

## **The Effects of Environmental Regulation On Technology Diffusion: The Case of Chlorine Manufacturing**

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ON TECHNOLOGY DIFFUSION:  
THE CASE OF CHLORINE MANUFACTURING**

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# THE EFFECTS OF ENVIRONMENTAL REGULATION ON TECHNOLOGY DIFFUSION: THE CASE OF CHLORINE MANUFACTURING

by  
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We use a hazard model to estimate the effect of environmental regulation on the diffusion of membrane cell production technology in the chlorine manufacturing industry. We estimate the effect of regulation on both the adoption of the membrane technology at existing plants and on the exit of existing plants using older technologies. We find that environmental regulation did affect the diffusion of the cleaner technology in the chlorine industry. However, it did so not by encouraging the adoption of membrane cells by existing facilities, but by reducing the demand for chlorine and hence encouraging the shutdown of facilities using the environmentally inferior options.

## 1. Introduction

In order to assess the effects of regulation on environmental and economic performance of firms, it is important to understand the interaction between regulation and technological change. The costs of compliance with environmental regulations are determined, in part, by the cost and availability of alternative production and abatement technologies, and regulations themselves can affect the nature and rate of technological change (Jaffe, Newell, and Stavins 2002). As a result, the economic and environmental impacts of regulation are affected by the technology choices made by individual plants.

We examine the effect of regulation on technological change in the chlorine manufacturing industry by focusing on the diffusion<sup>1</sup> of membrane cell technology, widely viewed as environmentally superior to both mercury cell and diaphragm cell technologies. The chlorine manufacturing industry has experienced a substantial shift over time towards the membrane technology, but only a relatively small fraction of this change has come about through adoption of cleaner technologies at existing plants.<sup>2</sup>

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<sup>1</sup> Schumpeter (1942) distinguished three stages in the process by which a new, superior technology permeates the marketplace. First, *invention* consists of the development of a scientifically or technically new product or process. Second, *innovation* occurs when a new product or process is commercialized, that is, made available on the market. Third, a successful innovation gradually comes to be widely available for use in relevant applications through adoption by firms or individuals, a process labeled *diffusion*. See Jaffe, Newell, and Stavins (2002) for a comprehensive summary of the literature on the effect of environmental policy on technology diffusion.

<sup>2</sup> In this context, adoption by an existing plant can mean both conversion of all of an existing plant's capacity (retrofitting) or a combination of retrofitting and new capacity expansion at an existing plant. In the latter case, some capacity is maintained using the older technology. Of the existing plants that adopted

Most of the change has been due to the use of membrane cells by newly constructed facilities (entry) and the closing of facilities using diaphragm and mercury cells (exit). Therefore, in this context, technology diffusion can be viewed as a combination of adoption, entry, and exit decisions.

In this paper, we examine econometrically two of these aspects of diffusion — adoption and exit behavior — to assess the effects of environmental regulation.<sup>3</sup> Employing plant-level data on technology choice, economic variables, and regulatory variables from 1976 to 2001, we examine these adoption and exit decisions with a hazard model, considering the effects of both direct regulation of chlorine manufacturing and regulation of downstream users of chlorine.

We find that environmental regulation had an effect on technological change, but not in the way that many advocates would argue. Direct regulation of chlorine manufacturing did not have a statistically significant effect on adoption of membrane technology by existing plants. However, regulation of downstream uses of chlorine changed demand for chlorine, causing plants which disproportionately used the older, less environmentally sound technologies to close. In this way, regulations tended to increase over time the share of plants using the cleaner, membrane technology. This pattern in which environmental regulations have their greatest influence on technology diffusion through systematic effects on exit (and effects on adoption at time of entry), rather than effects on adoption at existing plants, is consistent with previous findings with regard to technology *innovation*.<sup>4</sup>

## 2. The Chlorine Manufacturing Industry

Over 95 percent of the world's chlorine is produced by an electrolytic process in which electric current is introduced to a salt-water brine, resulting in the separation of chlorine, hydrogen gas and caustic soda (sodium hydroxide). Three different types of cells have been employed in this electrolytic process: the mercury cell, the diaphragm cell, and the membrane cell.

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the membrane technology, about half were total retrofits and half were combinations of retrofit and expansions.

<sup>3</sup> The entry aspect is empirically difficult to estimate because one only has data on facilities that choose to enter and cannot observe or infer all the possible firms that could have entered during a time period but did not. This renders probabilistic empirical analysis of the entry decision infeasible.

<sup>4</sup> Newell, Jaffe, and Stavins (1999) find this pattern in the effects of regulation on the innovation of energy-efficiency attributes of a variety of home appliances.

The mercury cell is widely viewed as having the greatest potential for environmental damage, due to the potential release of mercury, a highly persistent and bio-accumulative toxin. The diaphragm cell technology, which accounts for two-thirds of chlorine produced in the United States, is considered to be more environmentally benign than the mercury cell, although not without its own environmental risks, since the diaphragm cell is composed of layers of asbestos. The newer membrane process, accounting for less than one third of chlorine produced in the United States (Chlorine Institute 2001), is the most environmentally benign.

Over the past 25 years, there has been a gradual movement from mercury and diaphragm cells to membrane technology. In 1975, plants using mercury cells accounted for 22 percent of total chlorine capacity, plants using diaphragm cells accounted for 73 percent, and membrane cell plant capacity was less than one percent of the total.<sup>5</sup> By 2001, mercury cell capacity had fallen to 10 percent, diaphragm cells accounted for 67 percent, and membrane cells accounted for 20 percent (Chlorine Institute 2001).<sup>6</sup> Some of the significant increase in membrane cell capacity has come from adoption of membrane cells at existing facilities, but the bulk of the diffusion has taken place through entry and exit of facilities using mercury and diaphragm cells. This pattern of diffusion is illustrated in Figure 1. The solid black column represents the total number of facilities that contributed to diffusion of membrane technology during the five-year period, either through entry, exit, or adoption at existing plants. The largest share of diffusion came through closure of mercury and diaphragm plants. The next largest contributor to diffusion was adoption by existing plants. New entry played the smallest role.

### **3. The Regulation of Chlorine Manufacturing**

In 1972, a widely publicized incident of mercury poisoning in Minamata Bay, Japan led the Japanese government to prohibit the use of mercury cells for chlorine production. The United States did not follow suit, but it did impose more stringent environmental constraints on mercury cell units during the early 1970s. Subsequently, chlorine manufacturing became subject to increased regulation under the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), popularly known as Superfund.<sup>7</sup> In addition, chlorine manufacturing became subject to public disclosure requirements under the Toxics Release Inventory (TRI), which has required large manufacturing facilities to make public their annual releases of over 300 different toxic chemicals since 1986. Nearly all chlorine manufacturing plants are large

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<sup>5</sup> The remaining four percent of chlorine was produced at facilities that used a method other than electrolysis.

<sup>6</sup> The remaining three percent of chlorine was produced at facilities that use a method other than electrolysis.

<sup>7</sup> These command-and-control regulations typically involve both fixed and variable compliance costs.

enough to meet the reporting thresholds for the TRI, and are thus required to disclose their release levels.<sup>8</sup>

In addition to regulation of the chlorine manufacturing process, there has also been increased environmental pressure on industries that use chlorine as an input. This indirect regulation is potentially important for chlorine manufacturing technology choices because a large share of chlorine is manufactured for on-site use in the production of other products. In our sample, 54 percent of facilities are co-located with manufacturing units in different three-digit SIC codes, the most frequently observed pairings being with organic chemical, plastics, and pulp and paper mills. Changes in regulations in these downstream industries can have substantial impacts on the demand for chlorine and can affect the rate of entry and exit of chlorine production plants.

Two major (indirect) regulations may have altered the demand for chlorine. One is the Montreal Protocol, which regulates the production of ozone-depleting chemicals, such as chlorofluorocarbons (CFCs), for which chlorine is a key ingredient. In 1987, the Montreal Protocol imposed a timeline for phasing out CFC production in the United States and other industrialized countries. The other potentially important indirect regulation is the so-called “Cluster Rule” regulation of releases from pulp and paper mills. Finalized in 1998, the Cluster Rule, tightened restrictions on the release of chlorinated compounds to both water and air. This led to increased interest by the industry in non-chlorine bleaching agents, which in turn may have affected the economic viability of some chlorine plants.

#### 4. Empirical Model

We utilize a proportional hazard model to analyze the effects of economic and regulatory variables on adoption and exit decisions by chlorine manufacturing plants from 1976 to 2001. The hazard model is appropriate because our focus is on the *timing* of technology decisions.<sup>9</sup> Plants face different anticipated returns to adoption of membrane technology. Those with higher anticipated returns are expected to adopt earlier, if adoption cost is falling over time. Economic and regulatory conditions can affect expected costs and returns, and, hence, affect the timing of adoption.<sup>10</sup>

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<sup>8</sup> Large manufacturing facilities are defined as having 10 or more employees and using/processing 25,000 pounds per year or manufacturing 10,000 pounds per year of a listed chemical.

<sup>9</sup> See Kiefer (1988) for a general discussion of the use of hazard models in economics. Kerr and Newell (2001) utilize a hazard model to study the effect of different regulatory instruments on the rate of isomerization adoption by oil refineries.

<sup>10</sup> The model of facility-decision making that underlies the hazard framework is one in which the facility chooses the optimal time of adoption or shutdown to maximize expected returns. Alternative theoretical and empirical models were considered. In particular, the multinomial logit model would be consistent with a decision-making framework where in every period the plant gets a draw of a series of random variables and based on that draw chooses to shutdown, operate using the same technology, or operate using (at least partially) a new technology. Snyder (2002) includes a discussion of model choice in this context. The results are very similar using these two different modeling approaches.

The hazard function is defined as the probability of adopting membrane technology, given that the facility has not yet adopted:

$$h(t) = \frac{f(t)}{1 - F(t)}$$

where  $f(t)$  is the probability density function for adoption and  $F(t)$  is the cumulative distribution function. To measure the effects of explanatory variables on the hazard rate, we employ the proportional hazard model, which separates the hazard rate into two components: a baseline hazard rate which is a function of time,  $h_0(t)$ ; and a function of the covariates, usually defined as  $\exp(X'\beta)$ , where  $\beta$  is a vector of parameters that weight the explanatory variables  $X$ . Combining these, the hazard rate  $h(t)$  is written:

$$h(t) = h_0(t)\exp(X'\beta).$$

The coefficients are then estimated using maximum likelihood.<sup>11</sup>

In a proportional hazard model, the changes in the explanatory variables shift the baseline hazard. The baseline hazard function can be left unspecified, as in a Cox proportional hazard model, or parameterized by specifying a particular distribution for  $f(t)$ . While the Cox proportional hazard model has the advantage of not requiring assumptions about the form of the underlying hazard function, it also has a major shortcoming for this analysis: the effects of any pure time series variables cannot be estimated. Since these effects are potentially important, we instead adopt the parameterized baseline hazard approach.

Use of a parameterized baseline hazard model requires a choice of specification. An exponential density function yields a constant baseline hazard function. Other specifications yield baseline hazard functions that are functions of time, allowing for the possibility that the baseline hazard increases or decreases over time. Commonly used distributions that yield monotonically increasing or decreasing hazard functions are the Weibull and the Gompertz density functions (Kennedy 1998).

Without strong *a priori* notions regarding the shape of the underlying baseline hazard, we begin by assuming a constant baseline hazard function (i.e., an exponential density function) and estimate the hazard model for the adoption and exit decisions. By assuming an exponential density function, we are assuming that the baseline hazard rate is constant.<sup>12</sup> We conduct sensitivity analyses to determine the robustness of the results.

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<sup>11</sup> A facility that adopts (exits) within the time frame has a contribution to the likelihood function equivalent to the density at time  $t$ . A facility that does not adopt (exit) is treated as censored. Its contribution to the likelihood function consists of the probability of survival to time  $t$ . Facilities that exit before adopting the membrane technology are treated as censored in the adoption model.

<sup>12</sup> Assuming a constant baseline hazard function does not imply that the probability of adoption is constant over time. If the covariates vary over time, the probability of adoption will also vary. In particular, the

## 5. Data

### 5.1 *Dependent Variables*

Data on cell technology use at U.S. chlorine manufacturing plants were obtained from the Chlorine Institute (2002) and from the Directory of Chemical Producers (SRI 1976-2001). One of our two dependent variables, CONVERT, is an indicator of membrane adoption at an existing plant, and takes a value of one in the last year a facility used the old technology.<sup>13</sup> The other dependent variable, SHUTDOWN, takes a value of one if a facility closed during a given year.<sup>14</sup> Table 1 provides summary statistics for the variables used in the analysis.

### 5.2 *Explanatory Variables*

*Size:* Empirical research on technology diffusion has frequently found that larger plants are more likely to adopt new technologies or adopt more quickly (David 1966, Griliches 1957, Kerr and Newell 2000). We employ two measures of size — plant capacity and net sales of the parent company. These measures reflect two different notions of size. Plant capacity refers to the share of the individual plant in the chlorine market. In contrast, net sales are measured at the parent company, not the individual production unit, and hence serve as a proxy for access to capital, risk aversion, and other firm-specific factors.

*Complexity:* Chlorine is often produced and used on-site as an input in the production of other products. Fifty-four percent of the chlorine manufacturing facilities in our sample were co-located with manufacturing units operating in a different three-digit SIC code, usually other chemical products or pulp and paper. Such “complexity” of operation might affect both the exit and adoption decisions, because the more integrated is chlorine production with other high value-added goods, the more costly and difficult it might be to shut down a plant either temporarily or permanently. This is particularly true

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assumption of a constant baseline hazard rate can generate the typical S-shaped pattern of adoption frequently observed in empirical studies of technology diffusion (Jaffe, Newell, and Stavins 2002).

<sup>13</sup>Defining the variable CONVERT to take a value of one in the last year in which a facility used the old technology was done for technical reasons. STATA implements the hazard function estimation by assuming that any event variables, such as CONVERT, that take a value of 1, indicate that the event occurred at the end of the period. So if a facility uses the membrane technology in 2000 and mercury cells in 1999, then we assume the change occurred at the end of 1999.

<sup>14</sup> Adoption of membrane cells takes place at both mercury and diaphragm cell plants, with greater frequency at diaphragm plants. In addition, there have been three plants that converted from mercury to diaphragm cells over this time period. These conversions are not included in the variable CONVERT. Similarly, plants using all three technologies have shutdown over the period including three plants that had converted to the membrane cell.



for chlorine manufacturing because transportation of chlorine is dangerous and itself highly regulated. The variable, COMPLEX, is an integer variable that indicates the number of other production processes, as captured in three-digit SIC codes, that occur at the manufacturing site.<sup>15</sup> We also used a series of dummy variables representing the industry or industries co-located with a given chlorine plant. The variables CO-PAPER, CO-PLASTICS, and CO-ORGANICS take a value of 1 if the plant also produces pulp and paper products, plastics, and organic chemicals respectively.

*General Economic Conditions:* Chlorine production is a pro-cyclical industry. We employ two measures of business activity — lagged values of GDP in the chemical manufacturing industry, and lagged values of the real price of chlorine.<sup>16</sup>

*Regulatory Variables:* As described above, several regulatory regimes may have affected the rate and direction of technology diffusion in the chlorine industry. We construct dummy variables that capture whether a facility was affected by a specific regulatory regime including: Superfund, the Montreal Protocol, the pulp and paper cluster rule, and the Toxics Release Inventory.<sup>17</sup> We also include a dummy variable that indicates whether the plant uses mercury cells, because these cells have been more heavily regulated under various regulatory regimes.<sup>18</sup>

## 6. Results

### 6.1 The Adoption Decision

We have complete data on 51 facilities, eight of which adopted the membrane technology during the sample period.<sup>19</sup> The earliest observed adoption at an existing

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<sup>15</sup> Other measures of complexity were also constructed, including a binomial dummy reflecting multiple production processes. The coefficients are roughly the same, but the binomial variable tends to be less statistically powerful in explaining variation in adoption and exit decisions.

<sup>16</sup> We tried alternative lag structures to account for different expectations mechanisms. The results were robust to changes in the lag structure over one to five years.

<sup>17</sup> To construct the pulp and paper indicator, we used self-reported SIC codes from the plants Toxic Release Inventory reports. If the chlorine plant was co-located with a pulp and paper plant (SIC 26) we assumed the plant was affected by the cluster rule. For the Montreal Protocol indicator we cross-referenced chlorine plants with plants manufacturing the following chemicals regulated under the Protocol: fluorocarbons, chlorinated methanes, and chlorinated solvents. The list of plants producing these ozone-depleting chemicals was obtained from the Stanford Research Institute, Chemical Economics Handbook (SRI 1993).

<sup>18</sup> This will pick up any variation that is common across plants using the same technology, some of which may be regulatory and some of which may not be.

<sup>19</sup> We have data on net sales only for plants owned by publicly traded companies. Restricting our sample to publicly traded companies reduces the sample from 65 facilities to 51 facilities. We also estimated the model with the full sample, and found that the model performed poorly. One possible explanation for the difference in results across the two samples is that net sales controls for important differences in adoption timing decisions across companies, because all plants owned by the same company have the same value for net sales in any given year.

plant was in 1983, and the latest was in 1999. The results of the estimation of the hazard model for the adoption decision are presented in Table 2.

A brief note on interpreting the results from the proportional hazard model is required. The results reported in Table 2 are not the estimated values of the coefficients,  $\beta$ , but rather the estimated hazard rates. Thus, an estimated hazard rate greater than 1.0 indicates that an increase in the covariate increases the baseline hazard, while estimated hazard rates less than 1.0 indicate that the respective variable decreases the baseline hazard.<sup>20</sup> Due to the non-linear nature of the hazard function, the coefficients do not have a direct interpretation. In order to provide information on the relative importance of the explanatory variables on the hazard rate, we calculate the hazard rate when all continuous variables are evaluated at their mean and indicator variables are set to zero. The mean hazard rate for the adoption model was 1.28 percent. The impact on the mean hazard rate of increasing a continuous variable by 10 percent or changing an indicator variable to one, *ceteris paribus*, is reported in Table 4.

The analysis shows that larger plants and plants owned by firms with larger sales volumes were slightly more likely to switch to the membrane technology. A ten percent increase in either of the variables from their respective mean values leads to roughly a 0.1 percentage point increase in the hazard rate. Complex facilities were substantially less likely to switch. If complexity is broken down by industry, chlorine plants co-located with pulp and paper mills and plastics plants were significantly less likely to adopt.

Increases in the lagged real price of chlorine (a proxy for expected future prices) made technology changes less likely. A ten percent increase in price above the mean causes the average hazard rate to fall by 0.26 percentage points. A potential explanation for this result is that the opportunity cost of the downtime necessary to change technologies is greater when real prices are higher. When GDP in the chemical industry was used as an indicator of business activity, the sign and magnitude of the effect was similar, but the results were not statistically significant.

In none of the specifications were the effects of the regulatory variables on the likelihood of adopting membrane technology statistically significant. Mercury plants, which were subject to stringent regulation for water, air, and hazardous waste removal, were no more likely to switch to the membrane technology than diaphragm plants. Similarly, TRI reporting appears to have had no significant effect on adoption decisions, whether TRI is measured as a simple indicator variable, by rank of total releases, or by magnitude of reported releases.<sup>21</sup>

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<sup>20</sup>Standard errors and significance levels are presented in the table, but significance levels are determined by the coefficient estimates and the standard errors, not the estimated hazard rates and the standard errors. Also, because the likelihood ratio is estimated using repeated observations on the same plant, the assumption of independent identically distributed error terms is suspect. We instead estimate and report clustered standard errors that are adjusted for correlation among observations from the same plant, but assume independence across plants.

<sup>21</sup> We tested the robustness of the results to changes in the shape of the underlying hazard function, and found that the signs and magnitudes of the explanatory variables' estimated parameters did not change

## 6.2 *The Exit Decision*

We also estimated a hazard model for the exit decision. The publicly-traded sample consisted of 55 facilities, 21 of which ceased operations between 1976 and 2001. We tested a variety of specifications, controlling for economic and regulatory determinants. The regression results are found in Table 3 and the incremental effects are provided in Table 4 for the preferred specification. The baseline exit hazard rate with all variables set at their mean (and zero for indicator variables) is 2.1 percent.

Despite the fact that the results of the exit analysis are not as robust to changes in specification as are the results of the adoption analysis, some interesting and quite striking patterns emerge. Although the economic covariates seem to have had little effect on the timing of exit decisions (with the exception of facility-level capacity, which retarded shutdown slightly), regulations do explain some of the variation in exit decisions. In particular, indirect regulation of the end-uses of chlorine accelerated shutdowns in certain industries. Facilities affected by the pulp and paper cluster rule and the Montreal Protocol were substantially more likely to shut down than were other facilities. If a facility was affected by the pulp and paper cluster rule the hazard rate for closing increased by 11.18 percentage points holding all else constant. Similarly, if a facility was affected by the Montreal Protocol the average hazard rate increased by 15.36 percentage points.

It may appear from the results that facilities that report to TRI were less likely to shutdown than facilities that did not report, but it is important to note that nearly all facilities that were still in operation in 1986 reported to TRI, and so this parameter may be picking up a simple time effect, rather than a true regulatory effect.<sup>22</sup>

## 7. Conclusions

Diffusion of new technology is the result of a combination of adoption at existing facilities and entry and exit of facilities with various technologies in place. In chlorine manufacturing, total capacity using the cleaner membrane technology has been increasing over the past 25 years. This increase is partly a result of adoption of membrane cells at existing plants, but mainly a consequence of plant startups and shutdowns.

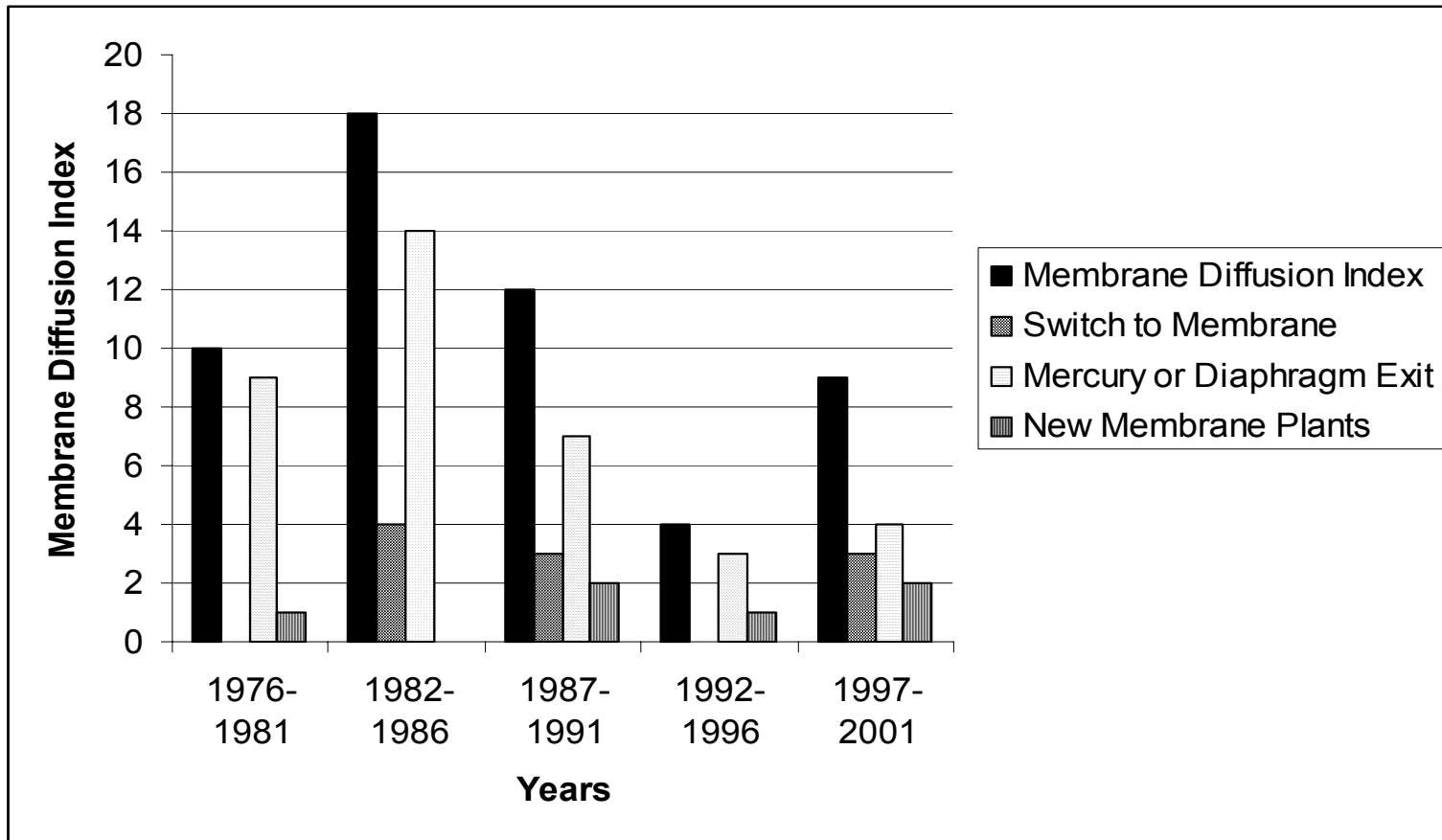
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substantially. The estimated parameters were not statistically different from one (in the case of the Weibull specification) or zero (in the case of the Gompertz specification), and so the assumption of a constant baseline hazard, consistent with the exponential hazard function, seems reasonable. We also tested whether facilities that eventually shutdown might be less likely to adopt, perhaps because these facilities have lower productivity. Kerr and Newell (2001) suggest including in the adoption model a dummy variable equal to one if a facility shutdowns or including the year in which a facility shuts down. We try both of these tests and in both cases the shutdown variables are not statistically significant and the remainder of the coefficients have the same magnitude and significance levels.

<sup>22</sup>We also estimated the model with other shapes of the underlying hazard function. With both the Weibull and Gompertz estimations, the baseline hazard was found to be increasing over time.

Our results indicate that regulatory factors have not had a statistically significant effect on the decision to adopt membrane cell technology at existing plants. On the other hand, indirect regulation of the end-uses of chlorine appears to have accelerated facility closures significantly, and thereby to have increased the share of plants using the cleaner, membrane technology for chlorine production.

Environmental regulation, in this study, did affect technological change. It did so not by encouraging the adoption of membrane cells by existing facilities, but by reducing the demand for chlorine and hence encouraging the shutdown of facilities using the environmentally inferior options.



**Figure 1: Diffusion of Membrane Cell Technology Over Time, By Source<sup>23</sup>**

<sup>23</sup> The membrane diffusion index is equivalent to the total number of facilities that contributed to diffusion during each five-year period, including existing plants that adopted the membrane technology, non-membrane plants that closed down, and new membrane plants that came on line.

**Table 1: Summary Statistics**

<b>Dependent Variables</b>					
	Obs.	Number of Facilities	Number of Facilities that Take Action		
Convert	1,181	74	10		
Shutdown	1,181	74	37		
<b>Continuous Variables</b>					
	Obs.	Mean	St. Dev.	Min	Max
Capacity (short tons per year)	1,159	272	390	5	2,600
Net Sales (millions of \$)	856	10,123	15,624	143	128,051
Real Price (\$)	1,181	170	68	75	420
GDP Chemicals (billions of \$)	1,143	93,546	46,982	35,516	191,135
Releases (pounds per year)	445	1,648,459	7,931,919	6	97,700,000
Complex	1,181	0.68	0.71	0	2
<b>Indicator Variables</b>					
	Obs.	Percent Yes			
Co-paper	1,181	11.69			
Co-plastics	1,181	16.09			
Co-organics	1,181	41.07			
TRI	1,181	56.05			
Superfund	1,181	20.58			
Mercury	1,181	42.08			
Pulp and Paper	1,181	1.27			
Montreal	1,181	9.48			

**Table 2: Membrane Adoption Results  
Hazard Rates with Standard Errors in Parentheses**

	Exponential 1	Exponential 2	Exponential 3	Exponential 4	Weibull	Gompertz
Capacity	1.001425 ** (0.0007202)	1.001449 ** (0.0007004)	1.001476 ** (0.0007129)	1.002269 ** (0.0010586)	1.002117 * (0.0011511)	1.0023333 ** (0.0011074)
Net Sales	1.000035 *** (0.0000123)	1.000037 *** (0.0000133)	1.000041 *** (0.0000153)	1.000071 *** (0.000023)	1.000067 *** (0.0000246)	1.000072 *** (0.0000242)
Real Price One Year Lag	0.9961022 *** (0.0012893)					
Real Price Two year lagged moving average		0.9889416 *** (0.0012408)		0.9867471 *** (0.0026144)	0.9870377 *** (0.0028184)	0.9866429 *** (0.0027934)
GDP Chem Two year lagged moving average			0.9999934 (0.0000139)			
Complex	0.2358819 (0.216387)	0.225293 * (0.2023285)	0.2404058 * (0.2048218)			
Co-paper				0.00000028 *** (0.00000027)	0.00000013 *** (0.00000012)	0.00000026 *** (0.00000026)
Co-plastics				0.0097311 ** (0.0206508)	0.0102585 ** (0.0224946)	0.0096947 ** (0.0203664)
Co-organics				0.6274791 (0.6050604)	0.6283377 (0.6444411)	0.6158373 (0.5958873)
Mercury	0.258763 (0.2909257)	0.2712354 (0.3052939)	0.2932001 (0.3300066)	0.202548 (0.2589724)	0.1713056 (0.2206982)	0.217482 (0.2860009)
Superfund	1.275348 (1.333887)	1.343678 (1.389239)	1.490352 (1.484371)	1.551733 (1.634522)	1.24555 (1.251182)	1.665934 (1.684931)
TRI	2.179805 (2.431213)	2.279155 (2.496303)	2.885759 (4.231192)	1.8559 (2.0166)	0.7977902 (1.474444)	2.348692 (3.94716)
Distribution Parameter (Weibull and Gompertz)					1.723105 (0.7962102)	-0.0250542 (0.077866)
Obs.	714	714	694	714	714	714
Facilities	51	51	51	51	51	51
Number of Adoptions	8	8	8	8	8	8

\*\*\* implies significance at the 1% level, \*\* implies significance at the 5% level, \* implies significance at the 10% level

**Table 3: Exit Results**  
**Hazard Rates with Standard Errors in Parentheses**

	Exponential 1	Exponential 2	Exponential 3	Exponential 4	Weibull	Gompertz
Capacity	0.9935431 ** (0.0026056)	0.9935382 ** (0.0026238)	0.9934989 ** (0.0027377)	0.9931131 ** (0.0028335)	0.9923375 ** (0.0029685)	0.991748 ** (0.0034752)
Net Sales	1.000009 (0.0000111)	1.000009 (0.0000114)	1.000011 (0.00001260)	1.000012 (0.0000137)	1.000008 (0.000011)	1.000009 (0.0000115)
Real Price One year lag	1.00174 (0.0041249)					
Real Price Two year lagged moving average		1.002117 (0.0054283)		1.002009 (0.0054321)	1.001332 (0.004993)	1.000866 (0.0049316)
GDP Chem Two year lagged moving average			0.9999946 (0.000009)			
Complex	0.8944402 (0.2685876)	0.8935033 (0.268834)	0.8619944 (0.2786425)		0.9424272 (0.3048175)	0.9914054 (0.3274504)
Co-paper				0.7961666 (0.303554)		
Co-plastics				0.5715986 (0.61176)		
Co-organics				1.134741 (0.5152976)		
Mercury	0.8087449 (0.34614)	0.8114902 (0.3457402)	0.8145432 (0.3493257)	0.7753466 (0.3399259)	0.6528025 (0.2965594)	0.6761894 (0.3297267)
Superfund	0.8674063 90.5206750	0.8683036 (0.5235591)	0.7278526 (0.4368655)	0.8980625 (0.5621039)	0.5445857 (0.3262042)	0.6521999 (0.4111954)
TRI	0.2004088 ** (0.1321814)	0.1984408 *** (0.1217438)	0.243056 (0.2233334)	0.2081657 ** (0.1290414)	0.0299395 *** (0.027257)	0.0179947 *** (0.0252212)
Pulp and Paper Cluster	6.217796 * (6.468991)	6.317912 * (6.50979)	8.449378 * (10.225)	6.306457 * (6.93193)	4.344673 (4.651529)	4.066813 (4.313415)
Montreal Protocol	8.219747 ** (8.127696)	8.305729 ** (8.184378)	7.646125 ** (7.033812)	6.900499 * (7.125591)	6.144653 (6.998081)	6.605846 (8.935923)
Distribution Parameter (Weibull and Gompertz)					2.726174 ** (0.6256582)	0.2156139 *** (0.0753273)
Obs.	830	830	740	830	830	830
Facilities	55	55	54	55	55	21
Number of Adoptions	21	21	20	21	21	55

\*\*\* implies significance at the 1% level, \*\* implies significance at the 5% level, \* implies significance at the 10% level



<b>Table 4: Effects of Covariates on the Mean Hazard Rate</b>			
		Change from Mean Hazard (Percentage Points)	
		Adoption	Exit
Economic Variables	Capacity	<b>0.08%</b>	<b>-0.34%</b>
	Net Sales	<b>0.10%</b>	0.02%
	Real Price of Chlorine	<b>-0.26%</b>	0.08%
	Complexity		-0.02%
	Co-Paper	<b>-1.28%</b>	
	Co-Plastics	<b>-1.27%</b>	
	Co-Organics	0.00%	
Regulations on Chlorine Production	Mercury	0.00%	-0.40%
	Superfund	0.71%	-0.28%
	TRI (Disclosure)	1.10%	<b>-1.69%</b>
Regulations on End-Use of Chlorine	Pulp and Paper Cluster		<b>11.18%</b>
	Montreal		<b>15.36%</b>

**Bold** indicates that respective *coefficients* are statistically different from zero at the 10 percent level or lower.

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