. At this point, marginal value of investment just equals normal marginal cost, leading to steady state (gross) investment at I₀. An unexpected change, however, can drive marginal value above this level. For example, suppose the prohibition of A drives the marginal value of added knowledge about substitution from V₀ to V₁. Ideally, the investor would like to invest I₁, where marginal value just covers the long-run, normal marginal cost of investment. But rapid investment brings adjustment costs into play, driving up the cost of investment. Suppose this is reflected by a schedule C. In the period following the prohibition, the investor will acquire I₂. As knowledge accumulates, V falls over time. Net investment continues as long as V exceeds C at any point beyond I₀. Salinger and Summers (1983) reports empirical results that indicate that C is typically steep; this suggests that net investment should continue for a long time. Substitution improves with each incremenl to knowledge.⁷

Improving substitution increases the cross-price elasticity between A and B. This generates better ways to shift to B and thereby reduces the price at which demand for A falls to zero. The size of these shifts over time should depend on the slope of the C function in Fig. 2.4. The faster the cost of new assets rises as demand for them rises in any period, the more slowly users of A will acquire new assets to allow adjustment.

The rise in demand for B should benefit owners of assets used jointly with B in the production of other goods, used to produce B

⁶This figure in fact reflects Tobin's q-theory of investment. Hayashi (1982) shows that q-theory is equivalent to neoclassical theory executed with adjustment costs.

⁷This view of improving substitution plays an important role in the welfare analysis offered in Sec. III.
itself, and used to produce these assets and others that facilitate substitution from A to B.

Since B is a mature chemical, we would expect the equilibrium in the market B to achieve a situation in which price returns to $P_B^0$. Price-quantity pairs would follow locus I in Fig. 2.5 through time.

**Response to a Prohibition with Anticipation**

The discussion so far assumes that consumers and producers do not anticipate the prohibition. Given the way regulations are promulgated in EPA, of course, anticipation is inevitable. Further, delaying a prohibition order for some period beyond the date when EPA decides to regulate can increase the effects of anticipation still further.

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*This, of course, is the meaning of the analysis in Fig. 2.4 when it is applied to the market for assets that produce B.*
Fig. 2.5—Time trends of price-quantity pairs under regulation
The general effect of anticipation is to add degrees of freedom in the actions consumers and producers take to adjust to a prohibition. Since they can behave as they would without advance warning, warning presumably allows them to avoid certain costs. We can expect to observe the following kinds of adjustment to reduce costs.

Owners of assets used to produce A, or used as complementary factors with A, will anticipate the devaluation of their assets. They will either stop replacing depreciating assets or acquire shorter-lived assets that cost more per unit of production. The exact pattern of investment during the period between announcement and prohibition depends on the prices asset owners expect for A and A-based products.

Anticipating the eventual loss of A, producers of A-based products will begin to consider substitution opportunities and new capital acquisitions to prepare for the prohibition. As Fig. 2.4 indicates, so long as the cost of new capital rises with the investment rate, investment costs can be moderated by spreading investment over time. Hence, the steeper that C rises in Fig. 2.4, the sooner we expect investment to start in anticipation of the prohibition.

Note that investment decisions here and in the production of A are interdependent. For simplicity, think of the relationship sequentially. Given investment on the demand side without regulation, suppose we find an investment pattern on the supply side that implies a rapid rise in the price of A before the prohibition takes effect. Such a price rise will encourage users to substitute away from A so rapidly that demand will not be sufficient to justify the new investment in production facilities. But if producers of A slow their planned investment, a smaller rise in price is required to justify their investment. Now A is worth more to users, and users slow their substitution plans to take advantage of lower prices for A, and so on. Such planning and counterplanning underlie the determination of an equilibrium path of the price of A that is compatible with investment plans among producers and consumers of A during the period leading to prohibition.⁹

⁹Current neoclassical practice would posit this kind of equilibrium—a rational expectations equilibrium—without further discussion. Austrian discussion would emphasize the absence of
Considerations similar to those for the user of A will drive the decisions of asset owners who plan to use or produce B. The faster investment costs rise with the rate of investment, the more they will react to an announcement. Their reactions, of course, must ultimately be compatible with the path of prices for B, which must also reflect the path of A prices up to the date of prohibition. That is, investment behavior by all of the parties shown in boxes 1, 5, 6, 18, and 19 in Fig. 2.1 is interdependent.

Without providing a formal proof based on this interdependence, we conjecture that the price of A will rise over the period from announcement to prohibition. (See locus II in Fig. 2.5.) The price of B may rise or fall. Because owners of assets that produce A or complements of A will divest in response to the announcement, the price of A will be forced up. It will continue to rise over time to support any continuing investment and to ration falling supplies of A and A-based products. The rising price of A will speed substitution toward B. If it is cost-effective for investors to expand assets that produce B in anticipation of future demand faster than the market for B grows, the price of B will fall (locus III); otherwise it will rise (locus IV). As we have seen, available empirical evidence suggests that investment costs rise fast enough with the rate of investment to suggest that a rise in the price of B is likely.

Such considerations indicate how complex the reaction to an anticipated prohibition might be, but they do not affect our qualitative discussion of what happens following a prohibition. A portion of the adjustment that would have taken place after an unanticipated prohibition is complete when prohibition comes, suggesting that less remains to be done. The adjustment that does occur takes place over a

equilibrium and the continual flow of information provided by prices during the adjustment period, suggesting lagged responses similar to those in a cobweb formulation. Both approaches have value. For analytic purposes, the equilibrium approach provides a simpler way to view the future. The analytical identification of the equilibrium for any explicit formulation of the relevant behavioral functions, however, is nontrivial.
longer period of time, reducing its cost and hence the swings in price we discussed earlier. Otherwise, the events following prohibition differ little from those discussed above.

Perhaps the most important implication of the analysis offered here for the period from announcement to prohibition is that the regulatory effects of a prohibition can occur well before the prohibition itself takes effect. In fact it can occur even before the announcement of prohibition occurs since regulation is discussed extensively before it is finally adopted. As the parties in Fig. 2.1 become increasingly convinced that a prohibition will be announced, they will begin to adjust in the ways discussed here. To the extent that beliefs about the probability of prohibition differ among these parties, we will see rates of adjustment at different levels from those implied by this analysis. But the qualitative analysis will be the same. This raises the serious problem of determining when reaction to regulation actually starts and hence how long is the effective lag. This lag could vary considerably among players with different expectations. And the lag could be large enough for most players so that the gap between the date of announcement and the date at which the prohibition takes effect is small relative to the total period of adjustment.

SUMMARY AND IMPLICATIONS

The prohibition most directly affects the producers of A, who include the owners of the assets used directly to produce A and those who provide other goods and services used as inputs in the production of A. Prohibiting the production of A eliminates revenues they expected to receive for their services. The consumers of A use A as an input together with other factors of production to produce still other goods. To the extent that a drop in the availability of A reduces the demand for these factors, their producers can also be hurt by the regulation.

Owners of factors that can substitute for A or A-based products, however, benefit. Given our assumptions, producers of goods based on B, and ultimately B itself, are among these; they face a regulation-induced increased demand for their services. Owners of assets used directly to
produce B and owners of assets that produce other inputs used to produce B all experience higher revenues. Similarly, providers and producers of factors used with B to produce other goods also see an increased demand for their services whether they are substitutes or complements.

Finally, producers of assets that facilitate the transition, either by making the transition easier or by allowing producers in the market for B to expand their production capacity faster, benefit from the regulation.

The size of regulation-induced allocative losses depends on the effects of a prohibition on prices and quantities in the markets examined here. The initial loss of the consumer and producer surpluses for chemical A when it is banned is the most obvious source of allocative loss. The size of these surpluses depends on the demand for and the marginal cost of A and on how they change over time in response to regulation. As investment in assets and knowledge occurs in the periods following prohibition or its announcement, new surpluses are created to offset a portion of the initial loss. How large these are and how rapidly they accumulate depends on all of the factors discussed in this section.\(^\text{10}\) Section III explores these issues in more detail.

\(^{10}\text{If B is a "new" chemical, the presence of learning by doing or transitory monopoly rents in the market for B also has important implications for allocative efficiency. While we do not discuss these in this Note, the framework in this section provides a useful starting point for understanding the behavioral implications of these considerations and their effect on the size and timing of policy-induced changes in allocative efficiency. We plan to examine these issues in the future.}
III. WELFARE MEASUREMENT BASED ON CASH FLOWS OVER TIME

As we have seen, a prohibition can affect markets that extend well beyond the market in which the prohibition is actually imposed. This section reviews the standard approach to measuring the welfare effects of a policy change that affects many markets.

The section starts by looking at the first period following a prohibition. This period or its functional equivalent, a typical year in a steady state that persists for many years after a regulatory change, is often the focus of regulatory analysis. In fact, this first year initiates a series of responses to regulatory change that preclude any notion of a typical year or steady state. For example, former consumers of a prohibited chemical seek and learn more about alternatives as time passes, reducing the costs that a prohibition imposes on them. Owners of assets formerly used to produce a prohibited chemical find alternative uses for their assets and experience a falling loss over time. Effects on other parties change in other ways. The analytic way to measure these changes described in this section views the changes a year at a time and then discusses the problem of aggregating effects over time.

MEASURING WELFARE EFFECTS IMMEDIATELY FOLLOWING A CHANGE

As we have seen, a prohibition affects markets both horizontally and vertically related to the regulated market. Consider effects on horizontally affected markets first.

The simple case of examining welfare effects on a regulated market and the market for a substitute is shown in Fig. 3.1. The market for chemical A appears in panel (a); that for chemical B is in panel (b). Both panels show quantity on the abscissa and price on the ordinate. $D_1^0$ and $C_1$ are the demand and marginal cost schedules for the period following prohibition if a prohibition had not occurred. A prohibition of the manufacture and use of A moves consumption of A from $Q_A^0$ to zero.
Fig. 3.1—Effects of a prohibition on horizontally related markets
Demand schedules shift to $D_i^1$ in response. $M$ is a *mutatis mutandis* demand curve that traces the price of $A$ as a prohibition is (hypothetically) imposed incrementally.\footnote{Palmer and Kohler (1985) discuss this curve in greater depth.}

Standard welfare analysis indicates that the shaded area measures the welfare loss caused by the prohibition in this period.\footnote{We use the Hicks-Hotelling formula as the standard approach to welfare measurement. This is $\Sigma \int [P_i(Q) - C_i(Q)]dQ_i$, where the summation is across all quantities, $Q_i$. $Q$ is a vector of all quantities, $P_i - M_i$ is the gap between price and marginal cost, and each integral is evaluated over the range of regulation-induced change in quantity. See, for example, Harberger (1971) or Just et al. (1982).} As the prohibition is incrementally imposed, the gap between marginal value (price) and marginal cost grows in the market for $A$, indicating an ever-growing incremental loss of net welfare. In the market for $B$, these increments move consumption up $C_B^0$, holding marginal value and cost equal at every point. Aggregating the effects of these incremental movements yields the shaded area in panel (a) and no net effect in panel (b).\footnote{The standard analysis allows many other measures, each based on adjusting quantities from pre- to post-regulatory levels in different sequences. We choose a measure that adjusts all quantities simultaneously in response to a hypothetical incremental implementation of the prohibition. That is, the measure is $\Sigma \int (P_i - C_i')(\partial Q_i/\partial s)ds$, where the prohibition is reflected as incremental changes in $s$. To understand $s$, think of using an incrementally imposed tax to effect the prohibition; the tax is increased until consumption of $A$ ends. Then we can think of $\partial Q_i/\partial s$ as the effect of each incremental tax increase on each quantity of interest and $ds$ as a counter that tracks "how fast" the tax rises. Although we speak of increments, of course, $s$ acts as a device to impose the prohibitionary tax instantly.} Where $A$ and $B$ are used by different industries, regulatory effects on their factors look very much like those in panel (b). A prohibition changes the demand for these factors, shifting price-quantity pairs in these markets along the relevant supply schedules. However, because price and marginal cost remain equal along these schedules, there are no net welfare effects in these markets.
Let us now consider vertically affected markets. \( C_A^0 \) in Fig. 3.1 reflects the total reservation value of the resources used to produce each increment of A. Resources include both those owned by the industry and those purchased. An increase in output generates \( Q_A dC_A + C_A dQ_A \) in incremental revenue for these resources and forces them to forgo \( C_A dQ_A \); the difference is \( Q_A dC_A \). Integrating from \( C_A = 0 \) to \( C_A = P_A \) yields the area we normally refer to as "producer surplus." A portion of this accrues to the industry producing A; the remainder accrues to inputs that this industry purchases.

Figure 3.2 illustrates a way to distinguish these portions. Quantity and price appear respectively on the abscissa and ordinate. \( C_A \) is the marginal cost schedule we observe in the market for A. Before

![Diagram](image)

Fig. 3.2—Allocation of producer surplus to inputs in production of A
regulation, this market equilibrates at \((P_A^0, Q_A^0)\). When demand falls below \(Q_A^0\), the marginal cost of producing A falls for two reasons. First, with input prices fixed, marginal production costs typically decline with lower production as the ratio of variable to fixed inputs falls, raising the marginal product of the variable inputs. Second, falling demand may drive down input prices. This is most likely to be important for specialized inputs like assets with limited alternative applications. Finally, factor prices reinforce rising marginal products, allowing marginal costs to fall faster as demand falls.

Holding input prices constant as demand falls from \(Q_A^0\), we can trace out a marginal cost schedule like \(C_A'\). \(C_A\) lies below this if falling input prices push marginal costs down farther. Area I is the surplus earned by the industry itself; area II accrues to purchased inputs. To simplify the analysis, we have assumed that all purchased inputs are available at constant prices. Under these circumstances, \(C_A\) and \(C_A'\) coincide and all producer surplus accrues to the producing industry. Similar arguments apply throughout the analysis wherever we observe producer surplus.

The existence of producer surplus raises a potential paradox in competitive markets. It suggests that owners of assets are earning rents over and above the opportunity costs of these assets. However, in competitive markets, these are quasirents that, over the life of an asset, are just sufficient to justify the initial investment. While producer surplus does not exist in competitive markets in the long run, a regulatory change can eliminate quasirents. That kind of loss is captured by the areas shown in Fig. 3.2.

The remaining portion of surplus, that between the initial price, \(P_A^0\), and \(N\) over the range from \(Q_A = 0\) to \(Q_A^0\) in Fig. 3.1, above, is typically called "consumer surplus" but in fact accrues to many different parties, as Fig. 3.3 illustrates. Panel (a) shows the market for a final product Z, which is produced using A. Panel (b) shows the market for A. Panel (c) shows the market for another factor, Y, which is used in the production of Z. Quantity and price appear,
Fig. 3.3—Allocation of consumer surplus associated with A
respectively, on the abscissa and ordinate in each panel. \( M_Z \) and \( M_Y \) are *mutatis mutandis* demand curves analogous to \( M_A \); they all trace out the price-quantity pairs that result from incrementally imposing the prohibition on manufacture and use of \( A \). Moving from \( Q_A^0 \) to the left reduces \( Q_Z \) and, by hypothesis, increases \( Q_Y \). Moving \( A \) to the left in panel (b) eliminates perceived value of \( P_A dQ_A \) and changes payments by \( P_A dQ_A + Q_A^0 dP_A \) for a net loss of \( Q_A dP_A \). Reducing \( A \) moves \( Z \) to the left in panel (a), imposing a loss of \( Q_Z dP_Z \) that can be derived in a similar manner. Reducing \( A \) moves \( Y \) to the right in panel (c), creating a gain of \( Q_Y dP_Y \). The changes in the three panels are related. In particular, \( Q_A dP_A = Q_Z dP_Z - Q_Y dP_Y \). That is, the loss in "consumer surplus" in panel (b) in fact reflects the loss in final consumer surplus, shown in panel (a), *less* the gain in producer surplus in panel (c). Hence, using the area between \( M_A \) and the initial price, \( P_A^0 \), can underestimate the true loss in consumer surplus imposed by a regulatory prohibition. The actual loss is larger than the area shown by the amount factors used with \( A \) to produce \( Z \) gain as a result of the prohibition.

We can now think about consumer surplus in panel (b) in a manner similar to that we used to distinguish who received producer surplus in Fig. 3.2, above. If \( P_Z \) and \( P_Y \) are constant, \( P_A \) must be constant. If \( P_Z \) is constant, the surplus that accrues to final consumers is zero and hence cannot change. In this case, losses of consumer surplus in panel

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*That is, the substitution effect of a higher cost of \( A \) dominates its output effect. For complementary factors, we would expect the opposite result. With only one other factor, gross substitutability is necessary; we assume here that this is large enough to outweigh the effect of higher cost on demand for \( Z \).*

*This is a consequence of the optimality conditions among these factors and product. For \( Z = f(A,Y) \) a production function, (i) \( dQ_Z = f_dQ_A + f_dQ_Y \) (total differentiation of the production function), (ii) \( P_i = P_i f_i \) (a condition of profit maximization), and (iii) \( Q_i dP_Z + P_i dQ_Z = P_A dQ_A + Q_A dP_A + P_Y dQ_Y + Q_Y dP_Y \) (total differentiation of the budget relationship in which revenue is exactly divided among factors). The expression in the text follows directly from multiplying (i) by \( P_Z \), substituting (ii) into (i), and subtracting the resulting expression from (iii). For more details, see Palmer and Kohler (1985).*
(b) indicate a drop in the price of Y and a loss of producer surplus by factors used with A in the production of Z. If \( p_Y \) is constant, on the other hand, the loss in panel (b) is in fact a loss in final consumer surplus.

From a social point of view, why do we need to distinguish who actually receives the "consumer" surplus measured in the market for A? Under our assumptions in Fig. 3.3, the surplus that final consumers of Z lose is larger than the area between \( M_A \) and \( P_A^0 \) in panel (b); it is offset by the net gain to all factors used with A in the production of Z. In the long term, however, the price of other factors is fixed. (Otherwise, the owners of Y could earn long-term rents on these assets.) A long-run demand curve for A, then, should just reflect the rents lost by final consumers in response to regulation. We need to distinguish final consumers from other claimants of rents because, in the absence of unique assets, only final consumers can earn rents that are at risk in the long run.

Analogous arguments apply to the consumer surplus associated with B. Where A and B are used as factors in the same production function, "consumer surplus" measured in each market in fact reflects producer well-being in the other, as well as welfare effects on other factors.

MEASURING WELFARE EFFECTS IN THE YEARS FOLLOWING A CHANGE

The analysis in Sec. II indicates that two kinds of changes occur in the years following a prohibition. First, former consumers of the prohibited chemical seek alternatives. In the meantime, costs of products previously based on the prohibited chemical rise; consumers of these products seek alternatives or more efficient ways to use the products. Second, asset levels adjust. Stocks of assets specialized to the production or use of the prohibited chemical fall as they depreciate, reducing the potential product from these assets. Assets associated with new alternatives to the prohibited chemical and products based on it expand as demand for them rises. As Sec. II stresses, these processes occur over time. As they occur, the annual measures shown in Fig. 3.1, above, lose their relevance. New measures are required for
each year. Consider measures associated with each kind of change in turn.

**Consumer Responses**

The consumer responses that concern us are all new investments induced by the prohibition. The prohibition disturbs the equilibrium in a series of markets, creating opportunities for creative investors in knowledge. To the extent that investment yields knowledge, it is a form of induced technical change that expands the set of opportunities beyond those available immediately following the prohibition. The welfare effects of such technical change can be measured as those of any technical change would be. The easiest way to think of such measures is as reductions in the cost of providing the final goods that final consumers value. Fig. 3.4 illustrates such an approach.

Panel (a) shows the market for a final good, $Z$, originally based on the prohibited chemical, $A$. Price and quantity are on the ordinate and abscissa, respectively. Panel (b) shows an analogous market for $X$, a final good based on a substitute chemical, $B$. $Q^0_Z$ and $Q^0_X$ show consumption levels before a prohibition occurred. The prohibition immediately raises the cost of $Z$, shifting the marginal cost schedule from $C^0_Z$ to $C^1_Z$. $M_Z$ is a *mutatis mutandis* demand curve that shows the immediate reaction of final consumers as they shift from $Z$ toward $X$. Immediately following the prohibition, consumption levels lie at $Q^1_Z$ and $Q^1_X$.

Continuing investment yields more efficient ways to produce $Z$ and $X$, shifting $C_Z$ and $C_X$ down. Suppose they were to fall to $C^2_Z$ and $C^2_X$ in the second year following a prohibition. This would yield a gross social gain equal to the sum of areas I and II. The actual cost of investment must be subtracted from this gain, projected into the future and discounted to the year of investment, to yield the net social gain achieved. As innovation continues in succeeding years, analogous areas accrue, adding to the social gain achieved.
Fig. 3.4—Effects of regulation-induced technical change
This view of welfare measurement raises two important points. First and foremost, prohibitions and other regulatory changes typically induce a series of investments that allow the economy to adjust. It is not appropriate to include the cost of these adjustments as regulatory costs unless the gains that they yield are also counted. A prohibition does not compel anyone to make such investments; they are made only because someone expects them to yield benefits that at least offset their costs.

Second, the actual measurement of such net benefits is a demanding task. It requires that we posit a counterfactual marginal cost function \( C^1_x \) or \( C^0_x \) in Fig. 3.4) for each year following a prohibition and that we estimate the actual marginal cost function. If a function can be estimated, however, we can measure areas like I and II in Fig. 3.4 for each year following the prohibition. This area will include the gains created by all investment up to that year. A discounted sum of such areas can then be compared with the discounted sum of investment costs to calculate the full offset resulting from consumer responses to the prohibition.

The offset allowed by such responses should not be large enough to eliminate the social costs imposed by a prohibition. If that were possible, investment in innovation would have been profitable under the pre-regulatory environment. That is not to say that regulation never induces innovation that later turns out to completely eliminate the costs of the regulation; we should simply not expect it \textit{ex ante}. Nevertheless, such responses can offset a substantial portion of the cost of a prohibition. Their net benefits should not be neglected totally simply because they are difficult to measure.

\textbf{Asset Adjustments}

The second way in which adjustment can occur following a regulatory change is through changes in asset holdings. Owners of assets specialized to the regulated chemical or its inputs and products find alternative uses or stop replacing these assets as they depreciate.
Assets that can substitute for the regulated chemical or are related to goods that can substitute for it accumulate over time. Either type of change has effects similar to those discussed in terms of consumer responses and we can measure these effects in a similar way.

The parallel to our earlier discussion is most apparent when we discuss accumulation of new assets. Such accumulation following a regulatory change allows short-run marginal cost schedules to shift downward, just as $C_Z$ and $C_X$ shift down to $C_Z^2$ and $C_X^2$ in Fig. 3.4. Such shifts create gross social gains like those shown by areas I and II. To measure net social gains we must subtract from them their investment cost. Analysis like that in Fig. 2.4, above, tells us that net gains can be expected until actual and desired stock reach equality. At that point, net new investment stops and further investment yields no net gains.

How can we distinguish effects of investment in innovation from those of investment in new assets? With exceptional data and careful specification of the alternative investment processes, it may be possible to make such a division, but in general it will not. To the extent that we can measure areas like I and II in Fig. 3.4, we can say only that some form of regulation-induced investment created them. From a social point of view, we generally need not say whether that investment was in knowledge or tangible assets of some kind. In this sense, the "consumer" and "asset" adjustments we discuss here are cut from the same cloth.

Where assets are withdrawn from a market, or decumulate as owners fail to replace depreciating assets, short-run marginal cost schedules shift upward. We could potentially measure the loss of surplus associated with these assets with areas analogous to I and II in Fig. 3.4. Where markets continue to exist for the goods these assets produce, this is possible. The areas differ from those discussed above for two reasons. First, they now have negative value because rents are being eliminated. Second, no new investment is required to eliminate these rents. Hence, the areas generated in this fashion represent net social losses.

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6We must, of course, discount such net gains.
The most important circumstance in which regulation changes asset levels occurs in the market for the regulated chemical. If regulation prohibits use or production of a chemical, lost rents from the assets used to produce or process the chemical continue to accrue even if the market for these assets is eliminated by the regulation. Hence, while areas like I and II in Fig. 3.4 provide a conceptual way to think about these losses, we cannot measure these areas empirically by observing changes in prices or quantities. To the extent that standard welfare analysis focuses on measures that use empirically measured price or quantity changes, it cannot capture the value of rents lost when regulation takes specialized capital out of service. We discuss in Sec. IV an alternative approach that produces an empirically based way to measure such losses.

AGGREGATING EFFECTS MEASURED FOR INDIVIDUAL YEARS ACROSS TIME

The analysis above points to a series of annual effects on social welfare. Three points are important.

First, there will be a significant negative effect in the year immediately following the prohibition. This includes the loss of consumer surplus associated with final goods produced using the prohibited chemical and the quasirents that would otherwise have accrued to assets specialized to the prohibited chemical. The loss may be offset to some extent by rents accruing to existing assets that are substitutes for the prohibited chemical or its products.

Second, the loss will continue through time but each of them changes through time as consumers and asset owners adjust to the prohibition. Investment in new techniques to replace the prohibited chemical presumably yields net benefits that partially offset the initial loss of consumer surplus. Depreciation of assets over time assures that quasirents that would have accrued to assets displaced by the prohibition fall after the first year. On the other hand,

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7It will be correct, however, when assets are unspecialized.
additional rents earned by assets that act as substitutes for the prohibited chemical decline as these rents attract new investment in these assets.

Third, new investment in innovation ultimately exhausts opportunities for investment. That is, the initial loss of consumer surplus is increasingly offset over time, but the incremental offset falls until it reaches zero. The total effect is then constant over time. Forgone quasirents from assets specialized to the prohibited chemicals actually fall as these assets depreciate until they reach the end of their natural lives. At this point, no further costs are incurred by the owner of these assets. Rents earned by assets that substitute for the prohibited chemical and its products ultimately fall to the level that is just sufficient to cover new investment costs.

To complete the analysis, we must aggregate these effects over time. We use the social discount rate to calculate the net present value of these annual flows.

SUMMARY

This section has developed a number of basic results by viewing an unannounced prohibition in the terms of standard welfare measurement methods.

First, four kinds of welfare effects can be distinguished.

- Prohibition eliminates rents that accrue to final consumers of the goods produced with a prohibited chemical. When all affected chemicals are mature and a steady state characterizes the affected markets, these annual rents are constant over time.

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*This analysis does not consider the social benefits that presumably flow from a prohibition; it considers only the social costs created in the pursuit of these benefits.
*This presents a problem if we believe the social and private discount rates differ. Appendix B discusses this problem.
Prohibition eliminates quasirents that would have accrued to owners of assets that are retired or placed in lower-valued use as a result of the prohibition. As these assets depreciate over time, these losses decline and eventually fall to zero.

Prohibition creates net rents as a result of new investment in tangible assets and knowledge following the prohibition. Because the prohibition creates the opportunity for privately discounted benefits to exceed investment costs, the resulting net benefits must be credited to the prohibition. They can partially offset lost rents associated with the first kind of welfare effect.

Assets in existence when the prohibition occurred that act as substitutes for the prohibited chemical or its products can earn net rents until new investment reduces these rents to the level just required to sustain the existing capital stock.

Second, the four kinds of welfare effects above should be aggregated over time using a social discount rate. If the private and social discount rates are the same, in the absence of regulation we can expect investment costs to just offset quasirents. We should not expect this from new investment in tangible assets and innovation, where prohibition creates opportunities to capture net rents in new investment. In fact, we expect social discount rates to be lower than private discount rates, suggesting that even marginal private investment generates net social benefits. The net social value of investment eliminated or encouraged by a prohibition, which results from the difference between private and social discount rates, should be reflected in a complete cost-benefit analysis. It is less important to one concerned primarily with environmental policy.

Third, welfare effects take many different forms in this analysis. When all affected chemicals are mature, the initial effect of prohibition can be measured in the market for the prohibited chemical as the loss of "consumer" and producer surplus. The effects of prohibition-
induced investment in years following prohibition can be measured by subtracting investment costs from discounted sums of relevant areas created or destroyed by shifting demand and marginal cost functions. Conceptually, the easiest places to observe these changes are the final product markets associated with the affected chemicals. Shifts in the marginal cost schedules for these products point to accumulating assets and technical change. Rents created by these shifts, offset for the costs of the investment that induces them, represent social gains in the periods following prohibition. We cannot use market data during the period following a regulatory change to determine its effects on quasirents from assets retired or switched to lower-valued uses when the prohibition occurred. We address this kind of loss in Sec. IV.
IV. THE CHANGE IN ASSET VALUE AS A WELFARE MEASURE

As we have seen, policy effects on producers depend on how policy change affects the investment costs paid and quasirents received by producers. Most discussion of effects on producers focuses on producer surplus, which we normally think of as the aggregation of quasirents and investment costs associated with all of a producer's assets in one period.\(^1\) In some circumstances, it may be appropriate to focus on all of the quasirents and investment costs associated with a particular asset over time. For example, the net present value of future quasirents at any point in time equals the market value of the asset when we discount with a private rate. Hence, policy-induced changes in the market value of assets can provide information on how the owners of these assets perceive policy effects on their producer surplus in the future. Alternatively, we may want to treat different classes of assets differently for analytic purposes. For example, for new assets we must offset investment costs against the rents the investment makes possible. For existing rents, however, no offset is required. When we treat new and existing assets differently, it is often easier to use a measure of policy effects on quasirents that focuses on assets, not time periods. Such a measure addresses the effect of regulation on the value of assets. This section shows how to use policy-induced changes in the private and social value of assets to measure welfare losses.

QUASIRENTS AND INDIVIDUAL ASSET VALUE

Let us consider the linkage between an asset's value, the quasirents expected to accrue to it over time, and the way policy changes can affect these quasirents. Fig. 4.1 presents cash flows for a hypothetical asset in two different applications. Cash flows expected from the first are indicated by \(C_1\) and from the second by \(C_2\). The asset is switched from the first to the second use at time \(t_1\) when the second

\(^1\)See, for example, Harberger (1971), Just et al. (1982).
application yields a higher annual cash flow than the first. The asset is sold for scrap at time $t_S$ when its scrap value exceeds its remaining value in the second application. Over its lifetime, then, the asset has an expected cash flow profile indicated by the heavy locus $C^*$. 

At any point in time, say $t_0$, the value of the asset is the discounted area under $C^*$ and to the right of $t_0$. So long as the producer is not surprised over the life of the asset, the asset produces just enough quasirents—producer surplus—each period to cover the decline in its (resale) value over that period. This amount is known as the "economic depreciation" of the asset during the period. With a deep enough market in used assets, we could presumably use observable market values to calculate the economic depreciation for an asset. Alternatively, we can use assumptions about the characteristics of the
individual asset types—quasirent in the first period of alternative uses, depreciation rate in different uses, scrap value, and so on—as a basis for an analysis like that in Fig. 4.1.

How would we reflect regulatory change in such a figure? Let us illustrate how this is done with two examples.

Example 1. A prohibition on using existing machines. A product market is in steady state with no growth before regulation is changed. Price and quantity produced and consumed are constant over time. New machines to replace old ones as they are retired are available in any number at the same price as the old ones. The regulatory change prohibits all use of existing machines after $t_0$. As long as producers can buy new machines fast enough to avoid any interruption in production, life following the regulatory change continues as before. The old machine price and product price and quantity are sufficient to continue to encourage investment. Price and quantity in the market should not change.

Figure 4.1 provides a simple way to calculate the effects of the regulation. The asset owner will switch his machines to an alternative application early, losing the discounted value of the shaded area bounded by $C^*$, $C_2$, and $t_0$. If use in the second application had also been prohibited, the asset owner would lose the area below $C^*$ between $t_0$ and $t_5$. In either case, discounting these losses with the private discount rate would provide an estimate of regulatory effect on the value of this asset. The figure also provides a framework for calculating the social value of the loss in producer surplus by using the social discount rate.\(^2\) It should be clear that the regulation-induced loss grows as the remaining life in existing assets grows and the cash flow available from alternative uses falls. The approach

\(^2\)This measure of loss may appear to differ from that suggested by the standard approach to welfare measurement summarized in Sec. III. In fact, with no changes in prices or quantities, using the standard approach can be awkward. We must determine how annual cash flows differ with and without regulatory change. In this case, there is a difference in the timing of new investment. Appendix A explains this and shows that an approach based on comparing annual flows is equivalent to the approach presented here.
illustrated here is appropriate where the regulation does not change the cash flows expected for the asset. That is an appropriate assumption for the regulation in the first example.

Example 2. Imposition of a capital-intensive control technology. Other regulatory changes will affect prices or affect the net cash flow from particular applications directly. Suppose a control technology with a substantial capital cost but no operating costs must be applied to all producing machines in $t_0$, the year following a new regulation. This is equivalent to raising the cost of investment and producers will not invest in new machines unless prices rise enough to allow them to recover their investments.

The price of output from the first application in Fig. 4.1 would rise, shifting $C_1$ up and, perhaps, delaying a shift from the regulated application into the alternative. He would hold the asset in the regulated application if the shaded area that would be constructed with the new $C_1$ curve, properly discounted, were large enough to pay for the controls required by regulation. Otherwise, the owner would immediately switch the asset into the second application, incurring the shaded area, appropriately discounted, as the regulation-induced loss. For this type of regulation, the loss in producer surplus is the smaller of the quasirents that can be extracted from existing assets without driving them into alternative uses and the increased cost of the equipment itself. This loss equals the loss in the market value of the asset when we use a private discount rate; it equals the loss in social value with a social discount rate. Again, it should be clear that an owner would be more likely to buy control systems for newer assets and that the regulatory loss would tend to be larger as the remaining life of assets increased and the cash flows available from other uses fell.

"Standard" welfare analysis simply could not capture the subtlety of some of these events. It would indicate that output price had risen; the way in which this rise would be calculated could suggest that the rise was just sufficient to cover the higher capital costs associated with the controls. This would tell us nothing about the transition to a situation in which all assets are new; understanding this transition,
which is an important focus of our attention, would actually require
detail of the kind suggested in Fig. 4.1.

WHAT ASSET TYPES TO INCLUDE

Regulators may be interested in regulatory effects on producer
groups that own many kinds of assets. Regulation applied to a
particular industry will affect all of the assets directly employed in
that industry and assets in other industries that supply goods and
services to the regulated industry, compete with it by producing
substitute goods, or use its products as inputs.\(^3\) Within each of these
industries, regulation can affect the physical and intangible assets
owned by firms in the industries and human capital owned by the labor in
these industries. Given the long life of much specific human capital
and the importance of labor income even in relatively capital-intensive,
chemical-related industries, losses in human capital can easily dominate
those associated with physical capital.\(^4\)

Retrospective analyses of regulatory effects on asset values have
often included all of the assets owned by firms in an industry,
including intangibles like goodwill. That is, they have used the market
values of the shares of the firms affected.\(^5\) This approach works best
where a "pure play"--firms that perform specific functions related to
the chemical in question--can be identified. Where this is possible, it
has the advantage of including all physical and intangible assets in an

\(^3\)Note that any particular firm may be present in several of these
markets. For example, a chemical producer could easily produce
precursor chemicals, produce other chemicals that can serve as
substitutes in some uses, and market the chemicals it develops. It may
be difficult to allocate the assets it owns to these different
functions.

\(^4\)For example, the share of labor income in value added reported in
the 1977 input-output table, the most recent table available for the
U.S., is 51 percent for chemicals and selected chemical products
(industry number 27), 70 percent for plastics and synthetic materials
(28), 50 percent for drugs, cleaning and toilet preparations (29), and
45 percent for paints and allied products (30). U.S. Department of

\(^5\)For a good example and review of such models, see Schwert (1981).
industry that might be affected and using easily observable measures of their joint value. But it neglects changes in the value of human capital. Further, it is unlikely to be useful for prospective analysis of regulatory change because prospective stock values cannot be observed. But even where a "pure play" is identified, it can be difficult to sort out the effects of one regulatory change from all the other factors that affect a firm's value during the period in which the regulation is first announced, debated, adjusted, and finally adopted.

The type of analysis that is most likely to be useful to the analysis of regulating specific hazardous chemicals will focus on assets specific to the production of these chemicals. Depreciation schedules, based on schedules of cash flow like that in Fig. 4.1, can presumably be developed for the standard kinds of capital equipment and plant associated with chemical production; recent work developed for tax analysis may prove useful in this effort.\textsuperscript{6} Depreciation schedules for human capital will be more difficult to devise, particularly where they must segregate capital specialized to the regulated chemical from more general human capital embodied in labor. Much of the opposition to new regulation probably results from the loss it imposes on the value of skills that technical specialists, managers, and production workers have developed with respect to a specific chemical. But the rate of depreciation of human capital specific to a chemical will be hard to measure.

Intangible assets associated with research and development (R and D) pose a special problem in this approach. New chemicals that come under regulatory scrutiny will generally have supranormal quasirents associated with them--higher quasirents than those associated with the capital required to produce and market them. That is because these chemicals must, on average, also generate quasirents to repay the cost of developing them. Where chemicals are sold under license or royalty, we can readily infer the value of this quasirent. Where the same company develops, produces, and markets a chemical without using licensees, we face a difficult problem. With sufficient information

\textsuperscript{6}The basic reference is Hulten and Wykoff (1981).
about the market in which the chemical would be used and expectations
about its effects in that market, we could presumably estimate the
optimal marketing strategy for the firm and assume that the firm follows
that policy. Such efforts are more speculative than the other methods
suggested here, however, and can be expected to raise serious doubts
about the analysis.

SUMMARY

Policy-induced effects on asset values can provide an alternative
measure of welfare effects. Changes in market values reflect a private
perspective based on the private discount rate. But we can also focus
on assets from a social point of view when we wish to segregate assets
for analytic purposes. In particular, to determine policy effects on
quasirents expected from existing assets, this type of analysis is
vital.

Analysis of policy effects on asset values can focus on many forms
of assets, including physical, human, and financial varieties as well as
R and D, advertising, and general goodwill. The effects of a policy
change will be larger on these assets, (a) the fewer their alternative
uses, (b) the longer their normal lifetimes, and (c) the younger the
existing mix of capital when regulation changes. For quantitative
estimates of policy effects on asset values, we need fairly specific data
on the form of quasirents expected from assets over their lives. Good
data are beginning to be collected on the quasirents—"economic
depreciation"—from physical assets. Section V uses an analytic case
study to illustrate how to use such data to examine regulatory effects
on the owners of physical capital. More work is needed on other asset
types; the framework offered here should help structure empirical
inquiries about these.

7For a useful discussion of these issues, see McGee (1966).
V. THE U.S. BAN ON CHLOROFLUOROCARBON USE IN AEROSOLS:
A CASE STUDY OF NEGATIVE REGULATORY EFFECTS
ON EXISTING ASSETS

As indicated in sections IV and V, it is hard to use standard
welfare measures to quantify the negative effect of a regulatory change
on the owners of assets that exist when the change occurs. This factor
is the principal negative effect of regulatory change on manufacturers
and a major factor in general in transitory costs associated with
regulatory change. Section IV offers a method for measuring the size of
this effect. This section implements that method in a particular case--
the 1979 U.S. ban on "non-essential" use of chlorofluorocarbons (CFCs)
as aerosol propellants.

While previous attempts to measure the effects of this regulatory
change have yielded controversial policy implications, our primary
interest in the change is methodological.\textsuperscript{1} We draw the data for our
analysis from these studies, particularly the JACA report, and use
specific results from those studies as a reference point for comparison
with our results. But we do not attempt a comprehensive estimate of the
regulatory effects of this ban or a comprehensive critique of previous
studies. When we make comparisons, their intent is methodological:
This is the result of using the methods outlined in this Note relative
to the result that alternative methods would yield.

The aerosol ban has a number of features that make it attractive
for this methodological purpose. Data are available on the value of
existing assets. Data on substitutes and inputs to the regulated
chemicals ("precursor chemicals") are also available to support the
analysis. The ban uses explicit transition rules and its effects
reflect responses to regulation expected well before the regulatory
change took effect. And, perhaps most important for our purposes,

\textsuperscript{1}Previous attempts include Ando and Marshall (1983), hereafter the
JACA report, Kavanaugh et al. (1984), hereafter the ICF report, and
Yarrow (1986).
because the ban is not under scrutiny by U.S. domestic policymakers today, its use should not raise policy controversies that an analysis of a pending regulatory change might. The retrospective character of our analysis also lets us avoid many of the problems of predicting behavior discussed in Sec. II and rely on actual, observed behavior. Prospective regulatory analyses using this basic method, of course, would not have this luxury.

The case study proceeds in three stages. We first frame the analysis, reviewing when the effects of regulatory change began and how we should measure changes in asset values over time. We then estimate the "pre-regulatory" capacity of physical assets in two key industries potentially affected by the regulatory change—the aerosol filling industry and the manufacturing industries for CFCs and their primary precursor chemicals. Finally, we estimate the effects of regulatory change on the value of these assets. We employ sensitivity analysis to illustrate how alternative judgments about the characteristics of these assets affect our estimates of regulatory effect.

Given the primarily methodological purpose of this exercise, simplifying assumptions are used quite freely. For example, the possibilities of price changes are ignored, the time horizon is limited to 15 years, and all equipment within one industry is assumed to have the same overall life expectancy, though not necessarily the same remaining life at the time of regulation. Many of these assumptions are much more restrictive than the ones employed in the previous sections; data and space limitations make it impossible to carry out an example at the level of detail described in sections II through IV. As an illustration of the main concepts, the example presented here should suffice.

FRAMEWORK
When the Effects of the Ban Began

The use of CFCs as propellants in nonessential aerosols was banned in the United States in December 1978, and interstate shipments of such
products were prohibited in April 1979. However, the ban was announced considerably earlier (May 1977), labeling requirements were proposed (November 1976), and hearings on the environmental risks associated with CFC-propelled aerosols were held as early as 1974. The first bill proposing to ban CFCs was introduced in December 1974, and the state of Oregon imposed a ban on CFC-propelled aerosols in March 1975, well before the federal ban became effective. By the end of 1976, 30 states and/or localities were moving in that direction. The federal ban was thus certainly no surprise.

Indirect evidence supports the view that the regulation was anticipated as early as 1975. The number of aerosol fillings had begun to decline in 1973, probably at least in part in response to the recession. However, after 1975 the number of aerosols filled with hydrocarbons began to increase again, while CFC-propelled aerosols continued to decline. By the time the CFC ban became effective, the number of CFC-propelled aerosols produced annually had fallen to between one fourth and one third of the 1973/1974 level. To the extent that this reduction was due to disinvestment in the aerosol industry it indicates that producers of aerosols anticipated the ban and reacted to it rationally.

For the purposes of this example we therefore assume that investors discontinued investing in dedicated capital for the production of CFC-propelled aerosols in 1975. From that date on, the value of the capital stock declined each year as worn-out equipment was retired without being replaced. In 1979 the ban became effective, and the capital that had not been retired yet, and that was not subject to the essential use exemption, had its value reduced to scrap.  

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2For a detailed discussion of the regulatory history see the JACA report, 1983.
3We disregard the possibility of alternative uses for the installed capital stock (see below).
There are two additional effects that have to be considered in this case. First, a small quantity of CFCs (about 21 million pounds) is still used in essential aerosol applications. Thus, a fraction, about 5 percent, of the capital dedicated to CFC production for aerosol use was not devalued by the CFC ban. Second, consumers also anticipated the ban. An active education campaign by environmental groups raised the awareness of consumers, and many discontinued using CFC-propelled aerosols even before they were officially banned. To the extent that this decline in consumer demand outpaced the natural decline in productive capacity, it should be considered a cost of regulation. It had the effect of rendering fixed assets obsolete before they could be completely amortized.

For the period 1975 through 1978, therefore, we have to calculate the extent to which remaining capacity exceeded demand for CFC-propelled aerosols and their derived inputs. From 1979 on we have to calculate the extent to which remaining capacity exceeds the capacity necessary to satisfy the exempted demand. This concept is similar to what the JACA report calls the quantity "wedge."*

*Estimating the Value of Dedicated Capital

As explained in Sec. IV, the regulation-induced reduction in the value of a fixed asset is given by the reduction in the quasirents generated by this asset over the remaining economically useful life. With a few simplifying assumptions, we can estimate this reduction in value rather easily.

We make the following assumptions:

1. The assets are dedicated, i.e., they have no use in any alternative activity.

*The authors of the JACA report (we believe incorrectly) use predicted demand, rather than remaining capacity of fixed assets, as the upper bound of that wedge.
2. The owner of the fixed asset (the producer) expects to earn a fixed return per unit produced ("profit" per unit) net of maintenance and upkeep.\(^5\)

3. The productive capacity of each asset declines at a fixed proportional rate.\(^6\)

With exception of the first, these assumptions appear quite reasonable. Assuming that all assets currently used in the production of a product about to be banned have no alternative use is probably a considerable exaggeration. This is particularly true in the case of the CFC example. Only the use of CFCs in aerosols was banned, not CFC use overall. In fact, the use of CFCs in non-aerosol applications continued to expand rather vigorously, so that the capital dedicated to CFC production could continue to be used without any modifications. Even the production lines for filling CFC-propelled aerosols could be (and were) modified for use in filling HC-propelled products at relatively modest costs. Assuming that all this capital became worthless with the imposition of the ban is clearly an exaggeration. However, it is often impossible to ascertain which proportion of the capital stock is indeed dedicated, and what its value in alternative uses will be. For the purposes of this illustration, we therefore accept the first assumption but keep in mind that the resulting estimates are almost certainly biased upwards.

Data on average profits per unit of output (before taxes) can usually be obtained without too much difficulty. Assuming that this profit rate remains constant over the remainder of the asset's useful life is reasonable. Investors almost certainly made the same calculation when they decided what resources to devote to this asset.

\(^5\)This is equivalent to saying that variable costs have a fixed relationship to revenues so that quasirents per unit of output are fixed.

\(^6\)If the rate of decline is zero, the asset embodies a "one-hoss-shay" technology.
Finally, we make some assumptions regarding the output that the asset can produce per year. An optimistic assumption is that this output remains constant over the entire life of the asset. In most instances this output will correspond to the asset's long-run capacity. Many installations are capable of producing above that capacity for short periods of time, but the additional output produced during such peaks is usually offset by less than capacity output in subsequent periods. The net present value of the reduction in output from the time of the regulation until the asset is scrapped is the portion of the value of the asset that is subject to devaluation due to regulation. The market price of the asset at any point might be higher if the equipment has some scrap value, or if the asset can still be used in exempted applications.

Alternatively, the asset's productive capacity can be assumed to decline at a proportional rate. This assumption is intended to reflect that machinery and equipment can wear out, and as they get older they become more and more prone to breakdowns and down-time to allow for increased maintenance needs. This kind of economic depreciation is usually modeled with an exponential decay rate, whereby an asset's net output in time \( t \) is equal to the net output in time \( t - 1 \) divided by \( 1 + d \), where \( d \) is the rate of productivity decay. The value of such an asset also declines exponentially. The value of the asset in period \( t \) is given by the value in period \( t - 1 \) divided by \( 1 + e \), where \( 1 + e \) is given by \((1 + d)(1 + r)\), where \( r \) is the real social discount rate. The rate of exponential decline in asset value, \( e \), is called the rate of economic depreciation.\(^7\)

This decline continues until some period \( T \), when the asset is scrapped. \( T \) denotes the expected productive life of the asset, and the net present value of the difference between potential production and actual output, from the time of regulation until the asset reaches the age \( T \), is the value of the asset that is affected by regulation.

\(^7\)See for example Hulten, ed. (1981).
The proportional decay assumption has one attractive property for the analysis of transition costs. Since the rate of depreciation is constant, it turns out that the vintage distribution of the capital stock is unimportant. The productive capacity of the capital stock, and its value, will decline at the same constant rate as if it were a single piece of equipment.\footnote{This is strictly speaking only true for infinitely lived capital. If we assume a finite T, the vintage distribution must itself be exponential for this statement to hold. This is the case if we assume that the capital stock has been growing at a constant rate prior to regulation.} It has also been verified empirically that most types of capital do indeed display constant economic depreciation rates (Hulten and Wykoff, 1981).

We are now in a position formally to present the methodology for calculating the reduction in asset value due to a ban on the output from that asset. Let $X_{i,t}$ be the expected output producible from asset $i$ during period $t$, and let $T_i$ be the life expectancy of asset $i$. Assets differ in our analysis in terms of their vintage; asset $i$ refers to the $i$th vintage of capital still producing. Thus, by definition,

$$X_{i,t} = 0 \text{ for all } t > T_i.$$  

If we assume a one-hoss-shay technology, we also have

$$X_{i,t} = X_{i,0} \text{ for all } t \leq T_i,$$

and if we assume a constant positive rate of depreciation,

$$X_{i,t} = X_{i,t+1}(1 + d)^{-1} \text{ for all } t \leq T_i,$$

where $d$ is the rate of decay.

There are no empirical estimates available of the rate of decay in the aerosol or chemical industries. For the base case we assume a value of 10 percent per year. Together with our base case assumption for the
real discount rate of 4 percent per year, a figure commonly used in recent economic analyses performed in the federal government, our assumed value of d equal to 10 percent implies an economic rate of depreciation of 14.4 percent per year.

This figure is in line with econometric estimates of economic rates of depreciation. Hulten and Wykoff (1981), for example, have estimated economic rates of depreciation for a variety of assets, with most estimates falling in the 12 to 16 percent range, and an average of 13.3 percent. The most general category probably representative of the type of equipment used in the industries considered here ("other industrial equipment") had an estimate of 14.7 percent. Our assumed value of 14.4 percent is thus certainly reasonable and representative.

We shall measure the productive capacity of the capital stock in terms of the output that can be produced. We have, therefore, $X_t$, the total productive capacity installed in year $t$, given as

$$X_t = \sum_{i=1}^{K} X_{i,t}$$

for $K$ vintages of capital.

In year zero, prior to the announcement of regulation, we assume that this total productive capacity corresponded to the output actually produced. For different assumptions regarding (a) the distribution of vintages in the capital stock at this time, (b) its life expectancy, and (c) productive capacity decline with age, we can now calculate total installed capacity for each year into the future.

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9See, for example, U.S. Department of the Treasury (1984) and Office of the President (1985).

10Hulten and Wykoff estimate the same rate of economic depreciation for "instruments." "General industrial equipment" and "metalworking machinery" are slightly lower (12.25 percent), while "service industry machinery" and all transportation equipment are somewhat higher (16.5 to over 20 percent).
From this total capacity, we must deduct permitted production after the ban becomes effective (e.g., the essential use exemption), or actual demand prior to the effective date of the ban. The result is the regulation-induced reduction in output from "dedicated" assets for each year.

The resulting quantity reductions for each year are then multiplied by an estimate of the per unit profit (we use the rates estimated by JACA) and then discounted to time zero. We shall use the same real discount rate of 4 percent as a baseline and perform sensitivity analyses around this.

ESTIMATING INSTALLED CAPACITY

The ban reduced the value of two major types of assets. It affected assets in the aerosol filling industry and in the manufacturing industries for CFCs and precursor chemicals previously used to manufacture CFCs. As noted above, in all likelihood, alternative uses for these assets limited the effects of the ban. To keep our illustration simple, however, we ignore these alternative uses and calculate the effect the ban would have had if it forced owners to scrap these assets. To start our analysis, we must know the pre-regulatory capacity in these industries.

The Aerosol Industry

Prior to 1975, about 2.8 billion aerosol containers were produced and filled each year. After the ban in 1979, this number dropped to about 2.2 billion units (ICF report). CFC-filled units fell over the same time span from 1.5 in 1973 or 1.2 in 1974 to .4 billion units in 1979. Since then only units that are exempt under the essential use exemption can be filled with CFCs, and these account to about 5 percent of 1975 fillings,\textsuperscript{11} or about .05 billion units per year.

\textsuperscript{11}JACA report, Table V-14.
The drop in CFC fillings between 1975 and 1979 is remarkable for two reasons. First, it could be explained as the result of reduced productive capacity, as producers were divesting capital dedicated to the production of CFC-propelled aerosols. In this case, the economic costs of this drop would have been borne by the consumers, who faced a reduced supply of the product. Second, the reduction could be the result of reduced consumer demand due to increased awareness of the environmental danger of CFCs. In this case, the economic costs would be borne by the producers who faced a reduced demand for their output.

If the first explanation was correct, the reduction in CFC fillings should have been associated with a price increase, while in the second case it should have been associated with a price decrease. Between 1974 and 1979 the nominal price of aerosols increased; the price ratio of aerosol to non-aerosol packagings of the same products declined by about 10 to 15 percent. This price decline, however, had begun as early as 1960.\textsuperscript{12}

The price information thus appears to favor, however slightly, the explanation that the reduction in consumer demand was probably the primary cause for the drop in aerosol fillings. In fact, both explanations are probably correct. It is quite likely that producers of aerosol products discontinued investing in capital dedicated to the production of CFC-propelled aerosols in 1975,\textsuperscript{13} but that the reduction in consumer demand simply exceeded the rate at which producers could divest. For the purposes of this example, we will assume that producers did discontinue investing in 1975, and we will count the extent to which consumer demand fell faster than producer divestment as a part of the economic costs.

\textsuperscript{12}JACA report, Sec. III.
\textsuperscript{13}Even if producers did not anticipate the product ban, they probably reduced investment. It would be indeed irrational for any producer to continue investing and expanding dedicated capital in the face of a drop in consumer demand.
Figure 5.1 illustrates these points. All the data are from the JACA report. The smooth curve in the lower portion of the figure is our estimate of productive capacity for producing CFC-propelled aerosols based on an exponential decline in productivity and a weighted vintage distribution of the assets (see below). The shaded area between this curve and the actual number of CFC fillings is the economic transition cost borne by the producers. As can be seen, the actual number of fillings fell faster than the productive capacity declined between 1975 and 1979. Accordingly, some transition costs were already incurred during that period.  

14 JACA based its estimate of regulatory effect on a different concept altogether. It is illustrated by the gap between JACA's forecast of hypothetical sales for all aerosols in the absence of regulation, shown by the top line, and the quantity sold with regulation (actual to 1980, JACA forecast thereafter). The area between these two curves is what JACA refers to as the quantity "wedge." This area is
The Chemicals Industry

Estimates of the quantity of CFCs produced for use in aerosols prior to the ban are available from a variety of sources.\(^{15}\) From 1970 to 1975 CFC use in aerosols averaged around 42 percent of production. In 1974 it reached about 437 million pounds, slightly down from 468 million pounds in 1973 (Wolf, 1980). We can surmise that in 1975 the installed capital capacity for producing CFCs for aerosols ("dedicated" CFC capacity) was somewhere between 440 and 500 million pounds.

The total CFC production capacity was estimated to be 1195 million pounds in 1973,\(^{16}\) and 1320 million pounds in 1975.\(^{17}\) However, as Wolf (1980) points out, nameplate capacity in the CFC industry has typically been in excess of production by about 15 percent. Such excess capacity is not uncommon in process industries and is indeed necessary due to the need for batching production and having to meet demand peaks. Under normal circumstances annual production in 1975 was anticipated to be around 1148 million pounds. Assuming that 42 percent of this production capacity was dedicated to aerosols, it would appear that producers were anticipating an annual production of CFCs for aerosol use of around 482 million pounds.

For our example we shall use this estimate (482 million pounds) as a figure for CFC production capacity dedicated to aerosol use in 1975. Over time, as fully depreciated equipment was retired, this capacity declined, and was certainly smaller by 1979, when the ban became effective.\(^{18}\) The rate of decline depends on the assumptions regarding


\(^{16}\)Arthur D. Little, Inc. (1975).

\(^{17}\)Nooz et al. (1986)

\(^{18}\)Nooz et al. (1986) gives an estimate of 1085 million pounds for 1978. However, it is impossible to ascertain whether that reduction was due to regular wearing out of equipment, or whether it also included some plants that were retired early.
vintage and depreciation rates of dedicated capital, and we shall present a range of calculations for a variety of assumptions.

Assuming that production capacity for precursor chemicals is dedicated is certainly even less defensible than assuming that CFC production capacity is dedicated to aerosol use. However JACA (1983) makes that assumption, and we will simply adopt it here in the interest of simplicity. We also follow their methodology in calculating this "dedicated" capacity by using the technical input factors developed by Wolf (1980, Appendix A). Thus, the dedicated capacity for producing precursor chemicals to CFCs is in a fixed proportion to the CFC capacity, the factor of proportionality being given by the amount of the precursor chemical needed to produce one pound of CFC for aerosol use.

ILLUSTRATIVE RESULTS

Capital Vintage and Depreciation

The present value of the reduction in quasirents associated with the regulation is given by:

\[ \Delta Q = T \sum_{t=0}^{T} \left( k_t X_0 - X^*_t \right) (\pi) / (1 + r)^t, \]

where \( X_0 \) is industry output in year zero, \( k_t \) is the proportion of fixed capital surviving to year \( t \), \( X^*_t \) is actual consumption in year \( t \), and \( \pi \) is the profit rate per unit of output. By definition, we have \( k_0 = 1 \). The summation goes over all \( t \) until the last piece of capital has been fully amortized, i.e., \( k_T \) is zero.

The proportion of capital surviving to period \( t \) can depend on the vintage distribution of the capital stock at the time when the regulation is announced and on the rate of depreciation. In the simplest case, we assume a one-hoss-shay technology with a uniform vintage distribution.\(^1\) In this case, \( k_t \) is given simply by \( k_{t-1} - 1/T \), the fraction \( 1/T \) of the capital stock that wears out each year.

\(^1\)I.e., at time \( t = 0 \), the proportion of assets of a particular vintage is exactly the same for all possible vintages. The average age of the capital stock is then \( T/2 \).
If the industry has been expanding prior to the announcement of regulation, as is the case in our CFC example, a larger proportion of the capital stock is of more recent vintage. For the one-hoss-shay technology, this implies that the average age of the capital stock is less than $T/2$. In the example at hand, the industry has been growing at about 8 percent per year prior to the announcement of the ban, and we will assume that the capital stock has been growing at the same rate.

Let $v_i$ be the proportion of capital of vintage $i$, i.e., the proportion that is $i$ years old. Assuming that the producers have been increasing their capital stock along with the expansion of the industry (8 percent per year), we can conclude that $v_{i-1} = 1.08 v_i$. Together with the condition that the sum of capital of all vintages must add to $k_0 = 1$, we can calculate $v_i$ for all $i = 1, 2, \ldots T$. The capital surviving into the first period after the announcement of the ban is then given by $k_1 = k_0 - v_{T}$, for the second period $k_2 = k_1 - v_{T-1}$, etc. In general terms $k_{T+1} = k_T - v_T$.

If the productive capacity of each fixed asset in the capital stock is declining at a fixed rate, then $k_t = (k_{t-1} - v_{T-t})/(1 + d)$. The expression in parentheses represents the proportion of the capital stock that survives into the next period, i.e., that has not reached the end of its economic life. Then physical efficiency of these assets is furthermore reduced due to the decline in physical efficiency at the rate $d$. Again, if the vintage distribution is uniform, $v_i = 1/T$ for all $i$.

Table 5.1 gives the proportions of fixed assets surviving for the four cases discussed here. In this table we assume $T = 15$, and for the two rightmost columns, an economic depreciation rate of 14.73 percent and a real discount rate of 4 percent was assumed. The weighted vintage figures are based on a historical growth rate of 8 percent per year. In our opinion, the last column, based on exponentially declining efficiency of fixed assets and a weighted vintage distribution, embodies

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Note that the case of uniformly distributed vintage is simply a special case with $v_i = 1/T$ for all $i$. 
Table 5.1

PROPORTION OF FIXED ASSETS SURVIVNG TO PERIOD t

<table>
<thead>
<tr>
<th></th>
<th>One-Hoss-Shay Technology</th>
<th>Declining Physical Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vintage Distribution</td>
<td>Vintage Distribution</td>
</tr>
<tr>
<td></td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>t</td>
<td>Weighted</td>
<td>Weighted</td>
</tr>
<tr>
<td>0</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>1</td>
<td>0.933</td>
<td>0.880</td>
</tr>
<tr>
<td>2</td>
<td>0.867</td>
<td>0.772</td>
</tr>
<tr>
<td>3</td>
<td>0.800</td>
<td>0.673</td>
</tr>
<tr>
<td>4</td>
<td>0.733</td>
<td>0.583</td>
</tr>
<tr>
<td>5</td>
<td>0.667</td>
<td>0.502</td>
</tr>
<tr>
<td>6</td>
<td>0.600</td>
<td>0.427</td>
</tr>
<tr>
<td>7</td>
<td>0.533</td>
<td>0.360</td>
</tr>
<tr>
<td>8</td>
<td>0.467</td>
<td>0.299</td>
</tr>
<tr>
<td>9</td>
<td>0.400</td>
<td>0.243</td>
</tr>
<tr>
<td>10</td>
<td>0.333</td>
<td>0.192</td>
</tr>
<tr>
<td>11</td>
<td>0.267</td>
<td>0.146</td>
</tr>
<tr>
<td>12</td>
<td>0.200</td>
<td>0.104</td>
</tr>
<tr>
<td>13</td>
<td>0.133</td>
<td>0.066</td>
</tr>
<tr>
<td>14</td>
<td>0.067</td>
<td>0.031</td>
</tr>
<tr>
<td>15</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

the most realistic set of assumptions. We will refer to it as the base case.

Detailed Results for the Base Case

Figure 5.2 presents our estimates of productive capacity in the CFC industry for each year after 1974 based on a weighted vintage distribution. We also show actual production of CFCs for aerosol use over the same time period (JACA, Table V-14). The discounted value of the area between actual production and capacity, multiplied by the average profit per unit, represents the cost of regulation borne by producers.
Similar graphs can be drawn for each industry affected by a product ban. Table 5.2 gives the detailed figures for the base case. A quick comparison with the figures calculated by JACA, given in the last column of Table 5.2, reveals that these costs borne by producers are considerably lower than what JACA had estimated.

With two exceptions we have made the same assumptions as JACA. First, unlike JACA we assume that once a product is banned, producers stop acquiring capital to produce it so that productive capacity in the industry starts declining as soon as the product ban is announced. JACA in effect assumes that productive capacity continues to expand so that it counts among the costs to producers forgone quasi rents on these new investments without adjusting them for the cost of new investment. Because we expect quasi rents from new investment to be just sufficient
### Table 5.2
Detailed Results for the Base Case

<table>
<thead>
<tr>
<th>Industry</th>
<th>Total Output (b)</th>
<th>Price (c)</th>
<th>Total Sales (d)</th>
<th>Total Profit (e)</th>
<th>Regulation-Induced Reduction in Profits ($ millions, undiscounted)</th>
<th>Total Reduction in Profits Discounted to 1975 ( (r = .06) ) (d,a)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerosol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Containers</td>
<td>1.335</td>
<td>0.135</td>
<td>180.24</td>
<td>0.046</td>
<td>2.17 2.03 3.13 3.00 2.92 4.52 3.90 3.32 2.78 2.27 1.79 1.33</td>
<td>0.90 0.48 0.07 27.0 (104.8)</td>
</tr>
<tr>
<td>Valves</td>
<td>1.335</td>
<td>0.050</td>
<td>66.76</td>
<td>0.056</td>
<td>0.97 0.91 1.40 1.34 1.31 2.02 1.75 1.49 1.25 1.02 0.80 0.60</td>
<td>0.40 0.21 0.03 12.1 (46.4)</td>
</tr>
<tr>
<td>Fillers</td>
<td>1.335</td>
<td>0.590</td>
<td>787.72</td>
<td>0.068</td>
<td>13.44 12.59 19.38 18.55 18.10 28.00 24.16 20.58 17.22 14.07 11.09</td>
<td>8.26 5.56 2.96 45.0 (167.3)</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>1034.71</td>
<td></td>
<td>186.90</td>
<td>0.153</td>
<td>3.65 18.59 23.91 22.89 22.33 34.55 29.81 25.39 21.25 17.36 13.69</td>
<td>10.20 6.86 3.65 206.5 (799.3)</td>
</tr>
<tr>
<td><strong>Chemicals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC</td>
<td>482.09</td>
<td>0.370</td>
<td>178.37</td>
<td>0.069</td>
<td>12.31 1.00 0.47 3.81 4.66 7.31 6.36 5.68 4.65 3.88 3.16 2.47 1.82</td>
<td>1.20 0.61 0.03 36.1 (124.1)</td>
</tr>
<tr>
<td>HF (0.230)</td>
<td>110.88</td>
<td>0.334</td>
<td>37.03</td>
<td>0.069</td>
<td>2.56 0.21 0.10 0.79 0.97 1.52 1.32 1.14 0.97 0.81 0.66 0.51 0.38</td>
<td>0.25 0.13 0.01 7.5 (24.9)</td>
</tr>
<tr>
<td>CCl₂ (1.208)</td>
<td>581.60</td>
<td>0.130</td>
<td>75.58</td>
<td>0.069</td>
<td>5.52 0.42 0.20 1.61 1.97 3.10 2.69 2.32 1.97 1.65 1.34 1.05 0.77</td>
<td>0.51 0.26 0.01 15.3 (52.2)</td>
</tr>
<tr>
<td>CaF₂ (0.518)</td>
<td>249.48</td>
<td>0.054</td>
<td>13.47</td>
<td>0.069</td>
<td>0.93 0.08 0.06 0.29 0.35 0.55 0.48 0.41 0.35 0.29 0.24 0.19 0.14</td>
<td>0.09 0.05 0.00 2.7 (9.1)</td>
</tr>
<tr>
<td>Na₂SO₃ (0.690)</td>
<td>332.64</td>
<td>0.016</td>
<td>5.32</td>
<td>0.069</td>
<td>0.37 0.03 0.02 0.14 0.14 0.22 0.19 0.16 0.12 0.09 0.07 0.05 0.04</td>
<td>0.02 0.00 0.00 1.1 (3.6)</td>
</tr>
<tr>
<td>Sulfur (0.264)</td>
<td>119.75</td>
<td>0.017</td>
<td>2.04</td>
<td>0.069</td>
<td>0.14 0.01 0.01 0.06 0.05 0.08 0.07 0.04 0.05 0.04 0.03 0.04 0.04</td>
<td>0.02 0.01 0.00 1.1 (3.6)</td>
</tr>
<tr>
<td>Cl₂ (1.749)</td>
<td>865.03</td>
<td>0.043</td>
<td>36.25</td>
<td>0.069</td>
<td>2.50 0.20 0.09 0.77 0.95 1.49 1.29 1.11 0.95 0.79 0.64 0.50 0.37</td>
<td>0.24 0.12 0.03 7.3 (25.1)</td>
</tr>
<tr>
<td>CH₂ (0.030)</td>
<td>14.53</td>
<td>0.045</td>
<td>0.65</td>
<td>0.069</td>
<td>0.05 0.00 0.00 0.01 0.02 0.03 0.02 0.02 0.01 0.01 0.01 0.01 0.01</td>
<td>0.00 0.00 0.00 0.1 (0.4)</td>
</tr>
<tr>
<td>CH₃ (0.241)</td>
<td>116.28</td>
<td>0.070</td>
<td>8.14</td>
<td>0.069</td>
<td>0.56 0.05 0.02 0.17 0.21 0.33 0.29 0.25 0.21 0.18 0.14 0.11 0.08</td>
<td>0.05 0.05 0.03 1.6 (5.6)</td>
</tr>
<tr>
<td>C₆H₆ (0.996)</td>
<td>46.51</td>
<td>0.074</td>
<td>3.44</td>
<td>0.069</td>
<td>0.24 0.02 0.01 0.07 0.09 0.14 0.12 0.11 0.09 0.07 0.06 0.05 0.04</td>
<td>0.02 0.01 0.00 0.7 (2.8)</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>360.30</td>
<td></td>
<td>24.86</td>
<td>0.153</td>
<td>2.02 0.94 7.68 9.41 16.77 12.85 11.06 9.40 7.84 6.38 5.00 3.68 2.43</td>
<td>1.22 0.06 78.2 (284.0)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1395.02</td>
<td>90.95</td>
<td>180.60</td>
<td>16.67</td>
<td>31.59 32.30 37.10 47.40 60.87 34.79 29.09 23.74 18.68 13.88 9.29 4.88</td>
<td>0.61 279.3 (1030.2)</td>
</tr>
</tbody>
</table>

*a* Assuming physical efficiency of capital declining by .1 per year, weighted vintage distribution of capital, and 15-year life expectancy of capital (see text for details).

*b* Million units for the aerosol industry, million pounds for the chemicals industry.

*c* Dollars per unit or per pound.

*d* Million dollars.

*e* MCA estimates given in parentheses.

*f* The amount of precursor chemical used per pound of CFC produced is given in parentheses.
to cover investment costs, any investment forgone would have produced no net benefits. Second, we use a real discount rate of four percent to discount the producer costs back to 1975. JACA uses a (presumably nominal) discount rate of 9.4 percent. Changes in the discount rate affect more than just the discounting of future profit losses, and we will present some examples immediately below.

**Sensitivity Analysis**

The estimates of transition costs to producers depend crucially on the assumptions regarding the depreciation of the fixed assets. If the expected life of assets is longer than the 15 years assumed in our base case, then the asset is more valuable, because it could, *ceteris paribus*, have generated quasirents for a longer period of time. Similarly, changes in our assumptions regarding vintage distribution and the rate at which assets lose their physical efficiency over time will influence the results.

Table 5.3 provides estimates for a range of values of the parameters that influence productive capacity and hence expected quasirents. As expected, the range of estimates is substantial, underlining the importance of obtaining good estimates of these parameters when evaluating transition costs.

The role of the real discount rate has to be considered somewhat more closely. In addition to influencing the discounting of the predicted reduction in future profits, it also has an influence on the time at which a particular piece of equipment is retired. At higher discount rates, the present value of the expected future profits is lower. However, the scrap value of the equipment remains the same. Thus, since owners of fixed assets will scrap the equipment once its scrap value exceeds the discounted future quasirents that could be earned with it, fixed assets will be scrapped earlier when the discount rate is higher.
Table 5.3
SENSITIVITY OF PRODUCER COST ESTIMATES TO VARIOUS DEPRECIATION
AND VINTAGE ASSUMPTIONS
(in $ million)

<table>
<thead>
<tr>
<th>Rate of Physical Efficiency</th>
<th>Vintage Distribution Uniform</th>
<th>Vintage Distribution Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay^a</td>
<td>10 yrs</td>
<td>15 yrs</td>
</tr>
<tr>
<td>0^b</td>
<td>202.6</td>
<td>350.8</td>
</tr>
<tr>
<td>.1</td>
<td>146.9</td>
<td>236.5</td>
</tr>
<tr>
<td>.2</td>
<td>100.3</td>
<td>148.7</td>
</tr>
</tbody>
</table>

^aRate for individual pieces of equipment; the physical efficiency of the aggregate capital stock may decline at a different and not necessarily constant rate.

^bOne-hoss-shay technology.

We have no information on scrap values of equipment used in the aerosol industry or in the chemicals industry. However, each combination of expected asset life and economic rate of depreciation implies a specific scrap value. For example, the base case assumes a rate of economic depreciation of 14.4 percent per year. In the last year that it is used, the value of an asset has been depreciated to 15.2 percent of its original value. Because the asset is scrapped thereafter, its scrap value must be close to 15.2 percent.

By using these implied scrap values, the time when an asset is likely to be retired can be determined. Table 5.4 gives the range of estimates, starting from the base case. The second row of Table 5.4 repeats the base case as well as two other cases that differ from the base case only with respect to the assumed asset life. The second row
Table 5.4
TRANSITION COSTS FOR VARIOUS DISCOUNT RATES

<table>
<thead>
<tr>
<th>Scrap Value as Proportion of Initial Value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>(.298^b)</th>
<th>(.152^c)</th>
<th>(.078^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real discount rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.02</td>
<td>346.8 (11)</td>
<td>446.9 (17)</td>
<td>494.8 (23)</td>
</tr>
<tr>
<td>.04</td>
<td>286.0 (10)</td>
<td>364.8 (15)</td>
<td>408.1 (20)</td>
</tr>
<tr>
<td>.08</td>
<td>195.7 (8)</td>
<td>245.1 (11)</td>
<td>279.8 (15)</td>
</tr>
<tr>
<td>Nominal discount rate used in JACA report</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.094</td>
<td>162.8 (7)</td>
<td>227.4 (11)</td>
<td>251.4 (14)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Implied asset lives appear in parentheses.

<sup>b</sup>Based on an asset life of 10 years at \(r = .04\) and \(d = .10\).

<sup>c</sup>Based on an asset life of 15 years at \(r = .04\) and \(d = .10\).

<sup>d</sup>Based on an asset life of 20 years at \(r = .04\) and \(d = .10\).

corresponds exactly to the last three columns of the second row in Table 5.3. The first and the third rows give cost estimates and derived equipment lives for real discount rates that are one half and double the base case, respectively. Finally, the last row is based on the (nominal) discount rate used in the JACA report.

JACA assumes a discount rate of 9.4 percent and an expected asset life of 15 years. These assumptions are very close to those underlying the last figure in Table 5.4. The only differences are one year less in expected economic life of assets, a physical decay rate for equipment of
10 percent per year, and a halt to investment when the ban is announced. That this results in an estimate that is less than one fifth of JACA's underlines again the importance of understanding the nature and size of the stock of fixed assets at the time when regulation is announced.

CONCLUDING REMARKS

To measure the negative effects of the aerosol ban on owners of physical assets, we offer a fairly simple approach: Determine what the assets existing before regulation was anticipated could have produced without regulation. Compare it with what they in fact produced. Value the difference and discount it over time. Implementing each of these steps can involve subtle issues. For example, when was regulation first anticipated? How fast did the productive capacity of capital fall during the transition to regulation? Why did consumption apparently fall faster than capacity during the period before the ban became effective? Answers to these questions can drive the magnitude of the final cost estimate. They require a careful application of economic thinking to the particular context of the regulatory change.

Questions of this kind are likely to arise in any regulatory cost analysis. The specific questions will be different, but they will raise the same basic point: The approach offered here should start the analyst off on the right foot, but it cannot relieve him/her of the basic problem of viewing the approach in the right regulatory context. For example, it is important to understand that regulatory effects on quasirents associated with assets that existed before regulation are more important than effects on total production. But the analyst must still make important judgments in picking a starting date, depreciation rates, asset lifetimes, alternative uses, scrap values, and so on. Improved data will be able to improve many of these judgments but they can never replace judgments.

In sum, we view this case study as one illustration of a general approach. It should not be mistaken for a blueprint that is infinitely malleable in application. We expect the basic concepts offered here to be more transportable to other regulatory analyses than any specific formulas or methods used here.
Table 6.1 gives an overview of the different social cost components we associate with regulatory change and allocates them to producers/workers and consumers. Producers and workers are treated together because the transition costs that affect the human capital

<table>
<thead>
<tr>
<th>Time between expectation and effective date of regulation</th>
<th>Producers/Workers</th>
<th>Consumers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time between expectation and effective date of regulation</td>
<td>Investment and training end. Production declines and prices rise, but no social costs are incurred. Value of human and physical capital declines.</td>
<td>Declining production and increasing prices reduce consumer surplus. Some social costs are incurred.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Regulation (product ban)</th>
<th>Undepreciated portion of human and physical capital is reduced in value to discounted quasirents in next best alternative use. Principal cost to producers.</th>
<th>Remaining consumer surplus is eliminated. Consumer bears social costs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>After effective date of regulation</td>
<td>Invent new products and processes (e.g. reformulation). Social benefits exceed costs.</td>
<td>Potential consumer surplus is eliminated. Continuing social cost</td>
</tr>
<tr>
<td></td>
<td>Private costs of firms recovered from consumers who purchase products because their benefits exceed their costs.</td>
<td>New products generate new social benefits which offset part of lost consumer surplus.</td>
</tr>
</tbody>
</table>
owned by workers are exactly analogous to those affecting other forms of capital owned by investors. We distinguish three time periods, the interval between the first expectation of a ban and its effective date, the point in time when the ban takes effect, and the period after the ban has taken effect. All the costs and benefits accruing during these different periods can of course be discounted to any arbitrary time point.

In the long run when producers and workers earn only their normal return or wage, respectively, and the owners of capital have had time to adjust their capital stock to the new situation, all the social costs of the product ban will be borne by the consumers. The elimination of the consumer surplus is the only long-run social cost that we have to worry about. The surpluses of individual producers, i.e., the quasirents on fixed assets, are relevant only because past investment decisions cannot be costlessly reversed in the short run. In the long run there are no fixed assets, and hence no producer surplus that could be termed a long-run social cost.

In the short run, the owners of fixed capital may suffer losses due to changes in the regulatory environment. Banning a product devalues the specialized assets used in its production by reducing the expected quasirents that could have been earned in the future. Obviously this devaluation, and hence the social costs associated with it, applies only to fixed assets installed or otherwise irrevocably committed at the time when the ban takes effect. Future quasirents on capital not yet purchased and committed to the production of the banned products must not be counted as social costs.\(^2\)

\(^2\)We assume that consumer and producer surpluses are measured in the final goods market, so that the measure of consumer surplus represents the surplus going to final consumers, and the producer surplus represents the surplus of all producers, that is, the producers of final goods as well as all upstream producers of intermediate goods.

\(^2\)The common practice of treating producer surplus losses as analogous to consumer surplus losses and aggregating their discounted values over all future periods is therefore clearly unwarranted because it counts as social costs some outlays that can and will be avoided.
The same argument applies to the owners of human capital. If workers engaged in the production of the regulated product lose their jobs, their discounted future wages over the time remaining in their economically active life must be counted as a social cost. Against this cost one has to count the wages that can be earned in the next best alternative employment. Wages lost to workers not yet trained for the specific jobs cannot be counted as a social cost. This implies that measures such as "number of jobs lost" are of very little use in the absence of further information on the remaining expected economic life and the alternative employment opportunities of the particular workers involved.

If producers and workers anticipate the ban before its effective date, they can reduce the transition costs. Producers will stop investing in specialized capital that has an economic life in excess of the time remaining until the ban becomes effective, and workers will stop training for jobs in that line of business. In this manner the total fixed capital (human and physical) tied up in the production of the good to be banned will be smaller when the ban becomes effective. Neither of these two responses involves any net social cost to the producers and workers. However, as a consequence of such divestment, the product about to be banned will almost certainly become more expensive to consumers. This leads to a reduction in consumer surplus and hence social welfare even before the ban becomes effective.

Investment activities associated with entering alternative lines of business after the ban has been instituted, or the costs of training for new employment, should not on average involve a net social cost. In the case of the CFC ban, the firms' costs associated with reformulating the products to make them compatible with alternative propellants, for example, represent investments in new products. The costs of this investment will presumably be recouped from the consumers of the new products, who will purchase them only if the benefit they derive exceeds the costs of purchasing the products. In this manner, reformulation, like any other investment activity, will eventually generate new consumer surplus, a net benefit to society.
While these effects are fairly easy to understand and accept conceptually, they are not easy to measure in practice. Two difficulties are important.

The first is a lack of data. For example, because the method we present to measure negative regulatory effects on existing assets has not been used in the past, data to support it have not been collected. The analysis in Sec. V suggests the kind of data required and the range of answers that reasonable assumptions yield. Better data would allow us to narrow this range considerably. Similar data on and assumptions about specific human capital are much harder to develop. Given the importance of labor as an owner of existing assets, more empirical attention to the nature of these assets would significantly improve our ability to estimate regulatory costs. Similar statements can be made about the social costs and benefits associated with regulation-induced investments in innovation and new assets. In sum, while data are often difficult to find to measure the costs identified here, we hope the framework provided here will help regulatory analysts determine what data should be developed and collected.

The second is a lack of understanding of how consumers and producers make decisions over time in a regulatory setting of the kind outlined in Sec. II. For example, suppose everyone learns at time $t_1$ that a prohibition will occur at time $t_2$. Adjustments in asset holding will begin immediately. It is fairly easy to model the behavior of each individual actor in this simplified model of expectations, conditional on circumstances elsewhere remaining stable. But (a) circumstances elsewhere do not remain stable, (b) such a certainty-based model is quite naive, and (c) expectations about future regulation are likely to differ among actors. Operations research and game theoretic tools are available to improve our understanding of the investment decisions and paths of influence outlined in Sec. II. They could significantly improve the use of new data as they are developed to address the kinds of costs discussed here.
Even if these sorts of problems persist, however, as they probably will, the framework offered here should help OTS understand regulatory cost estimates it receives. For example, in the illustrative case study offered here, we found that previous studies grossly overestimated the regulation-induced injury to producers. This is so for two basic reasons: (a) The studies counted forgone profits from post-regulatory investment but neglected the avoided costs of this investment, which we expect on average to balance any profits. And (b) they counted the costs of investments in innovation following a regulatory change, while neglecting the benefits of these investments, benefits we expect on average to exceed these costs. Such general insights from the framework should help policymakers judge the adequacy of the cost estimates they must review while waiting for better data and models of dynamic behavior.
APPENDIX A

Section IV presents an approach to measuring regulation-induced changes in producer surplus that emphasizes the importance of existing assets and the quasirents associated with them. It notes the equivalence of the value of quasirents from existing assets and the cost of providing these from new investment in a competitive industry. It also notes that information on asset depreciation and vintage can be used to infer the value of changes in producer surplus. This appendix uses a simple but fairly general example to illustrate these two points. The points emerge as the example is developed.

Consider a situation like that in Example 1 in Sec. IV. An industry meets a steady demand for a good over time, using a constant number of identical one-hoss-shay machines\(^1\) that are replaced by identical machines as they come to the end of their useful lives. Each machine produces one unit, worth one dollar, per year for \(n\) years, and the industry replaces one machine per year. This implies that the industry employs \(n\) machines and produces \(n\) units a year. Figure A.1 illustrates this situation with \(n = 4\). Time is on the abscissa. Each block shows the production from a machine over its lifetime. The four machines in place at any time are labeled A, B, C, and D; when the life of an A machine ends, another A machine replaces it, and so on.

Regulation is announced in period \(t_0\) prohibiting any production from existing machines in the following period. Firms in the industry use a discount rate of \(r\), yielding a discount factor, \(\beta = 1/(1 + r)\). Any number of machines are available in any year at a cost of \(I\) dollars that is just covered by the revenues generated by production. That is,\(^2\)

\(^1\)An asset that generates a fixed real value of output each year over its life and then is retired with no scrap value is known as a one-hoss-shay investment. This form of investment is common in financial project analysis.

\(^2\)The sum of the finite geometric series, \(\beta^t\), over \(n\) terms is \(\beta/(1 - \beta^n)/(1 - \beta)\).
\[ I = \beta + \ldots + \beta^n = r^{-1}(1 - \beta^n). \]

Use the approach suggested in Sec. IV to determine the regulation-induced loss in producer surplus and compare this with the cost of using new machines to provide the quasirents still available from existing assets.

**LOSS OF QUASIRENTS FROM EXISTING ASSETS**

Figure A.1 tells us that three machines end their lives prematurely. The production expected from these machines is shown by the hatched areas of machines B, C, and D. The values of production lost in machines B, C, and D, respectively, discounted to period \( t_0 \), are \( \beta, \beta + \beta^2, \) and \( \beta + \beta^2 + \beta^3 \). These can also be written \( r^{-1}(1 - \beta) \), \( r^{-1}(1 - \beta^2) \), and \( r^{-1}(1 - \beta^3) \). Hence, it should be clear that the total regulation-induced loss in producer surplus is

\[
\begin{align*}
\text{-------------------------} & \\
| \text{A} | & | \\
\text{-------------------------} & \\
| \text{B} | & | \\
\text{-------------------------} & \\
| \text{C} | & | \\
\text{-------------------------} & \\
| \text{D} | & | \\
\text{-------------------------} & \\
| \text{A} | & | \\
| \text{B} | & | \\
| \text{C} | & | \\
| \text{D} | & | \\
\end{align*}
\]

Fig. A.1 -- Schematic diagram of asset use and replacement
\[
\begin{align*}
    r^{-1}(n - \sum_{t=1}^{n} \beta^{t}) &= r^{-1}[n - r^{-1}(1 - \beta^{n})]. \tag{A.1}
\end{align*}
\]

COST OF USING NEW ASSETS TO PROVIDE LOST QUASIRENTS

If new machines can be obtained to continue production beyond \(t_0\), and producers expect no further surprises, they will see no change in their future operating environment, and production and consumption can continue unperturbed. We should not expect to see any regulation-induced changes in price or quantity and hence in quasirents generated in any future period. The purchase of new machines on an accelerated schedule, however, introduces a one-time increase in investment cost. The simplest way to think of this is to imagine moving up the purchases of all machines in the future enough to avoid any interruption in production.

The simplest way to think about accelerated investment is to think of the investment cost of maintaining the capacity of produce one unit indefinitely into the future. It costs \(I\) today, \(I\) again \(n\) years from now, \(I\) again in \(2n\) years, and so on. The investment cost of this capacity, discounted to a year in which investment occurs, is

\[
    I^* = I + \beta^nI + \beta^{2n}I + \ldots = I/(1 - \beta^n) = r^{-1}.
\]

In the example in Fig. A.1, investment streams must be accelerated 1, 2, and 3 years to bring the B, C, and D machines on line at the same time the A machine was originally expected to start. The change in investment cost associated with such acceleration will be \((1 - \beta^t)I^*\) for the stream that is accelerated \(t\) years. For \(n\) machines, the total cost of acceleration, then, is
\[ I* \sum_{t=1}^{n} (1 - \beta^t) = r^{-1} [n - r^{-1} (1 - \beta^n)] , \]

which equals the loss calculated by the asset value method in (A.1). Table A.1 verifies the fact that the individual components of losses associated with each component of capacity match the loss in producer surplus and cost of new assets. In essence, the results in Table A.1 tell us that the cost of accelerating production over a given period is just equal to the value of production generated during that period, a result that reflects the fact that new investment just recovers enough in quasirents to cover the initial cost. The results in Table A.1 tell us that accelerated investment is in fact a one-time addition to the investment stream to cover the gap left by shutting down existing

Table A.1

<table>
<thead>
<tr>
<th>Component of Capacity</th>
<th>Years of Loss/Acceleration</th>
<th>Loss in Producer Surplus</th>
<th>Cost of New Assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>( \beta )</td>
<td>( r^{-1} (1 - \beta) )</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>( \beta + \beta^2 )</td>
<td>( r^{-1} (1 - \beta^2) )</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>( \beta + \beta^2 + \beta^3 )</td>
<td>( r^{-1} (1 - \beta^3) )</td>
</tr>
<tr>
<td>-</td>
<td>( t )</td>
<td>( \sum_{t=1}^{n} \beta^t )</td>
<td>( r^{-1} (1 - \beta^n) )</td>
</tr>
</tbody>
</table>

Note: \( \beta \) is the depreciation rate, \( r \) is the real interest rate, and \( n \) is the number of periods.
capacity and that the quasirents that can be earned by closing that gap are just sufficient to cover the cost of adding this capacity.

DISCUSSION

This basic result is dependent on choosing a one-hoss-shay investment pattern. With other investment patterns, this equivalence cannot always be sustained. The reason is that with other investment patterns, it is often impossible to achieve the original aggregate pattern of production over time. That is, other investment patterns introduce the problem of lumpiness to our analysis. Where lumpiness exists, it will always be necessary to add capacity that allows more production than the pre-regulatory investment plan would have allowed in order to meet the pre-regulatory production plan. Hence, lumpiness increases the cost of investment to replace the prematurely retired capacity. The price of output will increase. Demand and production over time will change and a more complicated analysis will be required.

But in general we can expect that, even when lumpiness is of practical importance, the measure of producer surplus loss developed here is still appropriate. Higher costs associated with lumpiness will affect consumer surplus, but should have no effects on the private perception of producer surplus in the long run. Future quasirents can be expected to offset these higher costs, leaving producers unaffected. Only the effects on quasirents from existing assets, captured in the approach suggested here, affect the privately perceived well-being of producers.
APPENDIX B

Section III explains that a discount rate must be chosen to aggregate effects measured on an annual basis. This can pose a problem if we believe the social and private discount rates differ.

The social discount rate is likely to be lower than the private rate for a number of reasons.¹ Some observers believe that the social discount rate should reflect the social rate of time preference, which the tax code assures is much lower than the pre-tax cost of capital that private industry uses as a discount rate. Other observers believe that the social rate should reflect the opportunity cost of funds, which are used to invest, in all alternative uses; because the tax code makes the opportunity cost of most funds lower than the privately perceived cost of capital, this approach also leads to a systematic difference. Still other observers believe that, while private risk premia reflect portfolios of limited size, the social view should look at the whole economy as a portfolio and consider only risks relevant from this perspective. This too leads to a social rate lower than the private rate.

The welfare analysis above is simplified by the fact that assets do not earn excess rents in a competitive market in the long run. This is appropriate only from the point of view that governs investment decisions in the private market. If the social discount rate is lower than the private discount rate, all investment carries a net social benefit that the private sector cannot perceive. Hence, investments we neglect because their private net present value is zero do have a positive social value. While this is an important issue, it is separable from the issue at hand. To make that clear, we take the following tack.

¹An extensive literature discusses this point. Useful surveys are available in Harberger (1975), Mishan (1971), and Prest and Turvey (1965).
We start by applying an estimate of the social discount rate to the annual flows identified above. The procedure is straightforward. If we believe a significant difference exists between the private and social rates, we then examine this difference separately.

Consider the implications for investments in which a private perspective suggests that benefits just offset costs. Suppose, for example, that the percentage rate of economic depreciation of an asset were constant at a rate \( \delta \) and its benefits just covered its costs in private terms. Let \( Q_0 \) be the quasirent in the first year of production and \( r_p \) be the private discount rate. Then its investment cost is \( Q_0 / (\delta + r_p) \). For a social discount rate of \( r_s \), its social value is \( Q_0 / (\delta + r_s) \). The ratio of its value to its cost in social terms, then, is \( (\delta + r_p)/ (\delta + r_s) \). With typical values of \( \delta = 0.12 \), \( r_p = 0.10 \), and \( r_s = 0.04 \), this ratio would be 1.375, suggesting that net social benefits equal about a quarter of the net present value of the quasirents from the investment. In general, the effect of the difference in private and social discount rates depends on the form of flows from the investment over time; the difference becomes more important as a larger share of future benefits can be expected in the far future.

These adjustments are easy to make if we can determine what level of investment to apply them to. The net value associated with the difference in the "steady state" levels of gross investment that would have occurred with and without regulatory change should be considered. For example, if technologies that replace those associated with the prohibited chemical are more capital-intensive than those used with the prohibited chemical, the prohibition generates an ancillary social benefit by moving the economy toward a more capital-intensive pattern of production than that favored by the private sector. We can recognize this ancillary effect by determining how much the prohibition increases investment and adjusting the value of this increase upward to reflect

\[ \text{In this calculation, capital should be broadly construed to include all assets--physical, human, financial, intangible, and so on--that transform an expenditure today into increased production in the future.} \]
the difference between private and social discount rates when private costs and benefits just offset one another. On the other hand, if a prohibition leads to the use of less capital-intensive technology, it will have negative ancillary social effects. Comparing the capital intensity of general investment patterns before and after a prohibition is not an easy task.

In deciding whether the difference between social and private discount rates is large enough to worry about, perhaps the key expression in the discussion above is "ancillary." A complete cost-benefit analysis should allow analysts and decisionmakers to identify "second-best" strategies that allow policy changes in one area—for example, chemicals policy—to make up for failures in other—say, tax policy. Practical cost-benefit analysis should probably give greatest attention to the immediate concerns of the relevant policymaker. In this particular case, he/she is probably more interested in chemicals than taxes. Hence, adjustment for the difference between social and private discount rates should not preoccupy the analyst comparing alternative chemical policies.
REFERENCES


