Can We Breathe and Be Economically Competitive?

Air Quality Regulations and Economic Growth in the

Metal Finishing Industry in Los Angeles

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Abstract

Air pollution emitted from firms and industries in the U.S. poses a significant threat to human health and the environment. Economists, however, have traditionally opposed environmental policies that regulate polluting industries based on the argument that regulations increase firm costs and lead to a decline in economic growth. Some recent research has challenged this standard economic argument, suggesting that polluting firms often adjust to environmental regulations by investing in cleaner technologies that increase productivity and foster economic growth. This study examines the effects of environmental regulations on economic growth and firm adjustment through a case study of the metal finishing industry in the South Coast Basin of Southern California (Basin). Metal finishing firms emit hexavalent chromium into the ambient air during the metal finishing process, a highly toxic chemical linked to cancer. The Basin has a large concentration of metal finishing firms and the industry in the Basin has been strictly regulated since 1988 by the South Coast Air Quality Management District (AQMD). A comparative analysis was conducted of the growth of the metal finishing industry in the Basin with the growth of the metal finishing industries in Chicago and Detroit. These two regions also have large concentrations of metal finishing firms, but have not been subject to the same regulations, providing the analysis with some quasi-experimental controls. The findings suggest that AQMD regulations have not have a detrimental impact on the growth of the metal finishing industry in the Basin. Moreover, the metal finishing industry in the Basin adjusted to regulations by adopting air pollution control technologies. AQMD regulations have substantially reduced the emission of hexavalent chromium into the ambient air from the metal finishing industry in the Basin, significantly reducing health risks to the total population.

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Introduction

Environmental pollution in the U.S. poses a significant threat to human health and the environment. Almost half of the people living in the U.S., for example, are exposed to unhealthy levels of air pollution in the form of either ozone or particulate matter (American Lung Association, 2008). Epidemiological studies have linked air pollution to adverse health effects in humans, including asthma, stunted lung growth, cardiovascular disease, and increased mortality (Ritz, Wilhelm, and Zhao, 2006). Moreover, according to the U.S. Environmental Protection Agency (2007), forty-five percent of the nation's 3.7 million miles of rivers and streams are not clean enough to support their designated uses, such as fishing and swimming. One half of the nation's 40.6 million acres of lakes, ponds, and reservoirs are impaired. One of the most serious environmental concerns is global warming. As a result of the emission of carbon into the air from industries and other sources, scientists predict significant regional climate change, such as increased storm frequency, drought and sea level rise (National Academy of Sciences Committee on the Science of Climate Change, 2001).

Despite these problems, most economists are strongly opposed to government regulations that are intended to clean up the environment (Bezdek, 2001; Jaffe et al.). According to standard economic theory, environmental regulations increase the costs that firms must allocate toward environmental compliance, reducing available resources to invest in research and development (Magat, 1978; Milliman and Prince, 1989; Steward, 1981). Consequently, regulated firms are placed at a competitive disadvantage in the marketplace when compared with their unregulated rivals. Moreover, firms will respond to environmental regulations by relocating to countries where environmental regulations are weak or nonexistent, resulting in significant job loss. The long run effects of environmental regulations on the economy, most economists argue, are a decline in productivity, a reduction in economic growth, and a decline in the standard of living for U.S. citizens.

A number of studies in the social sciences, however, have recently challenged the standard economic approach. A leading voice in this movement is Michael Porter, an economist at Harvard University (Porter, 1991: Porter and Linde, 1995). Porter has argued that environmental regulations can not only clean up the environment, they can also foster economic growth and competitiveness among firms and industries. According to this perspective, environmental regulations may encourage companies to develop new product and process technologies that reduce pollution while increasing firm productivity. Increased productivity translates into greater economic growth. Product innovations made in response to environmental regulations, moreover, may give firms a "first mover" advantage in international markets. Environmental regulations offer the possibility of a win-win situation for the environment and the economy because profitable innovations help to offset the cost of environmental compliance.

In this study I set out to examine the relationship between environmental regulations and economic growth. To investigate the question, I conducted a case study of the metal finishing industry in the South Coast Basin of Southern California (Basin). I chose this case study for the following reasons. First, metal finishing firms emit hexavalent chromium into the ambient air during the metal finishing process. Hexavalent chromium is a highly toxic chemical and scientific studies have linked it to cancer and other health problems in metal finishing workers and residents living near metal finishing facilities (California Air Resources Board, 2003; California Environmental Protection Agency, 2002). Second, the Basin has one of the largest concentrations of metal finishing companies in the country. The industry constitutes an important part of the region's manufacturing base. Third, the metal finishing industry in the

Basin, since 1988, has been subject to stringent environmental regulations by the South Coast Air Quality Management District (AQMD). The AQMD was established by the State of California in 1977 to regulate air quality in the Basin in compliance with the Clean Air Act of 1970.

To assess the effects of AQMD regulations on the economic growth of the metal finishing industry in the Basin, I conducted a comparative analysis of the growth of the metal finishing industry in the Basin with the growth of the metal finishing industries in Chicago and Detroit. Chicago and Detroit also have large concentrations of metal finishing firms and similar industry characteristics, but the industries in Chicago and Detroit have not been subject to the same level of strict environmental regulations. These circumstances provide the analysis with some quasi-experimental controls. According to standard economic theory, we would expect to find that the metal finishing industries in Chicago and Detroit experienced greater economic growth than the industry in the Basin since 1988. I also examined how the metal finishing industry in the Basin has adjusted to AQMD regulations. If Porter's hypothesis is correct, we would expect to find innovations emanating from the metal finishing industry in the Basin in response to the regulations. The following case study was based on a combination of census data, reports from industry associations and environmental organizations, and interviews with industry officials and environmental regulators.

The analysis revealed the following findings. First, AQMD policies regulating the emission of hexavalent chromium from the metal finishing industry in the Basin do not appear to have had a detrimental effect on the growth of the industry in the Basin. The industry in the Basin performed better than or comparable to the industries in Chicago and Detroit since 1988, despite being subject to more stringent regulations. Second, the industry in the Basin adjusted to the regulations by adopting pollution control technologies. There was little evidence that the industry adjusted through technology innovations, at least in the traditional sense conceptualized by Porter. However, innovations in chemical substitutes have slowly emerged from supplier firms, such as trivalent chromium, which are becoming economically and technically feasible. Finally, AQMD regulations have substantially reduced the emission of hexavalent chromium into the ambient air from the metal finishing industry in the Basin, significantly reducing health risks for the local population.

While the jury is still out on the long-term effects of environmental regulations on economic growth, the findings of this study provide one more piece of evidence that environmental regulations and economic growth can provide some "win-win" outcomes. A challenge for future research is to examine the effects of environmental regulations on economic growth and competitiveness using varied methodological approaches from multidisciplinary perspectives.

The remainder of this paper is organized as follows. In section I, I review the literature that has examined the relationship between environmental regulations and economic growth. In section II, I examine characteristics of the metal finishing industry, the industry process, and scientific studies linking the emission of hexavalent chromium to human health problems. In section III, I review AQMD and U.S. EPA environmental policies that regulate the emission of hexavalent chromium from the metal finishing industry. In section IV, I examine how the metal finishing industry in the Basin has adjusted to AQMD regulations. In section V, I present findings from my comparative analysis of the growth of the metal finishing industry in the Basin with the industries in Chicago, and Detroit. In section VI, I conclude with a summary.

Section I: Environmental Regulations and Economic Growth

Mainstream economic theory has long held that environmental regulations act as a major constraint on economic growth (Jaffe et. al., 2002; Magat, 1978; Milliman and Prince, 1989;). Environmental regulations, according to the argument, increase a firm's costs of production due to higher factor costs and increased environmental compliance costs. As a consequence, firms have fewer resources to invest in research and development, productive capacity, and other forms of technology. In the long run, environmental regulations place firms at a competitive disadvantage in the marketplace when compared with their unregulated rivals. Moreover, most economists argue that firms will adjust to environmental regulations by relocating to regions or countries where environmental regulations are less stringent or nonexistent, resulting in significant job loss and economic deterioration in the communities left behind. The long run effects of environmental regulations on the economy, according to standard economic theory, are a decline in firm productivity, job loss, and a reduction in the U.S. standard of living.

Empirical research in economics has supported the theoretical claim that environmental regulations impede economic growth. In a highly cited study, Jorgenson and Wilcoxen (1990) constructed a detailed model of the economy that incorporated the determinants of long-term economic growth. They estimated the impact of environmental regulations on the U.S. economy by simulating the growth of the economy between 1973 and 1985 with and without environmental regulations. According to their findings, environmental regulations reduced annual economic growth by about 0.2 percent per year. GNP by the early 1990s would have been about 2.5 percent higher in the absence of the regulations. In another study using the same methodology, Jorgenson and Wilcoxen (1992) assessed the impacts of the Clean Air Act

Amendments of 1990 on the U.S. economy. They estimated that GNP would have been about 3 percent higher by 2005 if it had not been for the CAA regulations.

Barbera and McConnell (1986) attempted to measure the effects of environmental regulations of the 1970s on economic productivity in several manufacturing industries, including paper, chemicals, stone, clay and glass, iron and steel, and non-ferrous metals. Comparing industry productivity for the 1970s to the 1960s, she found that environmental regulations caused an annual reduction in the rate of productivity growth of between .12% and .43.% in these industries. Gollop and Roberts (1983) measured and analyzed the effect of sulfur dioxide emission restrictions on the rate of productivity growth in the electric power industry between 1973 and 1979. Their econometric model incorporated the severity of the emission standard, the extent of enforcement, and the unconstrained emission rate of each facility. They concluded that the annual productivity growth of electric utilities declined by .59 percentage points over the period. Gray and Dadbegian (1995) used data from the Pollution Abatement and Control Expeditures (PACE) survey to assess the effects of environmental compliance costs on the productivity of oil refinearies. The PACE survey collects information on the capital and operating costs of environmental regulations for manufacturing industries in the U.S. economy. Their cross-sectional estimates indicated that $1 spent on pollution abatement by oil refineries induced a productivity loss of $1.35.

Jaffe and Palmer (1997) studied the effects of environmental regulations on technology innovation among firms and industries in the U.S. economy. The traditional economic assumption is that innovation leads to higher levels of productivity and economic growth, but environmental regulations restricts this process. Specifically, Jaffe and Palmer examined pollution control expenditures, R&D spending data, and patent data in a panel of industries between 1976 and 1989. Data on pollution control expenditures were taken from the PACE survey. They found some evidence that increases in PACE spending were associated with increases in R&D spending, but no evidence that this spending produced greater innovation as measured by successful patent applications. In another study on this question, Schmalensee (1994) argued that while R&D devoted to environmental compliance may increase with stricter environmental regulation, this increase will likely come at the expense of other research efforts that could have been more profitable.

There is, however, an emerging literature that has challenged the standard economic approach (Bezdek, 1994; Roediger-Schluga, 2004). A leading voice in this movement has been Michael Porter, an economist at Harvard University. Porter has argued that environmental regulations can stimulate economic growth while also cleaning up the environment (Porter, 1991; Porter and Linde, 1995). Environmental regulations, he argues, may induce firms and industries to develop new process and product innovations that reduce polluting inputs and outputs and increase firm productivity. Process innovations include the discovery of new materials, new equipment, new marketing methods, and new ways of organizing shop floor practices. Product innovations may lead to new markets and give firms a "first mover" advantage in international markets. According to Porter, environmental regulations result in a "win-win" situation because the profits that result from innovations and economic growth offset the costs of environmental compliance to firms and industries.

A number of studies in economics and other academic disciplines have produced findings consistent with Porter's general argument. Meyer (1993), for example, compared the stringency of environmental regulations across states. After controlling for exogenous economic factors, his findings revealed that states with stronger environmental regulations tended to have higher rates of economic growth than states with weak standards. In a study of oil refineries in Los Angeles, Berman and Bui (2001) argued that in meeting more stringent environmental standards, oil refineries actually increased their productivity and efficiency. Morgenstern et. al. (2000) examined the effects of environmental regulations on the pulp and paper, plastics, petroleum and steel sectors and concluded "that a million dollars of additional environmental expenditure is associated with an insignificant change in employment." Thomas and Ong (2003) found that many wood furniture firms in Los Angeles relocated to Mexico in the 1980s after being hit with environmental regulations. However, by the early 1990s the industry recovered through innovations in less polluting paints and solvents.

A major challenge of accurately assessing the impacts of environmental regulations on economic growth is obtaining reliable data. Traditional economic studies rely on large-scale econometric input-output models to estimate the impacts of environmental compliance costs on productivity in specific firms and industries. The findings of these studies have been challenged because data on environmental compliance costs are argued to be inaccurate (Jaffe et.al., 2002). Economic models also face limitations in controlling for the effects of exogenous political, economic, and technological changes on basic economic performance. Porter's work has been criticized for methodological shortcomings. For example, Jaffe et. al. (2002) have argued that even if industries reengineer processes in response to environmental regulations, as Porter maintains, these changes are unlikely to be reflected in published industry output measures. Moreover, Palmer et. al. (1995) have criticized Porter for relying too heavily on individual qualitative case studies of firms who have successfully innovated in response to environmental regulations to support his thesis (Palmer, Oates, & Portney, 1995). Anyone, they argue, can compile a list of case studies that prove almost anything. Jaffe, a leading scholar on the question, summarized the current state of the literature in the following way: “The evidence on induced innovation and the win-win hypothesis seems to be a case of a ‘partially full glass’ that analysts see as mostly full or mostly empty, depending on their perspective” (Jaffe et. al., 2002, p. 46).

Section II: The Metal Finishing Industry and The Emission of Hexavalent Chromium

Hexavalent chromium as a chemical used in the metal finishing process has been popular since it became commercially available in the 1920s (Baral et. al, 2006). Hexavalent chromium makes products shiny, attractive, and wear and tear-resistant.

The metal finishing industry can be divided into two distinct segments: “job shops” and “captive shops.” Job shops are independent operators that provide plating or anodizing services to a variety of industries (Haveman, 1998; U.S. Environmental Protection Agency, 1995). A typical job shop employs 15 to 20 people and generates $800,000 to $1 million in annual gross revenues (Chalmer, 2008). Captive shops operate within or for specific manufacturing companies. Captive shops generally have more predicable finishing requirements, are more specialized, and have a higher degree of automation. Job shops and captive shops typically do not compete against each other, although captive facilities may subcontract work to job shops that they are unable to perform. In both sectors, the metal finishing process is supervised by skilled electrochemical engineers, or by platers with long experience. In smaller facilities, the proprietor typically holds the expertise in plating or anodizing. Both segments of the industry are highly tied to the manufacturing sector, particularly automotive, electronics, computers, machinery, industrial equipment, defense, and aerospace (Pearce, 2005; U.S. Environmental Protection Agency, 1995).

Metal finishing firms (both job shops and captive shops) typically conduct one of three types of metal finishing processes: 1) hard chromium electroplating, 2) decorative chromium

Figure 1

Chromium Platting Processes

	HARD CHROMIUM PLATING	**DECORATIVE CHROMIUM PLATING**	**CHROMIC ACID ANODIZING**
Type of layer	Thick layer (2.5 μm – 760 μm)	Thin layer (0.003 μm-2.5 μm)	Electrochemical conversion
Properties provided	Corrosion protection, wear resistance, lubricity and oil retention among other properties	A decorative and protective finish	Corrosion and abrasion resistant surface by forming an oxide coating
Type of parts	Engine parts, industrial machinery, and tools	Bath fixtures, faucets, automotive bumpers and wheels, furniture components, motorcycle parts	Architectural applications, landing gears, giftware and novelties, automotive trim and bumpers
Plating duration	Hours or days	Seconds or minutes	<1 – 5 minutes
Substrate	Typically plated on steel	Typically plated on Nickel	Aluminum

Source: South Coast Air Quality Management District, 2003.

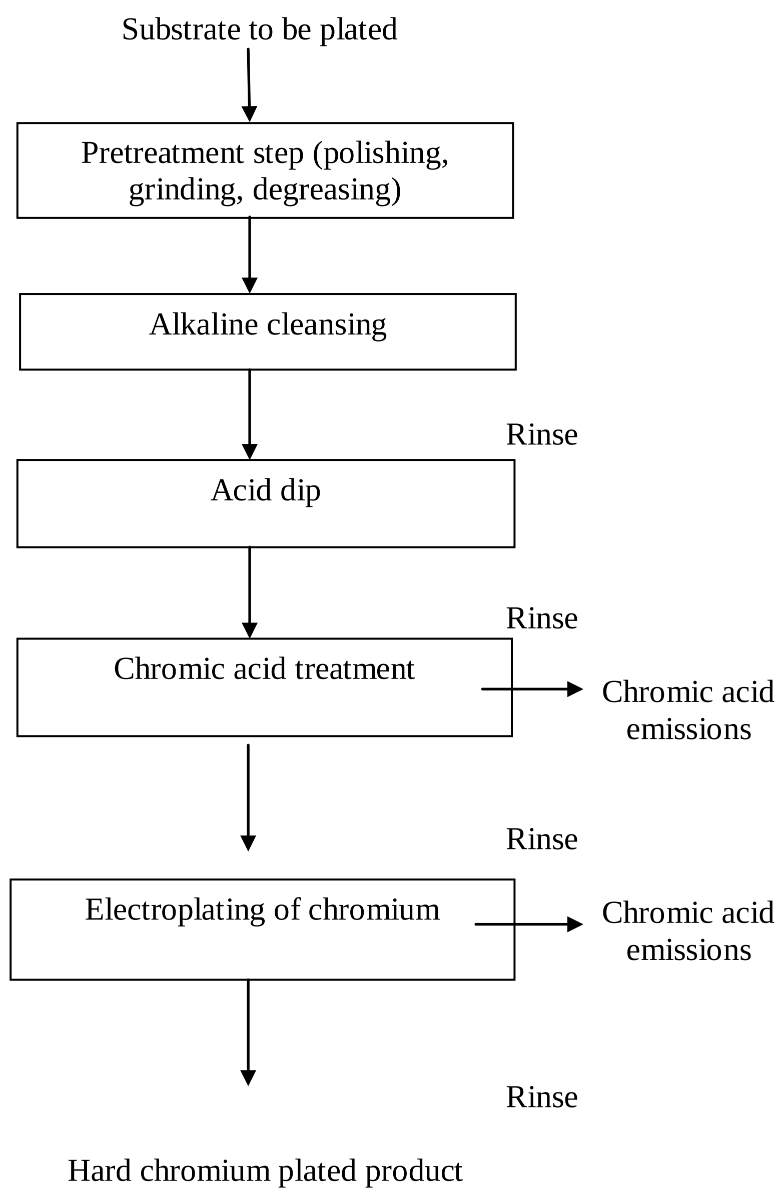
electroplating, and 3) chromium anodizing (Figure 1). The hard chromium electroplating process takes longer than the decorative plating or anodizing processes. It is measured in hours or days and deposits a "thick" layer of chromium on a base metal to provide wear and corrosion resistance for metal products such as hydraulic cylinders and rods, drills, pistons, cutting tools, crankshafts, printing plates, and industrial machinery. Decorative chromium electroplating, in contrast, is measured in seconds or minutes and deposits a "thin" layer of chromium on a base metal. Decorative chromium provides a bright finish and wear and tarnish resistance for products primarily used for aesthetic purposes. Common applications include bicycles, auto trim, tools, appliances, jewelry, and hardware. Chromium anodizing, the third category, is an electrochemical process in which aluminum is the anode. When an electric current passes through the electrolyte, it converts the metal surface to a durable aluminum oxide, providing corrosion and wear resistance. Products include aircraft parts and architectural products.

A typical flow chart for hard chromium electroplating is shown in Figure 2. The first step in hard chromium plating is pretreatment, which can be mechanical buffing, polishing, vapor degreasing, or soaking in an organic solvent. The pretreatment step is followed by alkaline cleaning in order to remove surface soil (U.S. Environmental Protection Agency, 1995b; Baral et. al, 2006). Alkaline cleaning is accomplished by soaking and/or an electrotic process. In electrolytic alkaline cleaning, gas evolution on the surface of the substrate enhances the cleaning agent's action. After rinsing, the base metal is dipped in acid to remove tarnish and neutralize the alkaline film on its surface. In the hard chromium plating operation, the cleaned substrate is subjected to anodizing treatment before chromium electroplating. However, for decorative chromium plating, an undercoat of copper or nickel is applied to the base metal before plating. The anodizing treatment applies a protective oxide film on the base metal. At the end, the chromium layer is electrodeposited on the base metal.

The hard, decorative, and anodizing processes release hexavalent chromium into the ambient air during the metal finishing process (see Figure 2). Hexavalent chromium is emitted into the ambient air when gas bubbles coated with a layer of the unused chromium solution from the plating bath rise to the surface as hydrogen and oxygen bubbles and break the surface of the plating bath to form a chromic acid mist. The emission of hexavalent chromium from the plating

Figure 2

The Hard Chromium Plating Process



bath is intensified because the plating efficiency of hexavalent chromium is very low compared to the plating efficiency of other chemicals. In general, approximately 20 percent of the chromic acid in a bath is plated onto a metal object during the metal finishing process. It should also be noted that the magnitude of emissions depends on several variables, including the concentration of chromic acid in the bath, ampere-hours used during plating, bath temperature, bath purity, and surface tension (South Coast Air Quality Management District, 2003).[1] As a result of a higher current density used in hard chromium plating, more chromic acid mist is generated in comparison to the decorative chromium plating and anodizing processes.

The emission of hexavalent chromium into the ambient air posses a severe health threat to the local population (California Air Resources Board, 2003; California Environmental Protection Agency, 2002). Metal finishing facilities are often located in proximity to residential areas with high population densities. Once emitted into the air, hexavalent chromium can be inhaled and trapped inside the lungs. Exposure to hexavalent chromium, even at low levels of concentration, has been associated with a number of health problems, including lung and nasal cancer, renal toxicity, respiratory irritation, nosebleeds, ulcers, holes in the nasal septum, skin ulcerations, and stomach and kidney problems (Agency for Toxic Substances and Disease Registry, 2001; California Air Resources Board, 1985; Pellerin and Booker, 2000). The International Agency for Research on Cancer, the World Health Organization, and the U.S. EPA have classified hexavalent chromium as a toxic chemical and a proven carcinogen (Baral et. al., 2006). Metal finishing workers in particular face the greatest health risk (Caglieri et. al., 2006). According to the Occupational Safety and Health Administration (2008), some 550,000 workers are exposed to hexavalent chromium on the job. One study found an increased incidence of lung cancer in a group of 2,357 workers at a chromate production plant (Gibb et. al., 2000).

Section III: Regulations and Pollution Control Technologies

The emission of hexavalent chromium from the metal finishing industry in the Basin has been regulated by the AQMD since 1988. AQMD's regulatory authority exists within the framework of the 1970 federal Clean Air Act (CAA). The CAA, including the CAA amendments of 1990, is designed to "protect and enhance the nation's air resources so as to promote the public health and welfare and the productive capacity of the population." The CAA created the Environmental Protection Agency (EPA) and authorized the EPA to establish national ambient air quality standards (NAAQSs) to limit levels of "criteria" pollutants, including carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur dioxide. Title III of the CAA directed the EPA to regulate toxic air contaminants (TACs), substances which have the potential to cause cancer and chronic and acute health effects in people. TACS are identified by state and federal agencies based on a review of available scientific evidence. States are required to develop state implementation plans (SIPs) that outline how they will meet EPA national standards for air quality. States that do not provide acceptable SIPs may lose federal funds and forfeit control over environmental regulatory authority within their own state. Under the CAA, states have the option of setting environmental standards that go beyond EPA mandates.

In 1977, the State of California created the AQMD to monitor and enforce air pollution control rules and regulations in the Basin in compliance with the CAA.[2] The AQMD's jurisdiction covers Los Angeles and Orange Counties and parts of Riverside and San Bernardino Counties, an area covering approximately 10,473 square miles. The AQMD is required to adopt an air quality management plan for the Basin demonstrating compliance with all federal and state ambient air quality standards. Because the region is home to approximately 16 million people and has one of the largest regional economies in the country, it has a severe air pollution problem

(Wilson, 2008). The poor air quality is compounded by the region's topography as mountains ringing the area create a bowl that restricts air circulation. The high levels of pollution in the Basin place residents at significant health risks (South Coast Air Quality Management District, 2008c). On overage, residents in the Basin are exposed to a lifetime cancer risk from toxic air pollution of 1,200 in 1 million, one of the highest risks in the country (South Coast Air Quality Management District, 2008a). Cancer risk is the number of excess cancer cases among a million people if the people are exposed to levels of a toxic air pollutant over 70 years As an example, a cancer risk of 100 in a million at a location means that the individuals staying at that location for 70 years have a 100 in a million chance of contracting cancer.

In the early 1980s, scientists from the State of California's Office of Environmental and Health Hazard Assessment (OEHHA) concluded that hexavalent chromium was a toxic air contaminant and a potent human carcinogen with no known safe level of exposure (California Air Resources Board, 1985).[3] At the time, approximately two-thirds of the total metal finishing firms in the State of California were located in the Basin. The industry in the Basin was responsible for emitting 7,924 tons of hexavalent chromium into the region's ambient air each year (Murchison et. Al., 1988).[4] The cancer risks to residents as a result of these emissions was estimated to be between 170 and 2000 cases per million. Accordingly, on June 3, 1988, the AQMD implemented Rule 1169 (California Air Resources Board, 1988).[5] Rule 1169 required metal finishing firms in the Basin to reduce their emissions of hexavalent chromium by 95 to 99 percent, depending on the type of metal finishing being performed, the size of the facility, and the level of throughput. It was estimated that the regulations would reduce the emission of hexavalent chromium into the region's ambient air by 11,700 pounds per year.

Regulators who implemented Rule 1169 concluded that non-toxic substitutes for hexavalent chromium were not technologically feasible. They therefore required the industry to adopt best available control technologies (BACT) which included the packed bed scrubber with an outlet de-mister, foams, and anti-mist additives (Murchison et. Al., 1988). Rule 1169 also included monitoring, work practice standards, recordkeeping, and reporting requirements. A detailed summary of Rule 1169 is provided in Appendix A.

In 1995, the United States Environmental Protection Agency (EPA), responding to mounting evidence linking hexavalent chromium to human health problems, initiated the National Emission Standard for Hazardous Air Pollutants (NESHAP) for Hard and Decorative Chromium Electroplating and Chromium Anodizing Tanks (U.S. Environmental Protection Agency, 1995). The 1995 NESHAP applied to the metal finishing industry nationwide and was more stringent than Rule 1169. Specific emission limits were established for hard chromium electroplating operations, increasing in stringency for facilities with a cumulative rectifier capacity greater than 60 million ampere-hours per year. The NESHAP required decorative chromium plating and chromic acid anodizing facilities to meet reduced exhaust standards, or maintain their plating baths at a maximum of 45 dynes per cm. It was estimated that the NESHAP would reduce the emission of hexavalent chromium nationally by 173 tons per year.

The NESHAP became effective for decorative chromium platters in 1996 and hard chromium and anodizing facilities in 1997. The U.S. EPA extended the deadline for compliance for hard chromium and anodizing facilities in the Basin until January 1998.[6] Like Rule 1169, the NESHAP required the metal finishing industry to achieve reductions in hexavalent chromium through the adoption of BACT pollution control technologies, which included HEPA filters and anti-mist additives. The NESHAP also included monitoring, work practice standards, recordkeeping and reporting requirements (see Appendix A for a detailed summary).

In 2000, AQMD regulators completed the Multiple Air Toxics Exposure Study (MATES II) (South Coast Air Quality Management District, 2000). The Mates II study was an urban toxics evaluation project initiated in 1977 by the AQMD's Governing Board as part of their Environmental Justice Initiative. The MATES II study identified the presence of hexavalent chromium in the Basin at levels that, despite earlier regulatory efforts, still posed significant health risks to the local population. Accordingly, in 2003 the AQMD replaced and strengthened the NESHAP regulations with Rule 1469 (South Coast Air Quality Management District, 2003; Selmi, 2005).

Rule 1469 was developed on the basis of two criteria: 1) distance from sensistive receptors (a sensitive receptor includes educational facilities, daycare centers, and health care facilities), and 2) level of cancer risk to residents. Rule 1469 required metal finishing facilities located less than 25 meters from a sensitive receptor and facilities located 100 meters or less from an existing school to reduce their emissions of hexavalent chromium to 0.0015 mg per ampere hour. Facilities located more than 25 meters from a sensitive receptor (with the exception of schools) were required to reduce hexavalent chromium emissions to a limit between 0.01 mg and .0015 mg per ampere-hour. Metal finishing firms in the Basin were again required to achieve reductions in hexavalent chromium through the adoption of BACT technologies, including (HEPA) filters and chemical fume suppressants. It was estimated that Rule 1469 would reduce the emission of hexavalent chromium into the region's ambient air by 48 pounds per year. Additional requirements of Rule 1469 are shown in Appendix A. Rule 1469 currently stands as the most stringent regulation in the country governing the emission of hexavalent chromium into the ambient air from the metal finishing industry.[7]

Section IV: The Adjustment Process

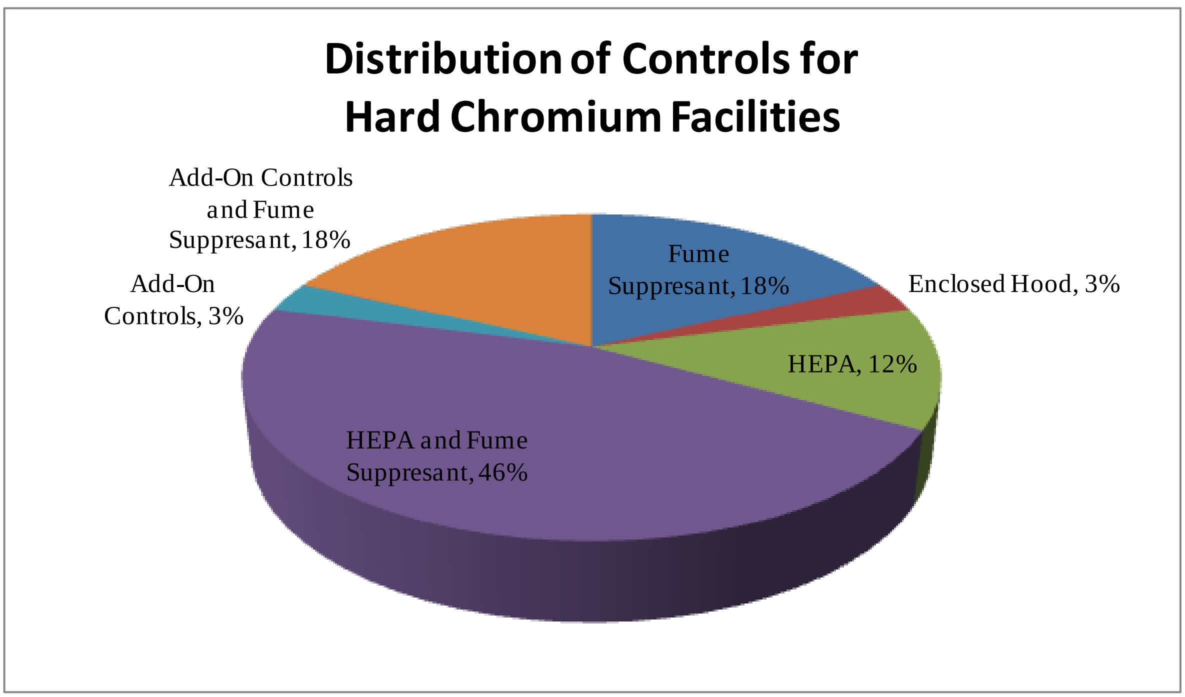
Firms may adjust to environmental regulations to achieve reductions in the emissions of pollutants into the ambient air in two basic ways: 1) firms may adopt existing technologies or, 2) firms may adjust through technology innovations. More specifically, firms may:

- Switch to less hazardous materials in production;
- Modify the production process to improve efficiency and reduce the use of toxic substances;
- Install more efficient equipment to reduce raw material consumption and produce less waste;
- Redesign products to reduce certain raw materials in products and packaging;
- Produce new products that are more environmentally efficient; and,
- Install pollution control equipment that captures polluting emissions.

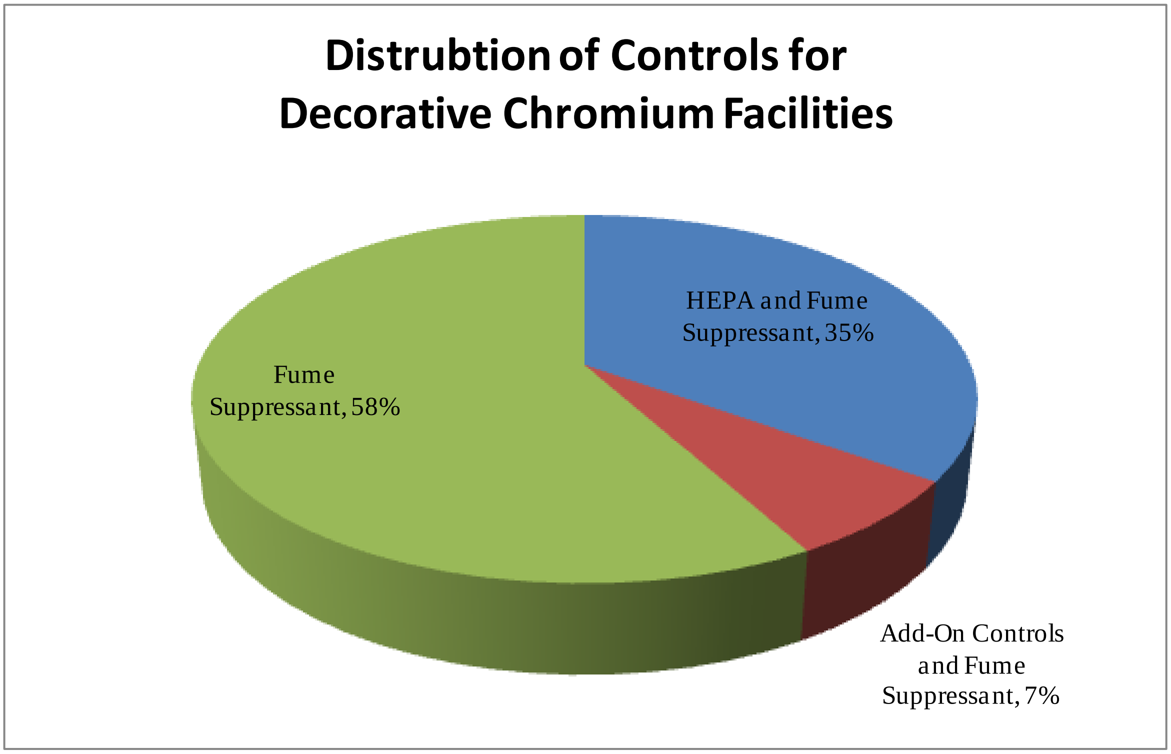
As noted in the previous section, environmental regulators have long viewed alternative chemicals to hexavalent chromium as economically and technically unfeasible. Hexavalent chromium remains the most effective and cost efficient chemical used in the metal finishing industry due to its powerful anticorrosive properties (Pellerin and Booker, 2000). Consequently, metal finishing firms have adjusted to environmental regulations through the adoption of pollution control technologies. Pollution control technologies enable them to continue to use hexavalent chromium in the production process. There is little evidence that metal finishing firms have adjusted to the regulations through technology innovations, at least in the traditional sense conceptualized by Porter. Innovations in alternative chemicals and processes have, however, taken place among supplier firms.

Metal finishers in the Basin have been given a degree of flexibility by AQMD regulators in the types of pollution control technologies they may adopt to reduce the emission of hexavalent chromium (Selmi, 2005). Hard chromium plating facilities have generally used add-on air pollution control devices including scrubbers, composite mesh pads, and HEPA filters. HEPA filters represent BACT for hard chromium plating facilities. Decorative chromium plating and chromic acid anodizing facilities have primarily used in-tank controls, such as chemical fume suppressants and polyballs. Chemical fume suppressants represent BACT for decorative platers. Appendix B contains a brief description of the air pollution control technologies metal finishers may adopt to comply with AQMD and federal NESHAP regulations.

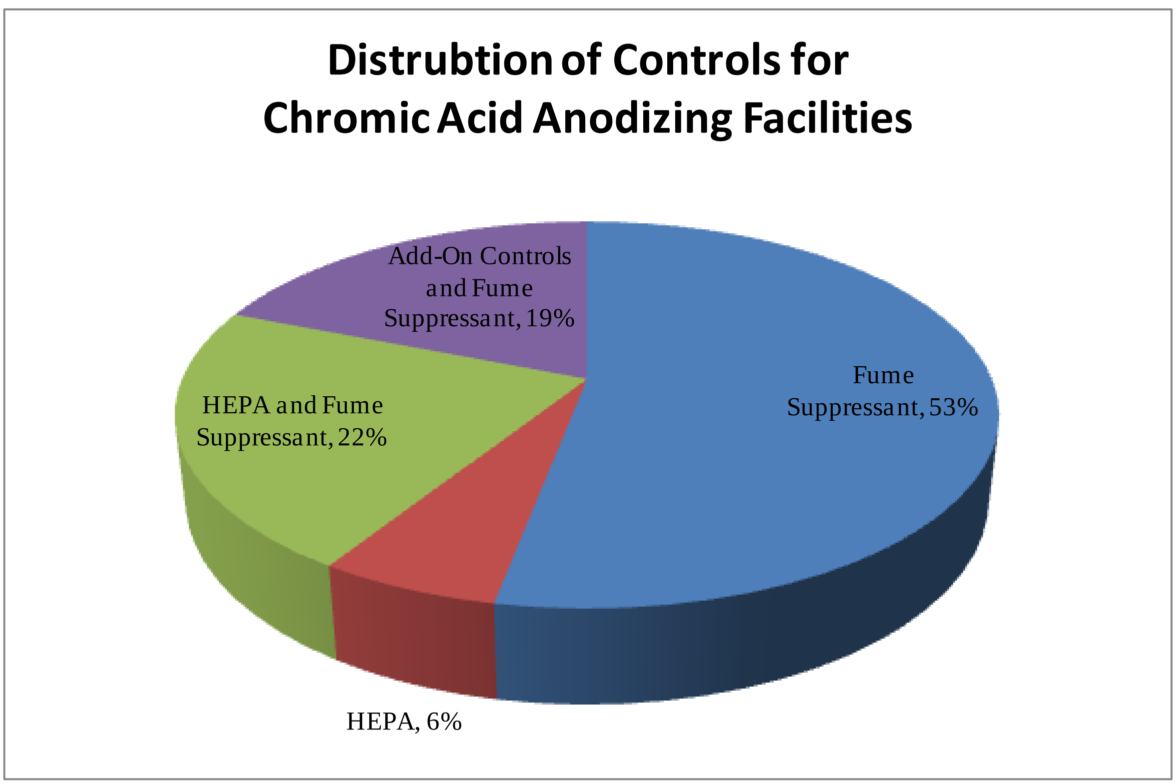
Figures 3 through 5 show the distributions of technologies currently used by hard, decorative, and anodizing facilities within the Basin to reduce chromium emissions. Most facilities are using fume suppressants, HEPA filters, or both.



Source: South Coast Air Quality Management District, 2008b.



Source: South Coast Air Quality Management District, 2008b.



Source: South Coast Air Quality Management District, 2008b.

While the metal finishing industry has complied with environmental regulations through the adoption of pollution control equipment, innovations in substitute chemicals that reduce or eliminate the emission of hexavalent chromium have been slowly emerging from supplier firms (South Coast Air Quality Management District, 2003; Frazer, 2006). To be viable substitutes for hexavalent chromium, alternative chemicals must yield quality coating properties and be cost-competitive. The most potential for substituting less polluting alternatives for hexavalent chromium are in those instances where the metal object being plated does not require all of the properties of hexavalent chromium. For example, there are certain metal products that do not require a bright metallic appearance or the same level of wear-resistant qualities that can be obtained through the exclusive use of hexavalent chromium (Frazer, 2006).

Currently, the most promising chemical substitute for hexavalent chromium is trivalent chromium (Schario, 2008; Cunningham, 2007). For some metal finishes, trivalent chromium can provide comparable physical properties and the same color quality as hexavalent chromium while reducing health, safety and environmental hazards. Trivalent chromium is not considered a toxic chemical by the scientific community. Trivalent chromium offers additional advantages. The use of trivalent chromium eliminates misting problems and allows for higher rack densities because the bath concentration is lower and drag out is reduced. The biggest limitation of trivalent chromium is that it cannot plate the full range of thicknesses as the hexavalent chromium process. Thicker coatings using trivalent chromium typically have problems with cracking, color, and palling. Trivalent chromium, therefore, is a more effective substitute for decorative chromium applications than hard chromium applications. Finally, a barrier facing the use of trivalent chromium is customer acceptance. Appendix C provides a brief overview of several additional potential alternatives to hexavalent chromium plating and chromic acid anodizing.

Metal finishing firms in the Basin are strictly monitored by the AQMD for compliance with Rule 1469. In a recent AQMD audit, some metal finishing firms in the Basin were cited for violations of shop floor practices. However, all metal finishing facilities were found to be in compliance with Rule 1469 with respect to having adopted the appropriate technologies to reduce the emission of hexavalent chromium into the ambient air (Nagavada, 2008).

While the industry in the Basin may be in compliance, some metal finishing firms in the Basin and other regions of the United States face barriers to efficiently adjusting to AQMD or federal NESHAP regulations. A recent study conducted by the U.S. EPA, for example, found that the industry in some regions of the country had high rates of non-compliance with the NESHAP regulations (U.S. Environmental Protection Agency, 2000). For example, in EPA region III, which is comprised of Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia, about 40% of facilities were found to be in violation of technology standards.

The EPA and other observers have identified barriers that some metal finishing firms may face to adjusting to environmental regulations and engaging in research and development. First, metal finishing firms involved in low value-added manufacturing generally experience the most difficulty engaging in research and development and complying with regulations. Low value-added metal finishing firms compete exclusively on price and generally have relatively low profit margins (Chalmer, 2008). Consequently, they often lack the capital to invest in research and development activities or in pollution control technologies. They may fall behind and become “trapped in older processes. Moreover, metal finishing firms engaged in low value-added finishing are more likely to relocate production offshore in response to environmental restrictions.

Second, a barrier to innovation and environmental compliance may be connected to the metal finishing industry's dependence on suppliers for their everyday operations and economic survival (Chalmer, 2008: Haveman, 1998). For example, the average metal finishing facility works with several suppliers of process chemistries and equipment. Metal finishers rely on suppliers for information concerning technology availability, technical support, and sometimes financial support. Moreover, the typical metal finishing firm – particularly smaller ones – do not have personnel with formal engineering experience. They must therefore rely on suppliers for this knowledge. The dependence on suppliers may be a barrier to innovation because the development of alternate "green" chemistries is typically a multi-year endeavor that requires a significant investment in research and development. In some instances suppliers may serve as barriers because they may be reluctant to suggest environmentally safer alternatives when such alternatives could result in lower sales.

A third potential barrier is liability concerns (Haveman 1995). Existing liabilities can overwhelm a metal finishing company, particularly a smaller operation, to pay for remediation. Some metal finishers may continue to operate at a profit loss due to the high environmental cleanup costs associated with shutting down and liquidating. Fourth, the use of hexavalent chromium among some metal finishing firms is a relatively small part of their operations. In such instances, it may be cost effective to eliminate chromium operations or outsource the work than to invest in environmental compliance and new technologies (Kirchner, 2006). Sixth, uncertainty or a lack of knowledge about the regulatory process and requirements may be a barrier. Firms may be confused or uninformed about compliance procedures. Seventh, some military and customer specifications continue to require the use of hexavalent chromium, even when safer substitutes or processes may be available. Finally, there is a small segment of the industry that the U.S. EPA refers to as "outlaw" firms (U.S. Environmental Protection Agency, 1994). Such firms are out of compliance and are not substantial competitors in the industry. They have little or no interest in complying with environmental regulations and have no incentive to improve their operations because they gain no competitive advantage. Such firms often operate without permits and are difficult to track down.

Section V: Environmental Regulations and Economic Growth

In this section I compare the growth of the metal finishing industry in the Basin with the growth of the metal finishing industries in Chicago and Detroit. As noted earlier, the AQMD's jurisdiction covers Los Angeles and Orange Counties and portions of Riverside and San Bernardino Counties. Because I use county level data for the following analysis, I have defined the Basin as Los Angeles and Orange Counties. The county level data provides consistent time trends. Data for Chicago are based on Cook County and data for Detroit are based on Wayne County.

The Basin, Chicago, and Detroit have historically had large concentrations of metal finishing firms. The concentration of the industry in all three regions is reflected in their large "location quotients." A location quotient is a ratio that compares the percentage of employment in a particular industry in a local economy to the percentage of employment in the same industry nationally. A location quotient greater than one indicates that the local share of employment in an industry is greater than the national share. If it is less than one, the local share is less than the national share. Also, a location quotient greater than one generally suggests that an industry is an exporter of goods from the local economy. The location quotient for the metal finishing industry in the Basin is 2.8, in Chicago it is 3.0, and in Detroit it is 3.1. Moreover, all three regions have historically had strong manufacturing sectors. In the Basin, 12 percent of total employment is in manufacturing, in Chicago it is 10 percent, and in Detroit it is 13 percent. This is important because, as noted earlier, the economic growth of the metal finishing industry is closely tied to the well-being of local and national manufacturing.

In addition to having similar industry characteristics, the Basin, Chicago, and Detroit have similar political institutions, at least to the degree that they are part of the federalist system of governance in the U.S. However, the metal finishing industry in the Basin has been subject to more onerous environmental policies than the metal finishing industries in Chicago and Detroit. Between 1988 and 1997, the emission of hexavalent chromium from the metal finishing industry was regulated in the Basin (Rule 1169) but not in Chicago or Detroit. From 1998 to 2002, the metal finishing industry in the Basin, Chicago, and Detroit were subject to the same federal NESHAP regulations (although the NESHAP was officially approved in 1995, it did not become effective for all metal finishers until 1998). Then, in 2003, the AQMD initiated more stringent regulations (Rule 1469) on the metal finishing industry in the Basin. These conditions provide this study with some quasi-experimental controls. According to standard economic theory, we should expect to find that the metal finishing industry in Chicago and Detroit out-performed the metal finishing industry in the Basin since 1988. The disparity in economic growth should be particularly severe between 1988 and 1997 when the industry in the Basin was regulated and the industries in Chicago and Detroit were not. In addition, AQMD's reputation as a strict environmental regulator, overall, should have discouraged companies from locating in the region.

A challenge of comparing growth in the metal finishing industry in the Basin with the growth of the industries in Chicago and Detroit is access to reliable data at the sub-state level. I was able to utilize two indicators at the County level as proxies for economic growth from 1982 to 2006: employment and payroll. The data is from the Bureau of the Census' County Business Patterns and is based on the Standard Industrial Classification (SIC) system and North American Industry Classification System Code (NAIC) system (U.S. Department of Commerce, 2006). The SIC and NAIC codes are statistical classification standards used for all establishment-based Federal economic statistics. The SIC code that most closely encompasses the metal finishing industry is SIC code 3471 (U.S. Environmental Protection Agency, 1995). In 1998, the Bureau of the Census replaced the SIC code system with the NAIC code system to better reflect U.S. economic relations with North America. SIC code 3471 was replaced with NAIC code 332813. The two definitions are comparable, making it possible to track industry trends between the two time periods.

Employment is the most reliable indicator for comparing the economic growth of the metal finishing industries in the Basin, Chicago, and Detroit. Metal finishing is a labor intensive industry where labor is the primary input into the firm's production function. Also, metal finishing firms have complied with environmental regulations by adopting pollution control technologies. Pollution control technologies may increase a metal finishing firm's costs, but do not have a substantial impact on the firm's overall demand for labor. Moreover, the debate in economics concerning the effects of environmental regulations on economic growth has primarily been centered around jobs. The second indicator, payroll, is a measure of output that includes all forms of compensation, such as salaries, wages, commissions, bonuses, and the value of taxable fringe benefits. Trends in payroll are a relatively reliable indicator of overall economic output. As firms expand, or more firms locate in a region, overall payroll should increase. Its relevant to note that metal finishing firms involved in high value-added manufacturing generally pay higher salaries and should therefore have higher levels of payroll.

Table 1 compares annual employment growth in the Basin with annual employment growth in Chicago and Detroit. The data is divided into four time periods between 1982 and 2006 corresponding with environmental policies. During the first period, 1982 to 1987, the metal finishing industry in all three regions were not subject to air quality regulations. Between 1988 and 1997, as noted, the metal finishing industry in the Basin was subject to AQMD regulations (Rule 1169) while the industries in Chicago and Detroit were not regulated. Between 1998 and 2003, the industry in all three regions were subject to the federal NESHAP regulations and between 2003 and 2006 the AQMD strengthened regulations on the metal finishing industry in the Basin (Rule 1469). The time period ends in 2006 because this is the most recent year for which employment and payroll data are available.

Contrary to expectations, the data in Table 1 suggests that the metal finishing industry in the Basin performed as well or better than the metal finishing industries in Chicago and Detroit, at least until 2003. Particularly striking is that annual employment growth in the Basin was greater than it was in Chicago and Detroit between 1988 and 1997, the time period when only the industry in the Basin was regulated. Annual employment growth in the Basin during this time was 0.1 percent compared to -0.3 percent in Chicago and -1.1 percent in Detroit. The industry in the Basin also out-performed the industries in Chicago and Detroit based on employment growth between 1998 and 2002 when all three regions were subject to the federal NESHAP regulations. During this time, annual employment growth was -1.5 percent in the Basin, -2.5% in Chicago, and -3.1 percent in Detroit. The exception is the period between 2003 and 2006 when annual

Table 1: Metal Finishing Employment Growth, 1982 - 2006*

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	1.4%	0.1%	-1.5%	-5.4%
Chicago	-0.1%	-0.3%	-2.5%	-2.5%
Detroit	12.2%	-1.1%	-3.1%	-4.3%

Table 2: Metal Finishing Employment Growth by Region Controlling for the Local Manufacturing Business Cycle, 1982 – 2006

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	1.3%	2.4%	3.0%	-3.2%
Chicago	3.1%	1.6%	5.0%	0.7%
Detroit	13.0%	0.2%	6.5%	0.1%

Table 3: Metal Finishing Employment Growth by Region Controlling for Industry Trends in Manufacturing, 1982 – 2006

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	1.9%	0.2%	3.5%	-4.1%
Chicago	0.4%	-0.1%	2.5%	-1.1%
Detroit	12.7%	-0.9%	1.9%	-3.0%

* U.S. Department of Commerce, 2006.

employment growth in the Basin was weaker than it was in Chicago and Detroit. Specifically, it was -5.4 percent in the Basin and -2.5 percent and -4.3 percent in Chicago and Detroit, respectively.

While the employment figures in Table 1 suggest that environmental regulations have not had a detrimental effect on the growth of the metal finishing industry in the Basin (at least until 2003), the data could be influenced by other economic and industry trends. There was a national economic recession between 1990 and 1991 and again in 2001. More importantly, the economic growth of the metal finishing industry is heavily influenced by conditions in the manufacturing sector. In the late 1980s and early 1990s, manufacturing in the Basin was hard hit by cutbacks in defense spending. The manufacturing sector in Detroit has experienced periodic downturns due to conditions in the automobile industry. Accordingly, I attempted to calculate the employment data while providing some level of control for the business cycle in local and national manufacturing. To assess the growth of the metal finishing industry in all three regions relative to the local business cycle in manufacturing, I subtracted the percentage of average annual employment growth in manufacturing in each region from the percentage of annual employment growth in metal finishing in each region. To assess the growth of the industry in all three regions relative to the business cycle in national manufacturing, I subtracted the percentage of average annual employment growth in national manufacturing from the percentage of average annual employment growth in the metal finishing industry in each region.

Data on annual employment growth in the metal finishing industries in the Basin, Chicago, and Detroit relative to the local business cycle are shown in Table 2. Employment growth in metal finishing was stronger in each region after providing some control for the local business cycle in manufacturing. This indicates that employment in the metal finishing industry in each region grew faster than employment in other local manufacturing sectors. More importantly, the industry in the Basin out-performed the industries in Chicago and Detroit between 1988 and 1997 after providing some control for the local manufacturing cycle. During this period, annual employment growth in the Basin was 2.4 percent compared to 1.6 percent in Chicago and only 0.2 percent in Detroit. Between 1988 and 2002, annual employment growth in the metal finishing industry in the Basin was positive and comparable to Chicago and Detroit: it was 3.0 percent in the Basin, 5.0 percent in Chicago, and 6.5 percent in Detroit. The exception, again, was the period 2003 and 2006 when annual employment growth in the Basin appears to have declined.

Table 3 shows annual employment growth in the metal finishing industries in the Basin, Chicago, and Detroit after providing a relative degree of control for the business cycle in national manufacturing. The data suggests that metal finishing employment growth was also generally stronger in each region compared to national manufacturing (although the influence of local manufacturing was stronger). After controlling for national manufacturing, annual employment growth was again stronger in the Basin than it was in Chicago and Detroit between 1988 and 1997. During this time, employment growth was 0.2 percent in the Basin, -0.1 percent in Chicago, and -0.9 percent in Detroit. Annual employment growth was also greater in the Basin between 1998 and 2002 after controlling for national manufacturing: it was 3.5 percent compared to 2.5 percent in Chicago and 1.9 percent in Detroit. Between 2003 and 2006, annual employment growth declined in each region.

Tables 4 through 6 show the same calculations for annual payroll growth in the metal finishing industries in the Basin, Chicago, and Detroit. Overall, the patterns observed for employment are replicated for the data on payroll. The payroll data suggest that the metal

Table 3: Metal Finishing Payroll Growth, 1982 - 2006*

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	6.3%	3.6%	-0.1%	-1.0%
Chicago	6.2%	4.8%	-1.6%	0.0%
Detroit	17.2%	2.9%	-0.9%	-3.8%

Table 4: Metal Finishing Payroll Growth Controlling for the Local Manufacturing Business Cycle, 1982 - 2006

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	1.0%	2.9%	2.3%	-2.2%
Chicago	4.3%	2.6%	5.7%	-0.3%
Detroit	12.8%	0.7%	7.3%	-9.7%

Table 5: Metal Finishing Payroll Growth by Region Controlling for Industry Trends in Manufacturing, 1982 - 2006

	No Regulations 1982-1987	Basin Regulated 1988-1997	Basin, Chicago, & the U.S. Regulated 1998-2002	Basin Regulations Strengthened 2003-2006
Basin	1.6%	0.02%	3.1%	-2.7%
Chicago	1.5%	1.2%	1.6%	-1.7%
Detroit	12.5%	-0.7%	2.3%	-5.5%

* U.S. Department of Commerce, 2006.

finishing industry in the Basin generally performed better than or comparable to the industries in Chicago and Detroit, particularly after controlling for the local manufacturing business cycle. As shown in Table 4, for example, annual payroll growth in the Basin between 1988 and 1997 after controlling for the local business cycle was 2.9 percent compared to 2.6 percent and 0.7 percent in Chicago and Detroit, respectively. As with employment, the exception is the period between 2003 and 2006. After controlling for the local business cycle between 2003 and 2006, annual payroll growth in the Basin was -2.2 percent compared to -0.3 percent in Chicago and -9.7 percent in Detroit.

Trends in annual employment and payroll growth in the Basin, Chicago, and Detroit, particularly between 2003 and 2006, could have been influenced by additional factors that are difficult, if not impossible, to measure. First, the costs associated with Rule 1469 could clearly have been a tipping point that caused metal finishing firms to leave the Basin or shutdown their operations after 2003. Rule 1469 represents the most stringent regulations in the country governing the emission of hexavalent chromium into the ambient air from the metal finishing industry. Second, job loss in the Basin, Chicago, and Detroit, could have been influenced by the level of value-added in manufacturing. As noted earlier, there has been a general trend in the metal finishing industry towards firms engaged in high value-added manufacturing. High value-added firms typically perform metal finishing operations for expensive and intricate parts, use of precious metals, or finishing to specifications (Haveman, 1998; Kirchner, 2006). They are likely to specialize in a few types of finishes that reinforces their competitive position and generally pay higher wages and salaries compared to metal finishing firms engaged in low value-added manufacturing. Accordingly, such firms tend to be more profitable and are better able to adjust to environmental regulations and competitive pressures when compared with low value-added firms. If a region had a higher proportion of finishing firms engaged in high value-added metal finishing, then job loss in that region could have been less severe as metal finishing firms were better able to adjust to regulations.

A third economic factor that has clearly influenced employment and payroll trends in the metal finishing industry but is difficult to measure is international competition, particularly from China. The metal finishing industry has historically located in large metropolitan areas near its customer base due to high transportation costs. Recent technology innovations in transportation, communications, and manufacturing processes, however, have transformed the global manufacturing supply chain in metal products. Manufacturers can now ship parts to China for chroming and then ship them back to the United States at a cost competitive with domestic platers (Hand, 2007). The appeal of locating metal finishing facilities in China includes low labor costs, a weak regulatory environment, currency policies, commodity subsidies, and other trade protections. The Basin's proximity to Asia, moreover, may have exacerbated outsourcing among metal finishing firms in the Basin. The Ports of long beach and Los Angeles make outsourcing to China particularly feasible.

It is difficult to gauge the effects of international competition on employment and payroll loss in metal finishing because official data are not available for the U.S. trade balance in metal finishing. By all available accounts, however, the impact has been significant and relatively recent. A 1998 survey of U.S. metal finishers conducted by the Surface Finishing Market Research Board (SFMRB), for example, found that only 2.7 percent of the industry was concerned about "loss of manufacturing" and only 7.1 percent was concerned about "foreign competition." Just a few years later, this picture changed dramatically. In a 2004 SFMRB survey, metal finishing firms ranked "business moving offshore" as the industry's number one challenge. In a 2007 SFMRB survey, 80 percent of establishments surveyed said that they were losing business to China (Hand, 2007). According to Dan Cunningham, Executive Director of the Metal Finishing Association of Southern California, the number one cause of job loss in the metal finishing industry in the Basin in recent years has been economic competition from China. (Cunningham, 2007)

Fourth, employment and payroll trends in the Basin, Chicago, and Detroit could have been influenced by the availability of trivalent chromium as a chemical substitute for hexavalent chromium among decorative chromium platters. Trivalent chromium, as noted earlier, has become an effective and efficient substitute for hexavalent chromium for some decorative chromium platters. Accordingly, converting to trivalent chromium would have been an efficient way to avoid environmental compliance. If a region had a high concentration of decorative chromium firms, then the employment and payroll impact could have been less severe. Finally, employment and payroll trends could have been affected by corporations manufacturing metal products for the military because the military often requires specific finishing applications (Chalmer, 2008).

Section VI: Conclusion

Standard economic theory has long maintained that environmental regulations have a detrimental effect on economic growth and the U.S. standard of living. An emerging literature in the social sciences, however, has cast some doubt on this argument as a general theoretical proposition. This study reinforces this skepticism. The findings of this case study on the effects of environmental regulations on the metal finishing industry in the Basin suggest that the regulations did not have a detrimental effect on the growth of the industry. The industry in the Basin performed comparably to the industries in Chicago and Detroit, although the industry in these regions were not subject to the same level of regulatory stringency. Moreover, the metal finishing industry in the Basin adjusted to the regulations by adopting pollution control technologies. There was little evidence that metal finishing firms adjusted to the regulations through technology innovations, at least in the traditional sense conceptualized by Porter.

While the jury is still out on the long-term effects of environmental regulations on economic growth, the findings of this study provide one small piece of evidence that environmental regulations and economic growth have the potential to create “win-win” outcomes. A challenge for future research is to examine the effects of environmental regulations on the economy using varied methodological approaches from multidisciplinary perspectives.

Endnotes

[1] Ampere-hours are the integral of electrical current applied to a plating tank over a period of time. Surface tension is the property, due to molecular forces, that exists in the surface film of all liquids and tends to prevent liquid from spreading (South Coast Air Quality Management District, 2003).
[2] The Lewis-Presley Air Quality Management Act, 1976 Cal. Stats., ch 324 (codified at Health & Safety Code, §§40400-40540).
[3] OEHHA is the state health agency for California and makes recommendations to the California Air Resources Board
[4] Regulators estimate the level of hexavalent chromium being emitted into the ambient air by multiplying an emission factor (millilgrams per ampere-hour) by actual or estimated activity data for a tank (Selmi, 2005). The level of emissions will vary by a number of factors, including firm size, type of metal plating, number of tanks, and ameper hours. The resulting figure is then converted to mass emissions in pounds per year. An estimation is then made of how much those emission factors can be reduced based on particular control technologies.
[5] The regulations were actually first implemented in 1988 by the State of California through the implementation of the Hexavalent Chromium Airborne Toxic Control Measure (ATCM) – Decorative and Hard Chromium Plating and Chromic Acid Anodizing Facilities (California Air Resources Board, 1988). Because such a large concentration of metal finishing companies were located in the Basin, the AQMD took responsibility for implementation and enforcement of this regulation among metal finishing firms in the Basin though Rule 1169.
[6] The AQMD modified Rule 1169 to be equivalent to the 1995 federal NESHAP. They were therefore still responsible for enforcing the regulations in the Basin (California Air Resources Board, 1998).
[7] The State of California is currently considering a statewide initiative that would replace Rule 1469 (California Air Resources Board, 2006).

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Appendix A: The Regulatory Framework

Rule Requirement	AQMD RULE 1169	FEDERAL NESHAP	RULE RULE 1469
Applicability	Decorative chrome, hard chrome, and chromic acid anodizing operations	Decorative chrome, hard chrome, and chromic acid anodizing operations, including trivalent chrome operations	Decorative chrome, hard chrome, and chromic acid anodizing operations, including trivalent chrome operations
Emission Limits	Small hard chrome operation: • Either 95 percent or more emission reduction, or emissions less than 0.15 mg/amp-hr Medium, hard chrome operation: • Either 99 percent or more emission reduction or emissions less than 0.03 mg/amp-hr Large, hard chrome operation: • Either 99.8 percent or more emission reduction or emissions less than 0.006 mg/amp-hr Decorative, chrome operation: • 95 percent or more emission reduction Anodizing Chrome Operation • Small ➢ Either 95 percent or more emission reduction or emissions less than 0.15 mg/amp-hr. • Medium ➢ Either 99 percent or more emission reduction or emissions less than 0.03 mg/amp-hr. • Large ➢ Either 99.8 percent or more emission reduction or emissions less than 0.006 mg/amp-hr.	Hard chrome plating: • Very Small – Compliance option available • Small ➢ 0.03 mg/dscm (existing); or ➢ 0.015 mg/dscm (new). • Large ➢ 0.015 mg/dscm (new). Decorative hexavalent chrome plating and chromic acid anodizing: • 0.01 mg/dscm; or • 45 dynes/cm surface tension of wetting agent chemical fume suppressant. Decorative trivalent chrome plating: • mg/dscm (unless wetting agent chemical fume suppressant is used)	Hexavalent chromium electroplating and chromic acid anodizing facilities 25 meters or less from a sensitive receptor or a residence, or 100 meters or less from an existing, as of date of rule adoption, school (kindergarten through grade 12): Emission Limit: • 0.0015 mg/AH Compliance Options: • Comply with applicable alternative compliance options in lieu of emission limits.

			Hexavalent chromium electroplating and chromic acid anodizing facilities greater than 25 meters from a sensitive receptor or a residence: <u>Emission Limits:</u> • Vented to air pollution controls ➢ Operating >12 hrs/day o 0.01 mg/AH (≤1,800,000 AH/yr); or o 0.0015 mg/AH (>1,800,000 AH/yr). ➢ Operating <12 hrs/day o 0.01 mg/AH (≤1,600,000 AH/yr); or o 0.0015 mg/AH (>1,600,000 AH/yr). • Not vented to air pollution controls ➢ 0.01 mg/AH (≤1,150,000 AH/yr); or ➢ 0.0015 mg/AH (>1,150,000 AH/yr). <u>Compliance Options:</u> • Comply with applicable alternative compliance options in lieu of emission limits; or • Comply with emission limitations using distance-adjusted ampere-hour limits Decorative trivalent chrome plating: • mg/dscm or 0.01 mg/ampere-hour (unless wetting agent chemical fume suppressant is used)
Emission Limits (Facilities Conducting Multiple Chrome Plating or Anodizing Processes)			Specify methodology for using weighted facility energy consumption to determine applicable emission limits.

Alternative Compliance Options		Option for very small hard chrome plating using 500,000 AH/yr or less to use a wetting agent chemical fume suppressant to achieve a surface tension of 45 dynes/cm.	Option for small hexavalent chromium electroplating and chromic acid anodizing facilities using 365,000 AH/yr or less to use certified fume suppressant or achieve a surface tension of 45 dynes/cm or less or the surface tension achieved during the fume suppressant certification process. There are additional provisions for facilities ≤25 meters from a sensitive receptor or residence or ≤100 meters from school existing as of the date of adoption • Install HEPA or equivalent air pollution control technique if a facility accrues 3 or more emission-related exceedances within a 5 year period. Exceedances are defined as: ➢ Exceeding the applicable surface tension limit; ➢ Exceeding AH/yr limits by 135,000 ampere-hours/yr or less; ➢ Exceeding the chromic acid weight concentration limit specified in a permit issued after the date of adoption; ➢ A missing or broken stalagmometer, tensiometer, or ampere-hour meter unless it is replaced or repaired.

			Allowance for completion of an inventory and health risk assessment: • HRAs approved prior to rule adoption must show cancer risk of: ➢ <25 in a million for facilities >25 meters from a sensitive receptor or residence; ➢ <10 in a million for facilities ≤25 meters from a sensitive receptor or residence or ≤100 meters from school existing as of the date of adoption • HRAs not approved prior to rule adoption: ➢ Show cancer risk of <25 in a million for facilities >25 meters from a sensitive receptor or residence, or <10 in a million for facilities ≤25 meters from a sensitive receptor or residence or ≤100 meters from school existing as of the date of adoption; ➢ Inventory and HRA must be submitted for approval by 1/1/04 • If an HRA is disapproved or if it is determined that cancer risk exceed HRA levels, use of a certified fume suppressant must begin within 60 days and the applicable emission limits must be met within one year after notification by the District.
			Allowance for completion of an emission reduction plan: • Option only for facilities ≤25 meters from a sensitive receptor or residence or ≤100 meters from school existing as of the date of adoption. • Demonstrate facility-wide hexavalent chromium emissions result in a cancer risk of ≤10 in a million using methods such as pollution prevention, voluntary, enforceable reductions in ampere-hour limits, or installation of add-on controls • Following plan approval, permit applications must be submitted within 90 days and any control equipment installed within 15 months

			Maximum Installed Controls: Use HEPA or an equivalent air pollution control technique and a certified wetting agent fume suppressant and comply with all applicable permit conditions and compliance plan conditions.
			Facility-wide Mass Emission Rate: For facilities >25 meters from a sensitive receptor or residence only, a demonstration that facility-wide emissions of hexavalent chromium do not exceed the following thresholds: • Vented to air pollution controls ➢ Operating >12 hrs/day = 0.04 lbs/yr ➢ Operating <12 hrs/day = 0.036 lbs/yr • Not vented to air pollution controls = 0.025 lbs/yr
Install non-resettable ampere-hour meters on each tank	Required	Not required	Required
Housekeeping Practices	Not required	Not required	Store chromic acid powder or flakes in a closed container in an enclosed storage area; transport chromic acid powder or flakes from enclosed storage area in a closed container; clean or contain spilled sludge containing hexavalent chromium within one hour to minimize trackout; clean surfaces within the enclosed storage area that accumulate dust; chromium or chromium containing wastes generated from housekeeping activities stored, disposed of, recovered, or recycled using practices that do not lead to fugitive dust
Training and Certification	Not required	Not required	Required initially no later than one year after rule adoption and every two years thereafter for facility personnel responsible for environmental compliance, maintaining plating bath chemistries, and testing and recording plating bath surface tension data; after one year from rule adoption, only persons who have completed a District-approved training program shall be responsible for recordkeeping.

Compliance Plan Submittal	Not required	Not Required	Specify the emission limitation, alternative standard, or alternative compliance option to be complied with; specify method or methods proposed to comply with emission limitation or alternative; if applicable, specify the name of the certified wetting agent fume suppressant used and the surface tension at which it was certified.
Performance Test Requirements	Not required	Initial test required except for decorative hexavalent chrome, chromic acid anodizing, and decorative trivalent chrome tanks using wetting agent chemical fume suppressants	Same
Certification of Wetting Agent Chemical Fume Suppressants		Not required	Certify wetting agent chemical fume suppressants to achieve a surface tension level at which an emission factor of 0.01 mg/AH is achieved. Wetting agent chemical fume suppressants must meet a surface tension of 45 dynes or less, unless an alternative has been approved by USEPA and CARB.
Work Practice Standards		Visually inspect control devices for proper drainage, unusual chromic acid buildup, and structural integrity	Visually inspect control devices for proper drainage, unusual chromic acid buildup, and structural integrity
Work Practice Standards (continued)		Visually inspect ductwork for leakage	Visually inspect ductwork for leakage
		Perform washdown of composite mesh pads, composite mesh pads/packed-bed scrubbers, fiber bed mist eliminators according to manufacturer recommendations	Perform washdown of composite mesh pads, composite mesh pads/packed bed scrubbers, fiber bed mist eliminators according to manufacturer recommendations
		Add fresh make-up water to the top of packed-beds whenever makeup water is added	Add almost identical inspection and maintenance requirements – add fresh make-up water to the packed-bed only
Continuous Compliance Monitoring	Implicitly requires a source test to ensure that the emissions limitation is met	Daily monitor and record the pressure drop and inlet velocity pressure across add-on control devices	Continuous monitoring of pressure drop and inlet volume pressure across add-on control devices, record values once per week
		Monitor and record surface tension of plating baths once every four hours for wetting agent chemical fume suppressants or combination wetting agent chemical fume suppressants/foam blanket fume suppressants	Monitor surface tension daily for 20 days, and weekly thereafter as long as surface tension meets limit established during certification of wetting agent chemical fume suppressant
		Hourly monitoring and recording of the thickness of fume suppressants forming a foam blanket	Monitor foam blanket thickness hourly for 15 days, and daily thereafter as long as there are no violations of the foam thickness requirement
Recordkeeping		Maintain inspection records for sources using add-on controls and for monitoring equipment used to document that required inspection and maintenance has taken place	Maintain inspection records for sources using add-on controls and for monitoring equipment used to document that required inspection and maintenance has taken place

Recordkeeping (continued)		Maintain records for each period of excess emissions of the process, add-on control, or monitoring equipment	Maintain records of emissions exceeding the emission limitation and/or monitoring parameter and include date of occurrence, duration, cause, and magnitude of the excess
		Maintain records showing total process operating time of the source	Record total ampere-hours expended each month and the total expended to date, rather than total process operating time
		If actual rectifier capacity is used to determine facility size, records of actual cumulative rectifier capacity of hard chrome tanks expended each month, and the total expended to date for the reporting period	
		Maintain records of date and time that fume suppressants are added to baths	Maintain records showing the date, time, volume and product identification of the fume suppressant added to the plating or anodizing bath
		Maintain records of bath components purchased with the wetting agent clearly identified as a bath constituent contained in one of the components	Maintain records showing bath components purchased with the wetting agent clearly identified as a bath constituent contained in one of the components
		Maintain records demonstrating whether a source is meeting the requirements for a waiver of recordkeeping or reporting requirements, if a source has been granted a waiver	Includes a process for obtaining approval of alternative requirements
		Not required	Maintain records demonstrating compliance with housekeeping practices, including dates on which specific activities were completed, and records showing that chromium or chromium-containing wastes have been stored, disposed of, recovered, or recycled using practices that do not lead to fugitive dust
Reporting Requirements – Initial Compliance Status Report		Report applicable emissions limitation and methods used to determine compliance	Included with Initial Compliance Status Report
		If a performance test is required, report the test report documenting the results	
Reporting Requirements – Initial Compliance Status Report (continued)		Report the type and quantity of hazardous air pollutants emitted by the source in mg/dscm or mg/hr For sources not required to conduct performance tests, the surface tension measurements	Included with Initial Compliance Status Report
		For each monitored parameter, report the specific operating parameter value or range that corresponds to compliance with the emission limit	
		Report the methods that will be used to determine continuous compliance	
		Describe the air pollution control technique	

		Include a statement that the owner or operator has completed and filed an operation and maintenance plan	
		Include a statement by the owner or operator as to whether the source has complied with this subpart	
		Not required	Report facility name, AQMD ID number, facility address, owner/operator name, telephone number in Initial Compliance Status Report
			Report distance from the center of the facility to the property line of the nearest commercial/industrial building and to the nearest residence in Initial Compliance Status Report
			Report sensitive receptor locations within one-quarter of a mile from the center of the facility in Initial Compliance Status Report
			Report maximum potential rectifier capacity per tank or tank potential to emit, if applicable in Initial Compliance Status Report
Reporting Requirements – Initial Compliance Status Report (continued)		If facility size is based on actual rectifier capacity, the record to support that a facility is small or medium.	Not included because facility size is not used as the basis for applicability of emission limits
Reporting Requirements – Ongoing Compliance Status Report		Semi-annual Ongoing Compliance Status Reports for major sources [except when the emission limit has been exceeded, then quarterly reports shall be submitted]	Annual Ongoing Compliance Status and Emission Reports for all sources required
		Report company name and address	Included with Ongoing Compliance Status and Emission Report
		Identify the operating parameter that is monitored for compliance determination	
		Report the relevant emissions limitation and the operating parameter value that corresponds to compliance	
		Report beginning and ending dates of the reporting period	
		Describe of the type of process performed	
		Describe total operating time during the reporting period	
		Include a summary of operating parameters	
		Include certification by a responsible official that inspection and maintenance provisions were followed according to the operation and maintenance plan for the source	

Reporting Requirements – Ongoing Compliance Status Report (continued)		If the operation and maintenance plan was not followed, an explanation and assessment of any excess emissions that occurred as a result and copies of report documenting why the plan was not followed	
		Describe any changes in monitoring processes or controls since the last reporting period	
		Name, title, and signature of the responsible official certifying accuracy of the report	Included with Ongoing Compliance Status and Emission Report
		Date of the report	
		Report the actual cumulative rectifier capacity for the reporting period and on a month-by-month basis, if the source is a hard plater limiting size by actual capacity	Include in the Ongoing Compliance Status and Emission Report the actual cumulative rectifier usage for the reporting period, on a month-by-month basis, for hard or decorative chromium plating and chromic acid anodizing
		Not required	Include in the Ongoing Compliance Status and Emission Report hexavalent chromium and trivalent chromium throughput data in pounds per year for the reporting period
		Not required	Include in the Ongoing Compliance Status and Emission Report sensitive receptor locations within one-quarter of a mile from the center of the facility if changed since submittal of the Initial Compliance Status Report
Reporting Requirements – Trivalent Chrome Baths		Report name, title, and address of the owner or operator and address of each source	Report name address of each source subject to this requirement
		Include a statement the Subpart N is the basis of the notification; identify each applicable emission limit and compliance source for each source; include a brief description of each affected source	Not required
Reporting Requirements – Trivalent Chrome Baths (continued)		Include a statement that a trivalent chrome process that incorporates a wetting agent will be used to comply	Include a statement that a trivalent chrome process that incorporates a wetting agent will be used to comply
		List bath components comprising the trivalent chromium bath, with wetting agent identified	List bath components comprising the trivalent chromium bath, with wetting agent identified
Approval of Alternative Requirements		The NESHAP allows alternative requirements	Process and criteria specified for establishing alternative requirements; EPA concurrence required on emissions related elements

Appendix B: Pollution Control Technologies

Chemical Fume Suppressants. As noted earlier, only about 20 percent of chromium from a metal finishing bath us deposited on a metal part. The remaining current forms bubbles (hydrogen gas at the cathode and oxygen at the anode) that rise to the surface of the bath. As these bubbles break the surface of the bath, hexavalent chromium is emitted into the ambient air. Surface tension is the force that keeps a fluid together at the air/fluid interface. It is expressed in force per unit of width such as dynes/centimeter. By reducing surface tension, the size of gas bubbles are reduced and they rise more slowly to the surface. They are therefore less likely to be emitted into the ambient air. Fume suppressants are effective for decorative plating and chromic acid anodizing facilities, but less effective for hard-chromium platting.

Mechanical Fume Suppressants. Mechanical fume suppressants are added to a plating bath's surface to form a physical barrier that helps prevent chromium mist from escaping the tank during plating. Mechanical fume suppressants are similar in appearance to ping-pong balls, often called "polyballs." Some metal finishing firms use mechanical fume suppressants in combination with a chemical fume suppressant. Mechanical fume suppressants can be a source of fugitive emissions if they are ejected from the tank when parts are removed and solution on the polyballs dries on the floor of the facility.

Foam Blanket Chemical Fume Suppressants. Foam blanket chemical fume suppressants generate a layer of foam on the surface of a plating bath when current is applied. The foam blanket is formed by agitation from the hydrogen and oxygen gas bubbles generated during plating. The blanket reduces hexavalent chromium emissions by physically entrapping the mist in the foam. These suppressants are effective when used by hard chrome plating facilities.

High Efficiency Particulate Arrestor (HEPA) filters. HEPA filters are considered the most effective pollution control technology for reducing hexavalent chromium emissions. HEPA filters are specifically designed for the collection of submicrometer particulate matter at high collection efficiencies. First developed in the 1940s for the Manhattan Project to control radioactive contaminants, HEPA filters are rated at 99.97 percent effectives in capturing particles of 0.3 um in diameter. HEPA filters are often installed downstream of another control device to lessen loading on the filter, thereby lengthening its life. HEPA filters need to be replaced annually and disposed of as hazardous waste. For all but very small facilities, HEPA filters are considred the most effective control of hexavalent chromium emissions.

Composite Mesh Pad (CMP). A Composite Mesh Pad (CMP) system (sometimes referred to as a "dry scrubber") typically consists of several layers of more than one monofilament diameter and/or interlocked fibers densely packed between two supporting grids. Most systems exist in two or three stages to ensure collection of reentrainment caused by wash down. A 3 stage system will remove small particles from one to 3 μm at about 99 percent efficiency. Each stage can capably remove particles at this size but it will take at least 3 stages to reach this efficiency. Filters must be changed every one to six years and need to be disposed of as hazardous waste.

Wet Scrubber. Wet scrubbers consist of a vertical column made of fiberglass or other non-corrosive material loosely filled with specially shaped plastic packing material which maximizes gas-to-liquid contact and minimizes pressure drop across the column. Exhaust air from plating or anodizing tank line enters at the bottom of the scrubber and exits at the top. A wet scrubber is similar to a CMP system except that before the first stage of filtration, there is a water wash down of the influent mist in order to increase the size of the particles in the mist. In this system, a packing media is used to coalesce these larger particles and allow them to drip off into a reservoir at the bottom of the scrubber.

Fiber-bed Mist Eliminator (FBME). A FBME removes contaminants from a gas stream through the mechanisms of inertial impaction, direct interception, and Brownian diffusion. A FBME consists of one or more fiber beds and each bed consists of a hollow cylinder formed from two concentric screens designed for horizontal, concurrent gas liquid flow through the fiber bed. It is typically installed downstream from another control device to prevent plugging (CDPHE, 1999). The filter should last four to six years and needs to be disposed of as hazardous waste.

Enclosed Tank Covers. For hard chromium plating and chromic acid anodizing facilities, enclosed tank covers, sometimes referred to as Merlin hoods, form a sealed system to capture the hexavalent chromium emissions within the enclosed area. Gasses resulting from plating are vented through a semi-permeable membrane which allows the hydrogen and oxygen to exit, but, due to its size, the hexavalent chromium does not pass through. Enclosed tank covers are generally not feasible for decorative chromium plating due to the short periods of time that plating actually occurs

Chevron mist eliminators. Chevron mist eliminators are designed to force mist-laden air to make several abrupt changes in direction between the entry and exit points of a baffle-like material. Since mist droplets are much heavier than air molecules, they have too much linear momentum to make sharp turns without impacting the baffles. Since many mist droplets impact on the baffles, a liquid film forms causing large droplets to coalesce and drop back down into the piece of equipment being controlled.

Appendix C: Alternative Chemical Processes

Alloy electroplating: Alloys can provide a range of physical and mechanical properties by combining different metals so that chromium plating can be replaced in certain applications. Alloy electroplating has certain advantages over chromium electroplating. For example, it provides uniform coating, and the process is energy efficient. Recent studies suggest that alloy plating coatings have good wear and build-up properties but many scale-up problems have kept them from becoming commercial. This alternative process holds promise for the future.

Electroless Nickel Phosphorous: Electroless nickel coatings have excellent wear and resistant properties and are used in a wide range of applications. Electroless nickel plates more evenly so that the need for substantial over plating often can be eliminated. The use of electroless nickel as an alternative, however, is limited by its somewhat poorer physical properties including lessened hardness and abrasion resistance. Also, electroless nickel cannot be plated as cost effectively as hex chrome. In addition, the bath life is finite and requires frequent disposal and replenishment, especially when thick deposits are being applied.

Nickel-Tungsten Electroplating: Two nickel tungsten-based alloy electroplating processes are available as potential alternatives to chrome plating: nickel-tungsten boron (Ni-W-B) and a nickel-tungsten silicon carbide composite (Ni-W-SiC). The two processes are similar in that they are both electrolytic and they deposit a coating of nickel and tungsten with minor percentages of either boron or silicon carbide to enhance the coating's properties. Both substitutes use less energy than hex chrome plating both for rectification and heating, resulting in reduced energy costs. Additionally, the deposits are more uniform than chrome, increasing plating line throughput and reducing reject rates. Each coating exhibits many of the same desirable properties as chrome plating, but additional testing is needed before widespread use can be expected.

Tin Cobalt Alloy: Tin-cobalt alloys provide a finish that is similar in appearance to chromium. The tin-cobalt appearance ranges in color from a bright, chromium appearance to a warm, silvery gray color. Color is controlled by varying the percent of tin in the alloy. To achieve the appearance of a chromium plate, the optimal tin-cobalt ratio in solution is 50:50. The tin-cobalt finish provides a hardness and wear resistance that is sufficient for most indoor, decorative applications. The process, either in rack or barrel operations, uses an alkaline sulfate system with optional wetter/amine-based liquid brighteners. Current applications of this plating alternative for chromium include automotive interior parts, computer components, bicycle spokes, flexible shower hoses, and screws.

Tin-Nickel Acid or Near Neutral: Tin-nickel alloy plating can be used as a replacement for decorative chromium plating for both indoor and outdoor applications because of its faint rose pink cast. This alloy is resistant to corrosion and tarnish and has good contact and wear resistance. Other advantages of this coating include excellent frictional resistance and the ability to retain an oil film on its surface. Tin-nickel alloy plating solutions have a high throwing power, which enables the solution to function where plating chromium in deep recesses is a problem.

Aluminum Ion Vapor Deposition: Ion vapor deposition (IVD) produces a multi-purpose coating that has excellent corrosion protection and no embrittlement problems. This technology has been used as an alternative to chromium coating in several applications. Extensive testing has shown that IVD aluminum protects substrates better than electroplated or vacuum-deposited chromium in acetic salt fog and outdoor environments. IVD also provides greater resistance to cracking.

Type II Sulfuric Acid Anodizing – often referred to as “regular,” “architectural,” or “sulfuric” anodizing. Sulfuric anodize is formed by using an electrolytic solution of sulfuric acid at room temperature. The process produces a fairly clear coating and is normally used for decorative purposes and provides some corrosion protection.