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Technology Adoption Indicators Applied to the ATP Flow-Control Machining Project

cylinder head combustion chamber

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Cover image: Processed cylinder head combustion chamber, courtesy of Extrude Hone Corporation (www.extrudehone.com).

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Office of Applied Economics
Building and Fire Research Laboratory
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Abstract

This report introduces technology adoption indicators (TAIs) that can be used to assess whether particular industries are likely to adopt new technologies. The TAIs are several measures of industry concentration, number of patents, number of research joint ventures, public policy, and history of technology adoption. Each TAI is supported by economic theory and confirmed by empirical studies. The TAIs are then applied to an analysis of whether a particular ATP-funded flow-control machining (FCM) technology might be adopted by two industries: lawnmower engine manufacturers and the airplane engine manufacturers. According to broadly defined TAI measures, based on Standard Industrial Classification (SIC) and the North American Industry Classification System (NAICS), lawnmower manufacturers are more likely than airplane engine manufacturers to adopt new technology. Using precise, narrowly defined data specific to the lawnmower engine industry, we confirmed that new technology adoption by lawnmower manufacturers is likely. In this case study, the regulatory environment—specifically, the environment created by Environmental Protection Agency (EPA) regulation—was the most important factor influencing the likelihood of the lawnmower engine industry adopting the FCM technology.

New EPA regulations require emissions-improving changes to most lawnmower engines currently available in the marketplace, and the FCM technology is a cost-competitive alternative to conventional emissions-improving technologies. We compare the cost of the FCM technology with the cost of more conventional technology for reducing engine emissions in four lawnmower engine market segments: small side-valve (SV) engines, small overhead-valve (OHV) engines, large side-valve engines, and large overhead-valve engines. For large SV engines, the cost advantage of the FCM technology is significant. For small SV engines, the FCM technology has a modest cost advantage.

We then use a dynamic macroeconomic model to compare the national economic impacts of the FCM technology cost and the conventional technology cost for each market segment. Either would reduce gross domestic product (GDP); however, for large SV engines, the FCM technology has less of a negative impact on GDP, personal income, and employment, compared with conventional technologies. The advantage of the FCM technology in this market is substantial. For example, using the FCM technology instead of conventional emission-lowering technology on large SV engines would result in savings of $982 million in GDP over the analysis period. For small SV engines, the use of the FCM technology in place of conventional technology would result in savings of $261 million in GDP over the analysis period.

Key words: Advanced Technology Program (ATP); benefit cost; program evaluation; technology adoption

Executive Summary

Introduction

In its 1995 General Competition, the Advanced Technology Program funded the Flow-Control Machining Project, a four-year $7.9 million research joint venture involving Extrude Hone Corporation, a small company in Irwin, PA, General Motors, the University of Pittsburgh, and the University of Nebraska at Lincoln to develop two new automated finishing processes and make them cost effective for large-production manufacturing. The Flow-Control Machining processes advance the state-of-the-art in manufacturing finishing by allowing manufacturers to more effectively fabricate parts for their intended functional performance. It uses neural-network algorithms, process control methods, and new abrading techniques to develop manufacturing processes that are economically compatible with high-volume, relatively low-value engines.

This report presents a case study of the economic impact of applying flow-control machining technology—first developed for the automobile industry—to the lawnmower industry. A Technology Adoption Indicator methodology is used to provide a structure for analysis of the adoption of technology by an industry. These indicators assist in the analysis of the potential for adoption of the Flow-Control Machining technology by the lawnmower industry.

The TAI framework has other applications for ATP. First, it can be used to identify promising case studies for project evaluation. Second, it offers a consistent and effective methodology for conducting case studies. Third, it can assist in evaluating the business plans of ATP proposers. Fourth, it can be used to advise ATP awardees on which industries are more likely to be potential adopters of their technologies.

The Technology Adoption Indicators: Development and Application to the Case Study

A significant amount of economic research shows that some industries adopt new technologies faster than others. For example, economic studies of industry R&D projects based on the structure-conduct-performance model have found that industry characteristics such as the number and size distribution of firms and quality of competition affect rates of technology adoption. Since the model is widely used for organizing and analyzing industry characteristics and behavior, we apply it to develop a set of indicators that assess the likelihood of technology adoption.

According to the structure-conduct-performance model, market structure affects market conduct, which in turn affects market performance. Industry characteristics, such as the numbers of sellers and buyers, affect selling and buying conduct, such as production, research and innovation, pricing behavior, advertising, investment, and legal tactics. Market conduct, in turn, affects the overall performance of the industry—that is, price and production levels. Public policy (such as taxes, subsidies, and regulations) affects both industry market structure and conduct. In the long run, all these conduct and performance activities affect the market structure.

Market structure is evidenced by industry concentration ratio measures such as four- and eight-firm concentration ratios and the Herfindahl-Hirshman Index. Industries characterized by mid-sized, competitive firms tend to adopt technology more than industries characterized by either many small firms by a few, very large firms (oligopolies). In short, economic research suggests there is an optimal range of industry concentration in which technology adoption is most likely.

The numbers of patents and research joint ventures provide indicators of market conduct and the supply of technology. Through regulation, public policy affects market conduct by serving as a driver of technology adoption.

In this study, we are not only concerned about the adoption of technology in general, but with the adoption of a specific technology. All else being constant, the fewer the number of competing technologies, the greater the likelihood of any one technology innovation being adopted. Specifically, if there is a great demand for technological innovation but few sources of technological innovation, then new innovations will be rarer and will have a greater chance of adoption. The lawnmower industry has fewer patents and research joint ventures than the airplane engine industry while having higher technology demand. Therefore, the likelihood for adoption of the FCM technology by the lawnmower industry is judged to be higher than the airplane engine industry.

In the case of the lawnmower industry, a specific public policy, in the form of an impending EPA regulation, is a key factor in likely market conduct. Pending EPA regulations aim to reduce small-engine emissions by 59% by 2007. No pending regulations affecting technology adoption by aircraft engine manufacturers have been identified.

Economic Case Study on the Impact of the Adoption of FCM in the Lawnmower Industry

An economic case study was performed of the impact of adoption of Flow-Control Machinery technology in the lawnmower engine application. This required first investigating the economic feasibility of lawnmower engine manufacturers using the FCM technology to meet the new EPA regulations for different types of engines. Then, for engines where adoption was economically feasible, a macroeconomic projection was made of the broader impact on U.S. economic output.

Engineering tests performed by Extrude Hone, the lead company in the ATP-funded research joint venture and inventor of the Flow-Control Machining technology, confirmed that the technology can be used to meet EPA's Phase 2 emissions requirements for 2007. Extrude Hone engineers also provided detailed data on the costs of applying the Flow-Control Machining technology to the full range of lawnmower engines.

An analysis of the total costs to the industry of the Extrude Hone FCM process was performed for each of four engine market segments and compared with the costs of meeting the EPA Phase 2 regulations with conventional technology, as estimated by the EPA.

The results are as follows:

- For “large, side-valve engines,” the FCM technology is the lower-cost option relative to the conventional technology both initially and over time because both the fixed costs and the ongoing variable costs are lower than for the conventional technology.

- For “small, side-valve engines,” the Flow-Control Machining technology is estimated to be significantly less expensive than the conventional technology in 2007 but slightly more expensive in later years. In particular, fixed costs are concentrated in that initial year of use, and the Flow-Control Machining technology has lower fixed costs than conventional technology. On the other hand, the Flow-Control Machining technology has slightly higher variable costs that make it less attractive over time.

- For “small, overhead-valve engines” and for “large, overhead-valve engines,” the Flow-Control Machining technology is more expensive in terms of both fixed and variable costs than the conventional technology.

The Regional Economic Models, Inc. (REMI) macroeconomic model was used to simulate the total national impact of adoption of the Flow-Control Machining technology for large and small side-valve engines. The macroeconomic model computes the total effect over time on the economy resulting from a change to a component of the economy. The model is based on economic theory, input-output (I/O) accounting, and econometrically estimated, time-dependent relationships between components of the economy.

The model captures the following effects across the economy: An increase in production costs in the lawnmower industry—by adopting either the Flow-Control Machining technology or conventional technology—will cause an increase in the selling price of lawnmowers. This in turn will cause a decrease in the number of units sold. As production costs rise, firms that seek to maintain current profit levels must increase their selling prices and/or reduce other production costs, including the costs of labor and capital (machinery). Decreased sales and cutting costs will reduce employment in the lawnmower industry and in industries that supply parts and services to it, thereby reducing aggregate income and the broad set of purchases this income supports (such as for purchasing cars, homes, services, and travel).

A comparison of the combined macroeconomic effects across the economy of Flow-Control Machining technology versus conventional technology shows the following:

- For both small, side-valve engines and large, side-valve engines, adoption of Flow-Control Machining technology is less costly to GDP, employment, and income in meeting the EPA regulations compared with adoption of conventional technology.

- For small, side-valve engines, there is a savings of $261 million in GDP, and $244 million in personal income over the three years 2007 to 2009 from using Flow-Control Machining technology.

- For large, side-valve engines, there is a savings of $982 million in GDP and $878 million in personal income over the five years 2003 to 2007. For these engines, the Flow-Control Machining technology saves 93% of GDP, employment, and personal income that would be lost using conventional technologies to address the EPA regulations.

Conclusion

The case study analysis performed clearly demonstrates the economic advantage of the FCM technology over conventional technologies for small and large side-valve lawnmower engines.

The Technology Adoption Indicators methodology provides a useful framework for assessing whether a particular industry will adopt new technologies, and further assists in the investigation of industry characteristics affecting technology adoption. In this case study, EPA regulation was the decisive factor indicating the likelihood of adoption of the FCM technology.

There are widespread differences across U.S. industries in the size and distribution of firms, in patents, in research joint ventures, and in the use of new technologies. Increased understanding of the relationships between these variables will help ATP assess the likelihood of adoption and the potential economic impact of the proposed projects.

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Glossary

ATP — Advanced Technology Program — A partnership between government and private industry to conduct high-risk research to develop enabling technologies that promise significant commercial payoffs and widespread benefits for the economy. (www.atp.nist.gov)

BEA — Bureau of Economic Analysis (www.bea.gov).

cc — Cubic centimeters — Industry standard abbreviation used in lieu of cm^3 when referring to engine displacement.

CO — Carbon monoxide — Colorless, odorless, and poisonous byproduct of combustion.

CORE — Collaborative Research database — A database of research joint ventures listed in the *Federal Register*, maintained by Dr. Albert Link of the University of North Carolina, with a grant from the National Science Foundation.

CR4 — Four-firm concentration ratio — In an identified industry, the market share held by the top four firms.

CR8 — Eight-firm concentration ratio — In an identified industry, the market share held by the top eight firms.

DOJ — U.S. Department of Justice (www.usdoj.gov).

EPA — U.S. Environmental Protection Agency (www.epa.gov).

FCM — Flow-control machining — Two finishing processes which increase the functional precision of cast-metal parts which carry fluids in interior passageways. FCM's first targeted application was to increase airflow in automobile engines, where the increase in functional precision can be used to increase engine horsepower, increase fuel efficiency, reduce emissions, and reduce the cost of engines.

FTC — Federal Trade Commission (www.ftc.gov).

GDP — Gross Domestic Product — The output of goods and services produced by labor and property located in the United States.

HC — Hydrocarbons — Byproducts of combustion, such as NMHC, that lead to ozone formation.

HP — Horsepower — Nonmetric measurement of power (see kilowatts, kW).

HHI — Herfindahl-Hirschman Index — In an identified industry, the sum of the squared percentage market shares of all the firms.

IPO — Initial public offering — The first market issuance of stock in a company.

kW — kilowatt — Metric measure of power, such as the power of an engine.

NAICS — North American Industry Classification System — Industry classification system, from 2 to 6 digits, that replaces SIC beginning in 1997. Provides consistent framework for collection, analysis, and dissemination of industrial statistics used by government policy analysts, by academics and researchers, by the business community, and by the public. Follows principle of aggregation that producing units that use similar production processes should be grouped together. Reflects changes in technology and growth and diversification of services in recent decades. (http://www.census.gov/naics)

NMHC — Nonmethane hydrocarbons — Byproducts of combustion that lead to ozone formation.

NOx — Nitrogen oxides — Byproducts of combustion that contribute to acid rain production.

OELink — Original Equipment Link — Database of small engine manufacturers and their products compiled and maintained by Power Systems Research, of St. Paul Minnesota (www.powersys.com).

OHV — Overhead-valve — An Otto-cycle, four-stroke engine in which the intake and exhaust valves are located above the combustion chamber within the cylinder head. Such engines are sometimes referred to as "valve-in-head" engines (*Federal Register*).

PM — Particulate matter — Solid pollutant in engine exhaust.

PPI — Progressive Policy Institute — (www.ppionline.org).

R&D — Research and development.

REMI — Regional Economic Models, Inc. — Amherst, MA developer of Policy Insight, macroeconomic forecasting software (www.remi.com).

RJV — Research joint venture — Any of a number of different cooperative business structures in which several firms (sometimes involving government agencies, such as ATP) pool resources in order to spur new research and development.

SCP — Structure-conduct-performance — A conceptual model commonly used in Industrial Organization, relating market structure to market conduct and market performance.

SIC — Standard Industrial Classification — Numerical coding system, from 2 to 4 digits, for systematically classifying industries (replaced by NAICS beginning in 1997).

SSIE — Small spark-ignition engines — Engines such as those used in lawnmowers.

SV — Side-valve — An Otto-cycle, four-stroke engine in which the intake and exhaust valves are located to the side of the cylinder, not within the cylinder head. Such engines are sometimes referred to as "L-head" engines (*Federal Register*).

TAI — Technology Adoption Indicators — A set of indicators that measure the likelihood of technology adoption derived from publicly available, broadly defined, industry-level data sets covering the manufacturing sector.

USPTO — U.S. Patent and Trademark Office (www.uspto.gov).

USPCS — U.S. patent classification system — A coding system used by the USPTO to classify patents, generally by the major function or operation of the patent.

1. Introduction

The Flow-Control Machining (FCM) Project is an ATP-funded research joint venture (RJV). Its partners are Extrude Hone Corporation (a small company in Irwin, PA, and inventor of the FCM technology), Ford Motor Company, General Motors, the University of Pittsburgh, and the University of Nebraska at Lincoln. The project resulted in the development of two finishing processes (the FCM technology) which increase the functional precision of cast-metal parts that carry fluids in interior passageways. Its first targeted application was increased airflow in automobile engines, analyzed in *Estimated Economic Impacts of the Advanced Technology Program's Flow-Control Machining Project: Early Applications in the Automobile Industry* (Ehlen 1999).

This report develops a set of technology adoption indicators (TAIs) and uses them to select and analyze possible spillover applications of the FCM technology, originally developed for the automotive industry. To guide this and future case studies, a TAI-based methodology was developed that provides a structure for the analysis of the adoption of applications by an industry. Although used to study application adoption here, the TAI framework has other applications for ATP. First, it can be used to identify promising case studies for project evaluation. Second, it offers a consistent and effective methodology for conducting case studies. Third, it can assist in evaluating business plans of ATP proposers. Fourth, it can be used to advise ATP awardees on which industries are more likely potential adopters of their technologies.

TAIs are defined based on the structure-conduct-performance (SCP) model widely used in economic analyses of industries (Scherer and Ross 1990). This model, supported by theoretical and empirical economic research, indicates that the structure of an industry affects its conduct and performance. For example, barriers to entry (structure) result in certain product-pricing behavior (conduct) that affects the ultimate efficiency and equity of the marketplace (performance).

We used the SCP model to identify industry characteristics that are related to technology adoption and to organize those characteristics. After identifying industry characteristics that influence technology adoption, an exhaustive search was undertaken for measures of those characteristics. The measures that are presented in this report had to meet several criteria. Industry structure measures had to be quantitative, publicly available, comprehensive, theoretically related to the motivation to adopt technology, and have empirical evidence in the literature to support the connection to technology demand. By "comprehensive," we mean that there are individual measures for every industry, at a minimum, broadly defined at the 6-digit North American Industry Classification System (NAICS) or 4-digit Standard Industrial Classification (SIC) level. (Narrowly defined data can often be found for a precisely defined industry, but unlike the broadly defined data, it is not available for other industries at the same level of resolution.) Industry conduct measures in this report also had to meet the same criteria and had to be theoretically related to the opportunity to adopt technology.

This report brings together the development of the TAI methodology with its application in a case study of the potential for adoption of the FCM technology for nonautomotive industries.

The selection of the case study is described using the broadly defined TAI measures. Once the selection has been made, more detailed industry-specific information is developed to supplement the broadly defined data. Individual case studies require narrowly defined data unique to the industry of each case study.

TAIs show that, of two preselected case study candidates, lawnmower manufacturers are more likely than aircraft manufacturers to adopt the flow-control machining technology spillover from the automotive industry.

On the demand side, the broadly defined market concentration indicators show a preference for the home lawn and garden industry (which includes the lawnmower manufacturers) over the aircraft engine industry. Narrowly defined data show that, according to the four- and eight-firm concentration ratios, the lawnmower industry is too highly concentrated to adopt technology. However, the HHI supported technology adoption by the lawnmower industry. The broadly defined patent TAI supported the selection of either the lawnmower industry or the airplane engine industry. The broadly defined research joint venture TAI showed that while both industries formed a significant number of RJVs, the airplane engine industry was somewhat more likely to adopt technology. The narrowly defined TAI data on patents, public policy, and historical technology adoption show that EPA regulations are likely to encourage the lawnmower manufacturers to adopt new engine technology.

Our analysis builds on the work and results described in a previous ATP report, *Estimated Economic Impacts of the Advanced Technology Program's Flow-Control Machining Project: Early Applications in the Automobile Industry* (Ehlen 1999). That earlier report presented a detailed analysis of the structure, conduct, and performance of the market for automobiles. Ehlen's analysis showed that, due to stringent government regulations on automobile fuel economy, the automobile industry is a likely adopter of new fuel efficiency technologies such as the ATP flow-control machining technology; even small, short-run applications of the technology to large automobiles could result in significant increases in automobile sales and employment. Ehlen's report, however, does not describe more generic metrics or approaches for estimating the likelihood of technology adoptions in other industries; nor does it address spillover applications outside the automotive industry.

Section 2 of this report describes our examination of the business and economics literature and our selection of candidate measures of technology adoption. The measurement, data sources, and evaluation of each are explained. Section 3 describes the application of the broadly defined indicators developed in Section 2 to the case-study candidates. Additional, narrowly defined data unique to the selected case study industry are introduced using the TAI methodology under the same SCP framework. Section 4 first discusses the four market segments to which the FCM technology could apply and develops separate estimates of the costs of complying with a recent EPA regulation using conventional or FCM technology. Section 4 concludes by explaining the macroeconomic modeling and presenting the results of the economic impact analysis of implementing the FCM technology versus conventional means of achieving compliance with the regulation. Section 5 summarizes the report and provides a discussion of future directions for this research.

2. Industry Characteristics Affecting Technology Adoption

This section presents the results of our research to develop a set of indicators that measure the likelihood of technology adoption. These indicators are subsequently used in our analysis of a specific ATP-funded technology, which was first developed for the automobile industry. The indicators developed in the report are derived from publicly available, broadly defined, industry-level data sets covering the manufacturing sector.

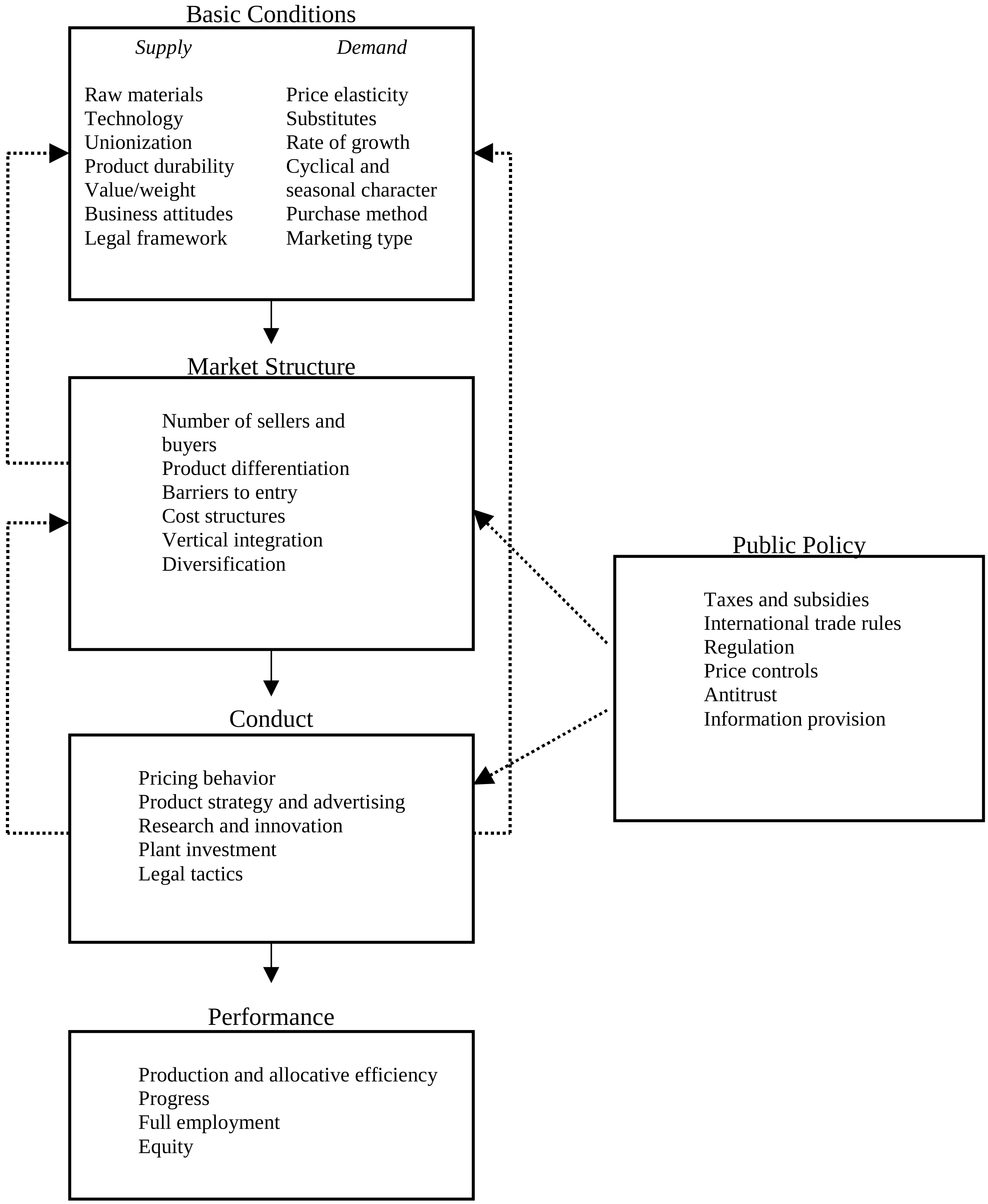
A significant amount of economic research has found that some industries adopt new technologies faster than others. For example, economic industrial organization studies based on the structure-conduct-performance (SCP) model have found that industry characteristics such as the number and size distribution of firms and quality of competition affect rates of technology adoption. Since the SCP model is widely used for organizing and analyzing industry characteristics and behavior, we apply it to develop a set of indicators that assess the likelihood of technology adoption.

According to the SCP model (Figure 1), market structure affects market conduct, which in turn affects market performance. Industry characteristics such as raw materials, technology, business attitudes, product substitutes, the ability of new firms to enter the market, and cyclical and seasonal demand determine the structure of industry, and in particular the numbers of sellers and buyers. This structure of sellers and buyers affects selling and buying conduct, such as production and pricing strategies, research and innovation, pricing behavior, advertising, investment, and legal tactics. Market conduct, in turn, affects the overall performance of the industry—that is, price and production levels. Public policy (such as taxes, subsidies, and regulations) affects both industry market structure and conduct. In the long run, these conduct and performance activities affect the market structure. While the conclusions drawn from early SCP models generally apply to all industries, recent SCP studies of specific industries augment the research with data specific to those industries.[1]

Using the SCP model, different industry characteristics can be logically organized and analyzed according to their effects on technology adoption. A TAI is developed based on an industry characteristic with broadly defined data (available at 4-digit SIC or 6-digit NAICS and lower resolutions) that meet the criteria laid out in Section 1 of this report. The characteristics and developed indicators are grouped under market structure (Section 2.1), conduct (Section 2.2), public policy (Section 2.3), and history (Section 2.4). The discussion of each measure includes both a description of the theoretical rationale for its use in assessing the likelihood of adoption and recently published research on the measure. The sections also address proposed measures that were candidates for inclusion as TAIs.

[1] This expansion of structure-conduct-performance analysis to include detailed industry-specific data has been termed “new industrial organization.” For a description, see Mansfield (1977).

Figure 1. The Structure-Conduct-Performance Model



Source: Scherer and Ross (1990), p. 5.

The broadly defined comprehensive industry data are used to demonstrate the industry selection process in this case study. Using narrowly defined specific industry data, we were able to more accurately calculate and apply the TAI measures in the selected industry.

Section 3 applies the broadly defined TAI data to two case-study candidates as a screening mechanism. The narrowly defined TAI data are developed and applied to only the selected case study application. Industry concentration and patent measures are recalculated using narrowly defined industry data. Narrowly defined data on TAIs that are unique to the chosen case study, such as the history of adoption and public policy, are also utilized.

2.1 Market Structure

An exhaustive search of the business and economics literature generated an abundance of indicators connecting industry structure to technology adoption. According to our established criteria, industry structure measures developed in this report had to be quantitative, be publicly available, measure each industry in the manufacturing sector individually, be theoretically related to the motivation to adopt technology, and have empirical evidence in the literature to support the connection to technology demand. For example, we identified concentration measures as most useful because they are available at the 6-digit NAICS industry level and are related to technology adoption. Other measures of industry structure that have a close theoretical relationship with technology adoption would require the collection and development of new data for each industry and are thus not developed in this report.

2.1.1 Industry Concentration

Concentration—the number of sellers—is one definition of competition, and affects conduct.[2] Examples of conduct are pricing behavior, R&D, plant investment, and technology innovation. Industry concentration therefore affects the demand for technology innovation and adoption and therefore the likelihood of technology adoption.

Industry concentration measures, as the name suggests, are used to benchmark industries by the market share (percentage of sales) held by the largest firms. Economic theory and empirical research suggest that highly concentrated industries, i.e., those in which most of the market is held by few firms (or by a single firm), face little pressure to adopt new technologies, thereby slowing innovation.[3] On the other hand, low concentration is not an optimal environment to encourage innovation. As Scherer and Ross (1990, p. 637) explain: “Up to a point, increased fragmentation stimulates more rapid and intense support of R&D. . . . But when the number of firms becomes so large that no individual firm can appropriate quasi-rents sufficient to cover its R&D costs, innovation can be slowed or even brought to a halt.” Scherer and Ross note that industries characterized by mid-sized, competitive firms tend to adopt technology more than industries characterized by either many small firms by a few, very large firms (oligopolies). Small firms in highly atomistic industries do not have the capital or opportunity to adopt new

[2] The concentration of buyers is also important, but in practice this is impossible to find out for all industries.
[3] For example, see Shepherd (1987). A focus on market concentration leaves out the effect of entry and exit conditions. The inclusion of such factors is explained in section 2.2.1.

technology, and severe oligopolies and monopolists face little pressure to adopt. In short, economic research suggests there is an optimal range of industry concentration in which technology adoption is most likely.[4]

There are two commonly used measures of industry concentration: the *n*-firm concentration ratio (CR), where *n* is the number of the largest firms included in the measure, and the Herfindahl-Hirschman Index (HHI).

The *n*-firm concentration ratio is the sum of the percentage market shares held by the *n* largest firms, or

$$CRn = \sum_{i=1}^{n} s_i \ . \qquad (1)$$

where *n* is the number of firms (e.g. 4 or 8) and s_i is the market share of firm *i*. The market share is measured as a percentage of sales. The CR4 (*n*=4) is the sum of the market shares of the largest four firms, and the CR8 (*n*=8) is the sum of the percentage market shares of the largest eight firms. An industry with exactly four firms has a CR4 of 100; while an industry with 10 equally sized firms has a CR4 of 40.

The HHI is defined as the sum of the squared percentage market shares of all firms in the industry, or

$$HHI = \sum_{i=1}^{N} s_i^2 \ , \qquad (2)$$

where *N* is the total number of firms in the industry and s_i is the market share of firm *i*. The HHI measure approaches 0 as all the firms in an industry approach zero market shares (theoretically perfect competition). The HHI has a maximum value of 10,000 when there is only a single firm—i.e., a monopolist. For a theoretical industry with 10 equally sized firms, the HHI would be 1,000 (= 10 x 10^2).

The HHI is a more comprehensive and revealing measure of industry concentration. Because it uses the square of market share, and includes the share of every firm, it is able to show differences in concentration between industries even when the CR4 measures (or CR8 measures) are identical. For example, industry A consists of eight firms with the following concentrations: 65, 5, 5, 5, 5, 5, 5, 5. The CR4 is 80 and the HHI is 4,400. Industry B consists of eight firms with the following concentrations: 20, 20, 20, 20, 5, 5, 5, 5. The CR4 is 80 but the HHI is only 1,700. The HHI, unlike the CR4, captures the fact that Industry B is less concentrated.

[4] In case studies, adding industry-specific information on the impact of concentration will improve the interpretation of the effect of concentration on the adoption of technology. For example, technology adoption should occur at lower concentrations in emerging industries driven by innovation (such as life-cycle work most suited to manufacturing). This is discussed in section 2.1.2.

According to Shepherd (1987), a CR4 between 40 and 60 identifies an industry with firm concentrations optimal for competitive behavior conducive to adopting new technologies. Scherer and Ross (1990) identify the bounds for the CR4 as 45 and 60. Scherer and Ross also report findings that the optimal CR8 for competitive industry is 70 (which roughly corresponds to a CR4 of 50 in the U.S. economy). We use a range of 10 points on either side of the optimal CR8 value as the range of values optimal for technology adoption.

The Federal Trade Commission (FTC) uses both the CR and the HHI to assess the extent to which a proposed merger will affect competition in that industry.[5] According to the U.S. Department of Justice (DOJ), a market with an HHI less than 1,000 is considered unconcentrated, between 1,000 and 1,800 moderately concentrated, and over 1,800 highly concentrated.[6] The DOJ is likely to challenge mergers that increase the HHI more than 100 points when the HHI index is greater than 1,800. A middle range—in which challenges depend on the increase in the HHI—occurs when the HHI is between 1,000 and 1,800. The FTC is unlikely to challenge mergers when the HHI is below 1,000. We use the DOJ definition of a moderately concentrated market (HHI between 1,000 and 1,800) to approximate the optimal industry concentration for technology adoption.

To plot and compare U.S. industry concentrations, we used the U.S. Census Bureau's 1997 Economic Census data on four (CR4) and eight (CR8) concentration ratios and the HHI index, for each six-digit NAICS code manufacturing industry. The CR4, CR8, and HHI values of the lawnmower-engine industry and the airplane engine industry are analyzed in Section 3.

2.1.2 Other Market Structure Measures

Industry concentration measures may be improved upon as indicators of technology adoption. First, they may be improved by more narrowly delineating the relevant industry. That is, by defining the industry more precisely than the six-digit NAICS level, more detailed economic information about technology adoption can be obtained. Analysis of some industries and markets may require a high level of resolution. Second, while concentration ratios are moderately correlated with technology adoption, measures with higher correlations could be developed. For example, entry and exit conditions—the ability of new firms to enter and leave the relevant industry—influence technology adoption even in highly concentrated industries. If entry is easy, even firms in highly concentrated industries are likely to adopt technology as a defense against new entrants.

New measures can be collected or constructed specifically for the industry under analysis. For example, according to Atkinson and Court (1998) at the Progressive Policy Institute (PPI), the relative number of new, fast-growing entrepreneurial companies in an industry is correlated with innovation and adoption of new technologies. The PPI researchers defined fast-growing companies as "companies with sales growth of at least 20% per year for four straight years," and notes that the number of initial public offerings (IPOs) reflects the increase in the number of fast-

[5] Dr. Michael McFalls (1997) of the FTC provides an in-depth discussion of the ways in which the FTC assesses market power during an analysis of joint ventures.
[6] Horizontal Merger Guidelines issued by the U.S. Department of Justice and the Federal Trade Commission, section 1.51 on the DOJ internet site www.usdoj.gov/atr/public/guidelines/horiz_book/15.html

growing entrepreneurial companies. “Economic churn”—the replacement of old firms by new, more efficient firms—is also correlated with technology adoption. The U.S. Census Bureau provides a single measure of industry births and deaths for the U.S. manufacturing sector as a whole but not for individual industries. These measures—fast-growing companies, number of IPOs, and establishment births and deaths—could provide additional information about technology adoption, but require further data development to apply to specific industries.

2.2 Market Conduct

Industry conduct measures developed for this report had to be quantitative, be publicly available, measure each industry in the manufacturing sector individually, be theoretically related to the opportunity to adopt technology, and have empirical evidence in the literature to support the connection to technology adoption. The TAIs on market conduct could be thought of as addressing the supply of technology innovation.

Measures of industry conduct include both direct and indirect measures of technology adoption. For example, technology adoption itself is market conduct. Other market conduct measures also have an impact on technology adoption. Of these, several measures, such as the number of RJVs and the number of patents, currently have broadly defined industry data sets available at the 4-digit SIC and higher resolutions. It is possible to improve upon these measures by increasing their resolution and by developing data for new measures.

2.2.1 Patent Counts and Technology Adoption

The mechanism by which the number of patents influences technology adoption is less theoretically founded than the connections of technology adoption with concentration ratios and HHI indices. In this report, we interpret the number of patents as an indicator of the supply of technology available to an industry, and as influencing market conduct through the amount of technology available to the industry.[7]

Griliches, Hall, and Pakes (1991) studied the relationships among R&D, patenting activity, and market value. Research continues on ways to use patent data to explain innovation. Recent research on “hot” patents and patent clustering has strengthened their empirical usefulness and could be incorporated into these indicators if broadly defined industry data become available (Breitzman 2001). (The duration of the payment of patent maintenance fees may relate to patent importance, and could be incorporated into patent indicators in the future.) The number of patents issued for potential application in an industry can be used as an indicator of technology adoption in that industry or in other “user” industries. The increase in innovation happens through a “supply-push” model of technology adoption, in which more patents result in the possibility of greater technology advances, as in the case of RJVs.

The mechanism by which the number of patents influences technology adoption is less theoretically founded than the connections of technology adoption with concentration ratios and HHI indices. Consequently, the interpretation of the number of patents is unclear. In this report,

[7] While the overall number of patents is an important indicator of technology supply, this measure does not address the marginal value of an additional patent.

we use the total number of patents granted over the last five years as an indication of the amount of new technology available.[8]

The output of patents, publications, citations, and other technology developments can be measured using data from the U.S. Patent and Trademark Office (USPTO).[9] The translation from the US Patenting Classification System (USPCS) to the SIC code system is straightforward, allowing industry-specific patent counts, though not at a high resolution. For the two industries under evaluation, patent data are available at the 3-digit SIC level. For any specific industry, it is possible to hone the patent-count measure to finer detail and greater accuracy by searching out patents directly applicable to that industry. The total number of patents as reported by the USPTO in SIC codes 13 to 39 from 1996 to 2000 are depicted in Appendix B.

The *Patenting Trends* database (USPTO 2001) provides two types of patent counts. The "whole" counting method matches the USPCS to all relevant SIC codes as explained in the *Patenting Trends* documentation:

> The USPCS to SIC Concordance assigns USPCS patent subclasses to all (up to seven) identified SIC-based product fields to which they are pertinent. In each of the 'Whole Counts' product field profiles, a patent is counted if the patent's 'original' USPCS subclass is matched, via concordance, to that product field. In the 'Whole Counts' profiles, for example, if a patent has 'original' classification in a USPCS subclass which is matched to 3 unique SIC-based product fields, that patent would be counted once in each of the three associated 'Whole Counts' profiles. (USPTO 2001)

The "fractional" counting method divides the USPCS patents equally among all the matched SIC fields. In other words, the patent found in three product fields would generate one-third of a patent in each SIC field. This has the effect of diluting the weight of broadly applicable patents and increasing the weight of patents dedicated to a single industry.

We use the number of patents reported in the USPTO database over the last five years to indicate the supply of innovation available to an industry. All else being equal, an industry with fewer patents is more attractive to developers and sellers of new technology. A developer of new technology would prefer to target an industry with higher demand for technology and fewer patents rather than an industry with less demand for technology and more patents.

2.2.2 Research Joint Ventures (RJVs), Innovation, and Technology Adoption

As was the case with patents, the mechanism by which the number of RJVs influences technology adoption is less theoretically founded than the connections of technology adoption with concentration ratios and HHI indices. Similarly, we interpret the number of RJVs as indicating the supply of technology available to an industry.

RJVs can increase the overall R&D in an industry in two ways. First, under certain conditions, economic theory shows that RJVs increase the level of research and development in an industry, thereby increasing the "supply" of new technology. These conditions are that the combined

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[8] In this report, the last five years of patents are combined to create the total number of patents available. Other ways of measuring patents include the number of highly cited patents and the rate of patenting.

[9] U.S. Patent and Trademark Office, *Patenting Trends in the United States 2000*. CD-ROM. December 2001.

returns to R&D exceed the private returns of the joint venture members (Stenbacka and Tombak 1997). Under these conditions, the absence of a joint venture is a “market failure,” wherein the optimal level of R&D is not attained by the market. RJVs that address suboptimal levels of R&D in competitive markets are often justified on this basis.[10] Second, the overall R&D in an industry can be increased when a legal restraint (such as anti-trust legislation) that hinders the formation of RJVs is lifted for certain RJVs that survive regulatory scrutiny. We use the survival of regulatory scrutiny as an indicator of RJVs that increase the overall level of R&D in an industry.

The Progressive Policy Institute (PPI) provided empirical evidence that collaboration and networks (such as RJVs) create more technology and innovation.[11] Causation could also run in the opposite direction—that is, industries characterized by innovation and technology adoption are conducive to RJV formation.[12] Therefore, applying the theoretical and empirical observations that RJVs are conducive to the creation of new technology, we are able to use the number of RJVs in an industry as an indicator of technology adoption in that industry. The increase in innovation happens through a “supply-push” model of technology adoption, in which more and greater technology advances developed by the RJVs become so compelling that they attract firms to adopt them.

To measure this relationship between R&D and innovation, the nonprofit organization Council on Competitiveness has developed the Innovation Index, which measures the relationship between industry R&D (as measured by patents) and employment in research and development, expenditures on research and development, percentage of R&D expenditures funded by private industry, and percentage of R&D performed by universities. Unfortunately, the Innovation Index is available only at the national level and not for individual industries. Estimates of the Innovation Index at a national level indicate a strong connection between R&D activities and innovation (patents).

The Collaborative Research (CORE) database[13] collects data on RJVs from *Federal Register* filings.[14] Parties involved in RJVs who wish to gain protection under the National Cooperative Research Act and the National Cooperative Research and Production Act must file public notice of the RJV in the *Federal Register*. The CORE database consists of firms that have announced their intentions in the Federal Register, which indicates a belief that the RJV is likely to be one that would otherwise not be permitted in the market, and one that would contribute positively to the current level of R&D because it has survived government scrutiny. The number of RJVs from the SIC codes 20 to 39, as reported in the CORE database, are depicted in Appendix C.

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[10] The assumptions made in a study—about the marketplace and the nature of the joint venture companies—are often the deciding factor in determining whether RJVs result in more or less R&D.
[11] The Progressive Policy Institute (PPI) is a non-profit think tank that has researched the characteristics of the “new economy,” one of which is rapid technological innovation.
[12] Robert P. Lynch (1989) lists several industry conditions that are conducive to JV formation. One important condition is “rapid changes occur in technology,” indicating technology adoption).
[13] The CORE database is funded by the National Science Foundation (NSF) and maintained by Dr. Albert Link of the University of North Carolina.
[14] Free internet access to the *Federal Register* is available at www.access.gpo.gov/nara. From this location, notices appearing in the *Federal Register* may be searched.

We use the number of RJVs reported in the CORE database as an indicator of the supply of technology available to an industry. All else being equal, an industry with fewer RJVs is more attractive to developers and sellers of new technology. A developer of new technology would prefer to target an industry with higher demand for technology and fewer RJVs rather than an industry with less demand for technology and more patents.

2.2.3 Other Industry Conduct Measures

In addition to RJVs and patents, there are other statistics that measure key industry characteristics relating to innovation and technology adoption. For example, empirical research of stock market reaction to RJV formation indicates that the formation of certain types of RJVs—such as that between a large and a small company—result in appreciation of stock prices.[15] Koh and Venkatraman (1991), McConnell and Nantell (1985), and Mohanram and Nanda (1995) demonstrate that the market reaction depends on the type of RJV and the characteristics of the involved companies. Empirical studies have addressed different RJV configurations and the impacts on R&D. For example, a RJV between a large and a small company combines the advantages of each firm size in technological innovation (Rothwell 1989). Technology adoption information obtained from RJV data could therefore be improved by controlling for the RJV configuration.

The amount of royalty revenues from technology licensing was used by Degnan (1999) as a proxy for the success of innovative activities resulting from U.S. R&D efforts. Data on U.S. royalty income were collected and compared to the national economic growth attributable to technological advances. Degnan found a strong correlation between R&D expenditures and innovation and economic prosperity. No industry-level R&D data about royalty revenues were found for inclusion as indicators of technology adoption.

2.3 Public Policy

As illustrated in Figure 1, public policy influences industry conduct via taxes, subsidies, regulations, and price controls. For example, a government subsidy would increase the production of the subsidized goods, whereas taxes would reduce the production of taxed goods. Regulations that raise the cost of the finished product act like taxes. Regulations that permit less-costly production alternatives would be similar to subsidies.

In the context of the supply-and-demand framework used in this report, public policy can act either as a demand or as a supply factor for technology innovation. Some policies (such as the limited suspension of antitrust regulations) can encourage the development of new technology supply. Other policies, such as specific regulations, tend to increase the demand for new technology. For example, air bag requirements in automobiles have required the implementation and refinement of sensing systems.

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[15] Stock prices increase based on an expectation of a successful joint venture leading to greater profit per share and/or increased dividends. Successful joint ventures produce new technology innovation and could, given pro-competition RJVs, also produce demand for technological innovation.

Regulation, as a public policy option, fits within the SCP model. It specifically affects structure and conduct. Regulations affect every industry, but each regulation varies in impact. There is no standardized, quantitative way to measure regulation or other aspects of public policy across industries. In a case study, specific interpretations of applicable public policies are required. The impact of regulation on this case study is discussed in Section 3.

2.4 Historical Patterns of Technology Adoption

The SCP model also takes into account industry-specific historical trends in market structure, as well as conduct, performance, and public policy. Industry-specific SCP trends can be used to assess the likelihood of technology adoption. In addition, the history of past technology adoption, as defined in an industry, provides valuable information about the likelihood of technology adoption in that industry in the future. There is no standardized way to account for past technology adoption with a broadly defined industry measure. In a case study, specific interpretations of what constitutes technology adoption, and time-trend data on those observable characteristics, are required. The impact of the history of technology adoption on this case study is discussed in Section 3.5

2.5 Summary of TAI Measures Used

In this report, the HHI and four- and eight-firm concentration ratios (CR4 and CR8) are used as indicators of demand for technology adoption. The number of patents and RJVs are used as indicators of supply of technology adoption. Public policy, through regulation, is another driver of technology adoption in this report. An examination of the history of technology adoption adds empirical observations to the analysis. Section 3 describes the application of the available data on these TAIs to the case-study candidates.

3. Selecting a Case Study Using Technology Adoption Indicators (TAIs)

The primary mission of the National Institute of Standards and Technology (NIST) is to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. The Advanced Technology Program (ATP) at NIST supports this mission by providing cost share awards to industry to develop high-risk, “enabling” technologies which can ultimately increase economic growth, the quality of jobs, and the quality of life that comes from such growth.

ATP projects are designed to be partnerships between government and industry. Individual awards are made to single firms or joint ventures of firms to produce technologies that enable the development of new products, processes, and services across diverse application areas. Universities, state and federal laboratories, and other nonprofit institutions also participate in the projects as members of joint ventures and as subcontractors. Awards are made based on rigorous peer-reviewed competitions designed to select those proposals best qualified in terms of their cutting-edge technological ideas and potential for national economic benefits. Emphasis is placed on the difference that ATP funding will make. Awards have specific cost-share rules: for example, joint-venture participants pay more than half of the total project costs. Single-company awardees pay all indirect project costs and may also cover some of the direct costs. Each award has a set of specific goals and completion dates.

The Flow-Control Machining (FCM) Project is an ATP joint venture, its partners being Extrude Hone Corporation, Ford Motor Company, General Motors, the University of Pittsburgh, and the University of Nebraska at Lincoln. The four-year project began in 1996 and its total funding was $7.9 million; $4.0 million was provided by Extrude Hone, Ford, and GM, and the remainder was provided by ATP. The project goal was to develop two finishing processes that increase the functional precision of cast-metal parts that carry fluids in interior passageways. Its first targeted application was increased airflow in automobile engines, where the increase in functional precision can be used to increase engine horsepower, increase fuel efficiency, reduce emissions, and reduce the cost of engines. While these two processes were initially aimed at the automobile industry, they also have broad application in other, non-automotive sectors. If diffused into a wide array of industries, such as aerospace, manufacturing tooling, and medical, the impact could be quite large.

The particular capabilities of the FCM technology allow it to be applied in a number of industries with significant societal benefit. For example, using the processes in personal watercraft could significantly reduce noise and pollution.[16] Using the FCM processes in lawnmower engines and other powered lawn and garden equipment could significantly decrease emissions and increase fuel efficiency and horsepower. Extrude Hone also indicated that airplane engine manufacturers could also be a potential adopter of the FCM technology. Using the processes in aircraft engine cooling systems could significantly reduce engine weight and therefore overall aircraft weight.

Of the many small-engine applications (including all-terrain vehicles and personal watercraft) that Extrude Hone was interested in, the company recommended the lawnmower engine

[16] Recent tests indicate that FCM can decrease personal watercraft (PWC) emissions by 50% while increasing power by 16%. Extrude Hone Corporation, “News Bulletin,” October 13, 2000.

application for this case study. A new EPA regulation, described in Section 3.4, was identified as a compelling driver of the adoption of the FCM technology in small engine applications. Interested manufacturers and Extrude Hone cooperated to test the FCM technology in lawnmower engines. Extrude Hone also indicated that airplane engine manufacturers could also be a potential adopter of the FCM technology, but was not pursuing that application.

Based on the interest shown by Extrude Hone and lawnmower engine manufacturers, as well as the economic implications of the use of the FCM technology in such a basic, widely used device, we selected the lawnmower engine application for an in-depth case study. We selected the airplane engine application as a comparison to the lawnmower application because the extremely high value and relatively low number of production units in airplane engine manufacturing provided a contrast to lawnmower engines.

In this chapter, the two applications—lawnmower engines and aircraft engines—illustrate the use of the TAI system as a screening mechanism to identify promising industries for technology adoption. This analysis results in the identification of lawnmower engines as the more likely adopter of the FCM technology. In the case study presented in the next chapter, we proceed with the quantitative analysis of the FCM technology in lawnmowers, based on our discussions with Extrude Hone and on the impact of a new EPA regulation, and supported by the TAI analysis.

In this chapter we illustrate the application of the TAIs, including the public policy (regulation) TAI.[17] We use the TAIs developed in Section 2 to guide us in selecting the best application for a prospective case study from these choices. Section 3.1 addresses the concentration ratios and HHI index, section 3.2 joint ventures, section 3.3 the number of patents, section 3.4 public policy and regulation, and section 3.5 historical adoption trends. In the sections on industry concentration, joint ventures, and patents, we address the broadly defined measures (4-digit SIC and 6-digit NAICS industries) followed by the narrowly defined measures (specific product market data). The broadly defined comprehensive industry data are used to demonstrate the use of TAIs in comparing industries. Using narrowly defined specific industry data, we were able to more accurately calculate and apply the TAI measures for the selected industry. The impact of public policy and regulation on the industry selected for the case study is analyzed using industry-specific information.

3.1 Industry Concentration

Concentration ratio and HHI data were obtained from a table (accessed online) in the *1997 Economic Census*, Manufacturing Subject Series (U.S. Bureau of the Census 1997): “Share of Value of Shipments Accounted for by the 4, 8, 20, and 50 Largest Companies in Each of the 3-, 4-, 5-, and 6-digit NAICS Industries: 1997.” The four-firm concentration ratios (CR4) for all 6-digit (NAICS) manufacturing industries are shown in Appendix D. Figure 2 presents data on the CR4, Figure 3 on the CR8, and Figure 4 on the HHI in the two 6-digit industry groups that include lawnmower firms and aircraft engine firms.

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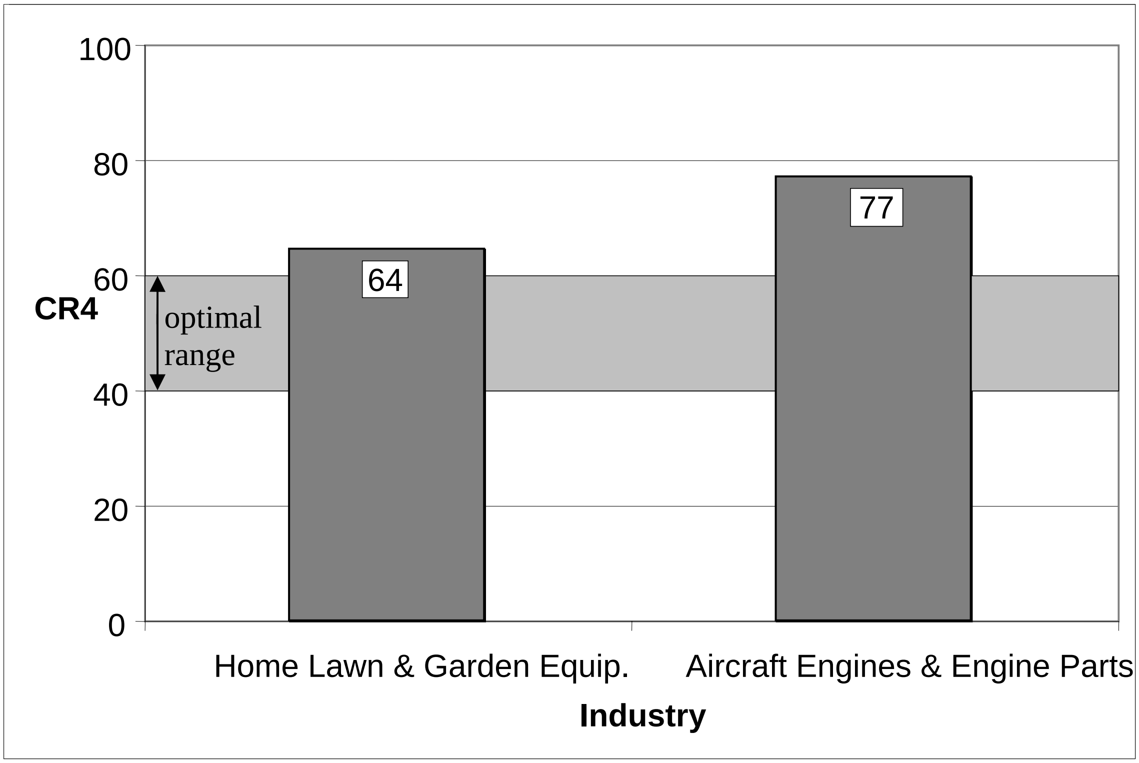
[17] The industry-specific measures were developed after all the broadly defined measures had been considered and a decision made on which application to choose for a case study. Once the target industry—lawnmowers—had been selected, additional narrowly defined data were developed. For presentation purposes, we appended the specific, narrowly defined measures immediately after the discussion of the broadly defined measures.

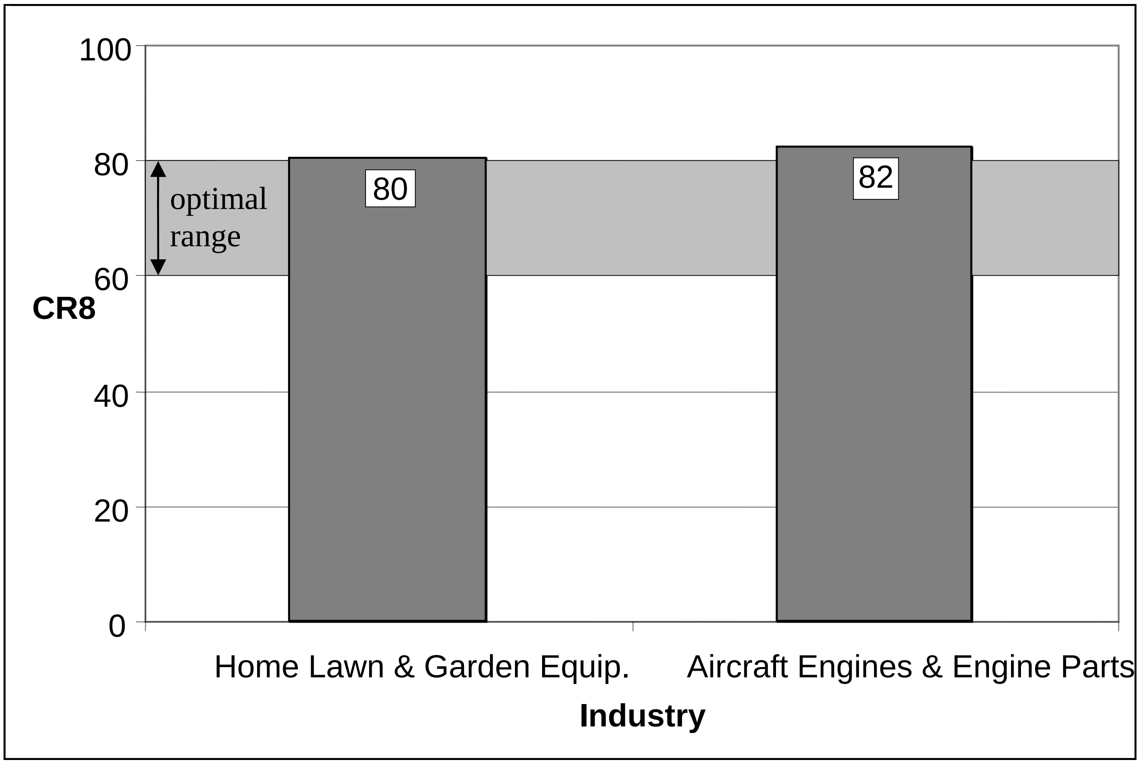
For the CR4, we use the bounds of 40 and 60 to identify an industry with market concentrations optimal for technology adoption (following the analysis of the optimal bounds identified in Chapter 2). For the CR8, we use a range of 60 to 80 to define the optimal market concentration for technology adoption. The HHI may be interpreted in a similar fashion. We use the range of 1,000 to 1,800 as the optimal range for technology adoption.

Figure 2. Four-Firm Concentration Ratios of Home Lawn and Garden Equipment and Aircraft Engines and Engine Parts



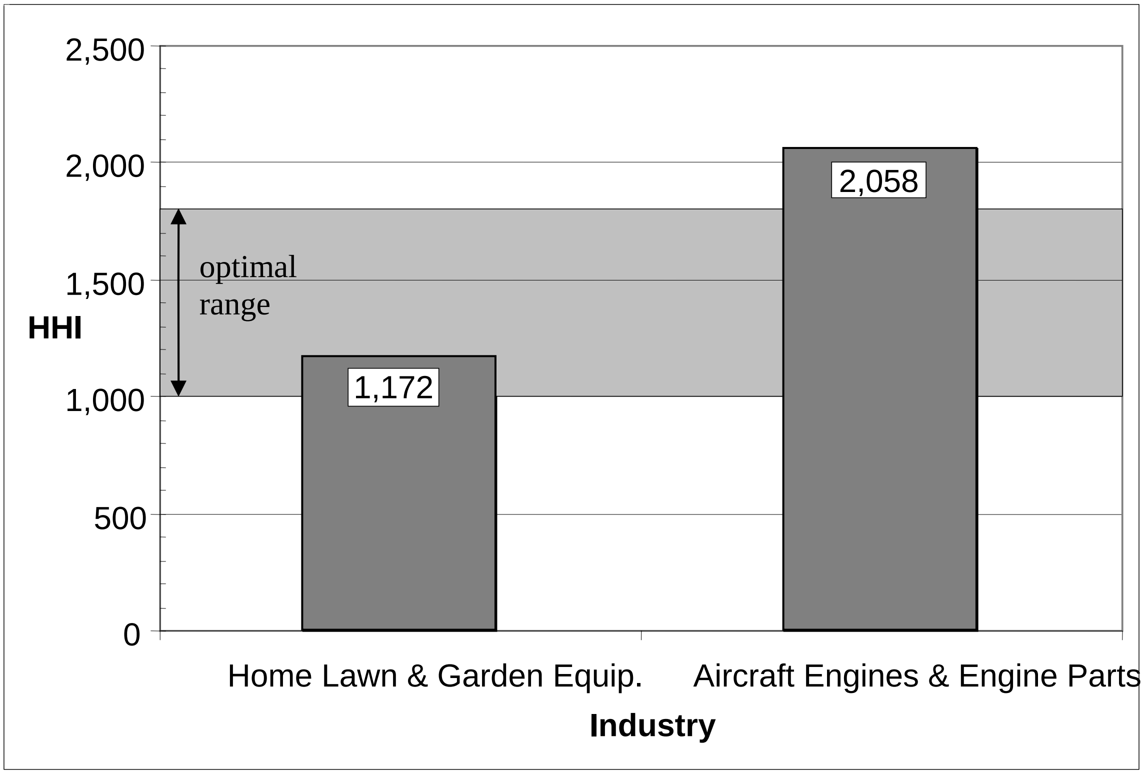
Source: U.S. Bureau of the Census (1997).

Figure 3. Eight-Firm Concentration Ratios of Home Lawn and Garden Equipment and Aircraft Engines and Engine Parts



Source: U.S. Bureau of the Census (1997).

Figure 4. Herfindahl-Hirschman Indices of Home Lawn and Garden Equipment and Aircraft Engines and Engine Parts



Source: U.S. Bureau of the Census (1997).

As shown in Figure 2, the CR4 (64) for Home Lawn and Garden Equipment is above 60, the upper limit for optimal technology adoption. The industry is close to, though not quite within, the optimal CR4 range for technology adoption. The CR4 (77) result for Aircraft Engines and Engine Parts indicates the structure is not optimal because the top four companies hold too much market share to spur technology adoption. The CR8 for Home Lawn and Garden Equipment (80), shown in Figure 3, is just barely within the optimal range of 60 to 80. However, the CR8 (82) for Aircraft Engines and Engine Parts is so close to the Home Lawn and Garden Equipment CR8 as to make any distinction impossible.

As shown in Figure 4, the Home Lawn and Garden Equipment industry HHI is 1,172, which is within the optimal range. The HHI statistic, because it includes all the firms in an industry, is a more comprehensive and revealing measure of industry concentration. Even though the CR8 for the two industries is similar, the HHI reveals that the Home Lawn and Garden Equipment industry is less concentrated than the Aircraft Engine and Engine Parts industry. We conclude that this industry consists of a large number of small firms that are large enough to have the resources and motivations to adopt new technology. In contrast, the industry that includes manufacturers of aircraft engines greatly exceeds the upper bound with an HHI statistic of 2,058. This signifies that the industry is more highly concentrated than is optimal for the adoption of new technology.

We applied the same measures (CR4, CR8, HHI) to narrowly defined CR4, CR8, and HHI data developed for the lawnmower industry itself.[18] Specialized data on the lawnmower market were obtained from the Power Systems Research OELink database (Power Systems Research 2001). These data allowed the creation of CR4, CR8, and HHI exclusively for lawnmower manufacturers. Figures 5 and 6 show the CR4 and CR8 concentration ratios developed from the OELink data. Figure 7 shows the HHI developed from the OELink data.

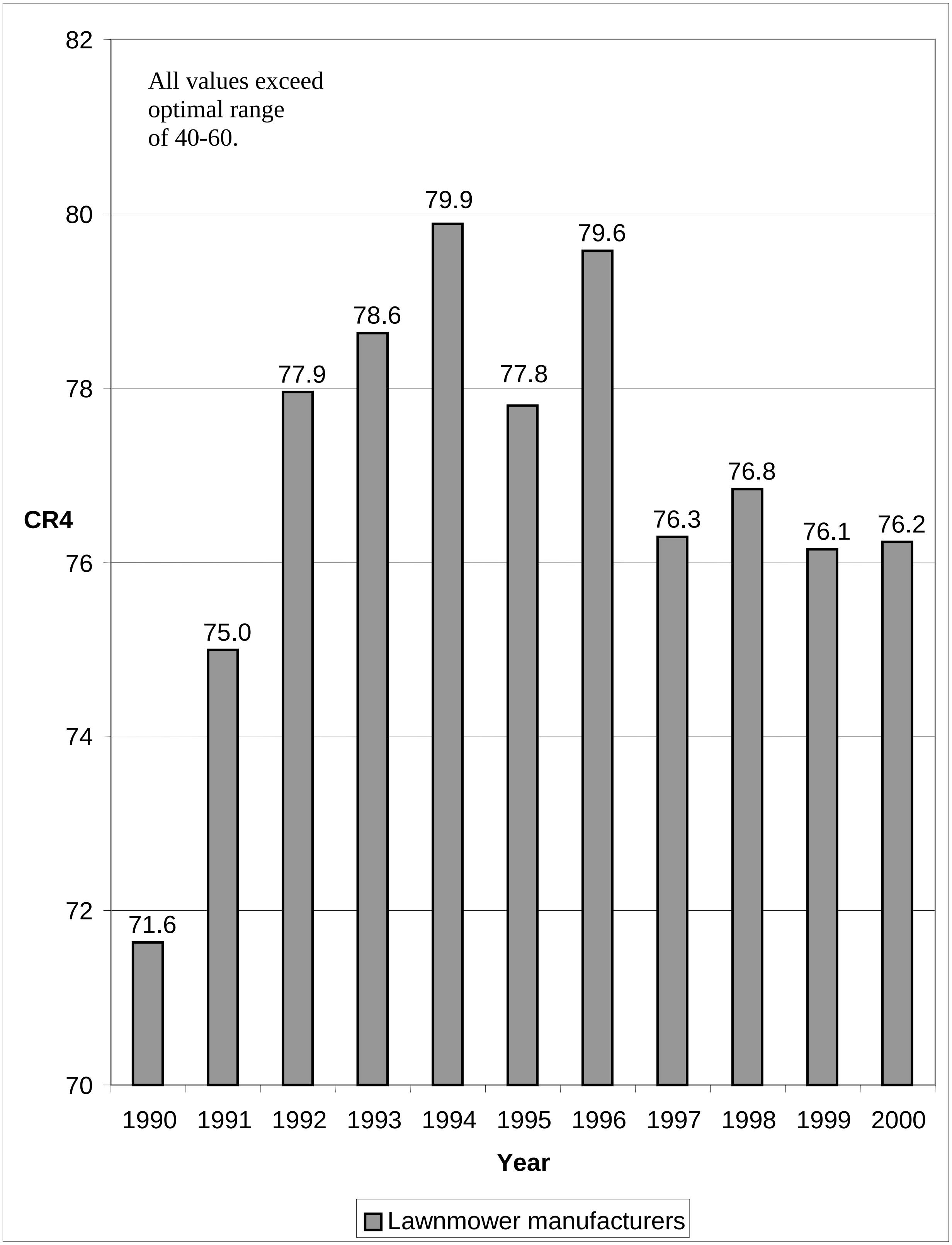
Constructed from the narrowly defined industry data, the CR4 and CR8 concentration indices both exceed the optimal ranges for technology adoption, throughout the entire time range. The more comprehensive and revealing HHI index, however, remains well within the optimal range for technology adoption. The HHI, while exhibiting a sharp spike mid-decade, ended at 1,666 in the year 2000, which is well within the optimal 1,000 to 1,800 range.

The concentration indices presented in Figures 5 to 7 are likely to be overestimates of the true indices for two reasons. First, the OELink data define the relevant marketplace narrowly. The inclusion of companies that *could* but are currently not producing lawnmowers lowers all the concentration indices. Other companies that use or produce small engines include all-terrain vehicles, personal watercraft, outboard motors, small motorcycles and mopeds, and snowmobiles. Overestimation of concentration indices also results because both imports of finished lawnmowers with U.S. engines and U.S.-assembled lawnmowers with non-U.S.-manufactured engines are not counted.

We conclude that, on the whole, the concentration ratio measures provide stronger support for adoption by the lawnmower industry than the aircraft engine industry. The comprehensive HHI measure indicates a strong preference for the lawnmower industry.

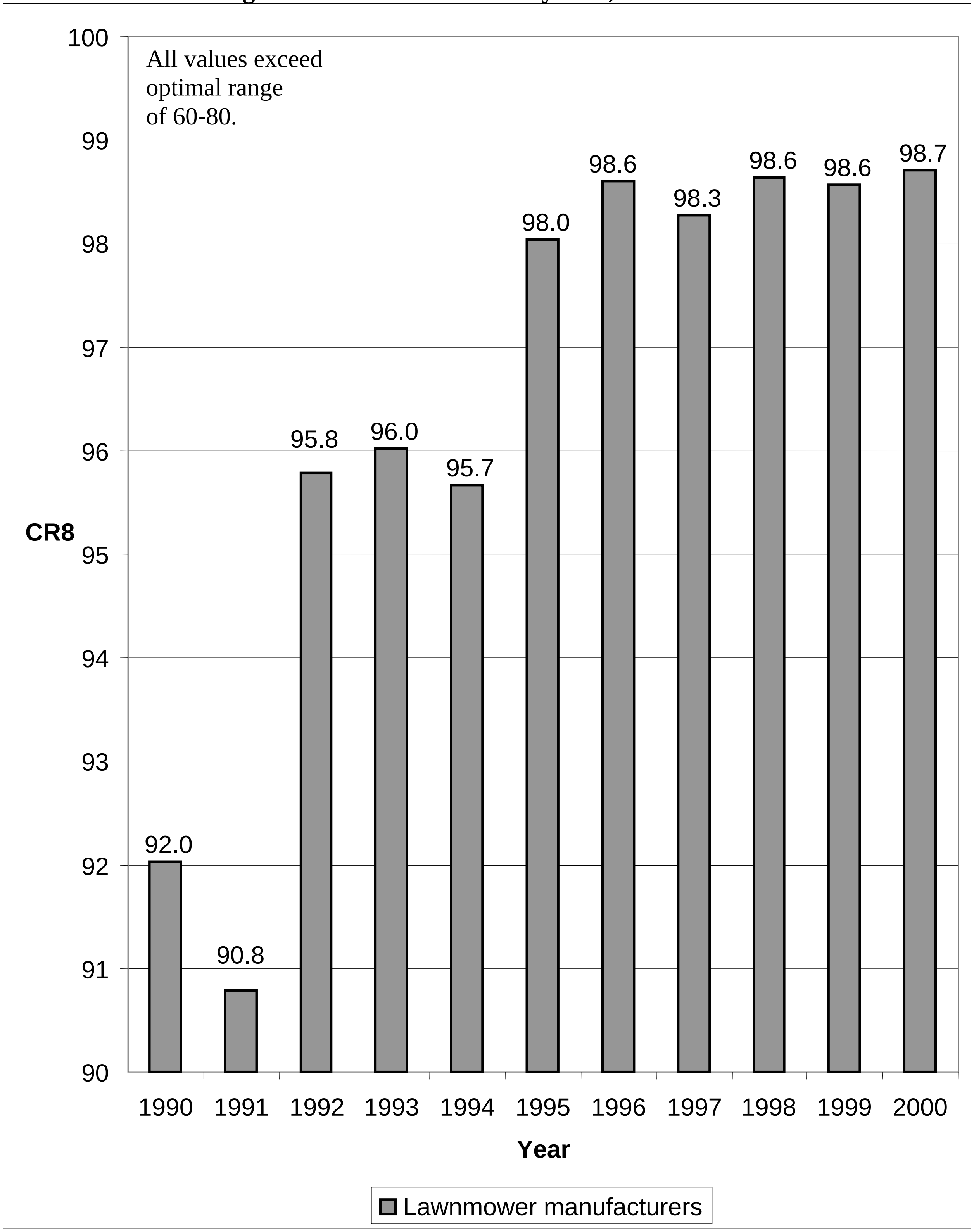
[18] Once the target industry—lawnmowers—had been selected (based on all the broadly defined TAIs), additional narrowly defined data were developed. In order to present these additional measures in the most appropriate location, we appended the specific, narrowly defined measures immediately after the discussion of the broadly defined measures. The specific measures were developed after all the broadly defined measures had been considered and a decision made on which application to choose for a case study.

Figure 5. Lawnmower Industry CR4, 1990 to 2000



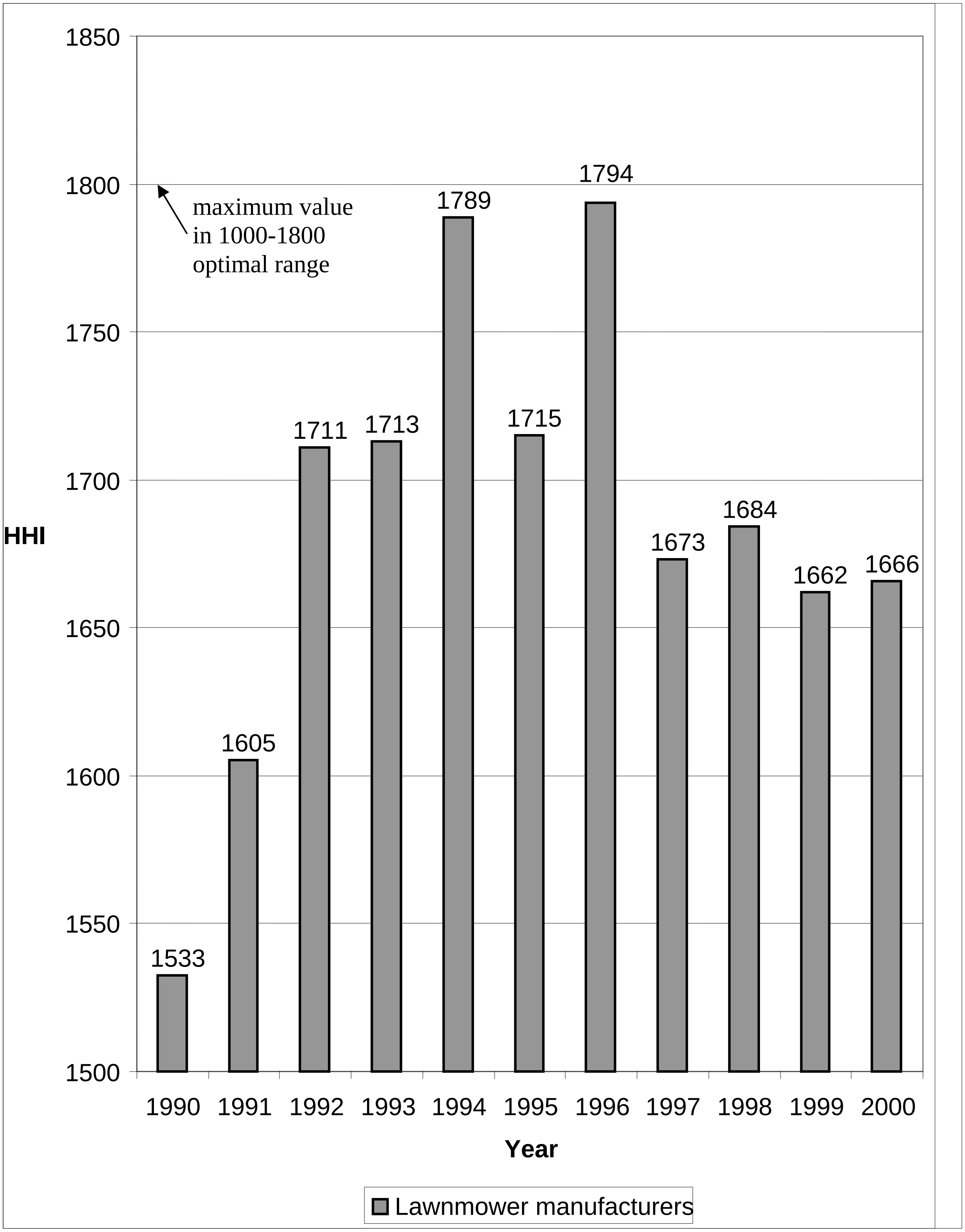
Source: Power Systems Research (2001).

Figure 6. Lawnmower Industry CR8, 1990 to 2000



Source: Power Systems Research (2001).

Figure 7. Lawnmower Industry HHI, 1990 to 2000



Source: Power Systems Research (2001).

3.2 Patent Counts

This section examines patent data to identify whether the two industries show a proclivity to supply technology. We describe the patent data source and the application of the patent TAI to both lawnmower and airplane engine manufacturers. Then the patent indicator is analyzed within the Structure-Conduct-Performance (SCP) framework, and the likelihoods of technology adoption by the two different manufacturers are compared.

The analysis of the number of patents in an industry is used to indicate the “supply” of innovation available to that industry. In this study, we are not only concerned about the adoption of technology in general, but with the adoption of a specific technology. All else being constant, the fewer the number of competing technologies, the greater the likelihood of any one technology innovation being adopted. Specifically, if there is a great demand for technological innovation but few sources of technological innovation, then a new innovation has a greater chance of adoption than if there were numerous innovations.

The mechanism by which the number of patents influences technology adoption is less theoretically founded than the connections of technology adoption with concentration ratios and HHI indices. Consequently, the best method for measuring the precise number and timing of patents is unclear, as is the interpretation of the selected measure. In this report, we use the total number of patents granted over the last five years.[19] Patent count data were obtained from a U.S. Patent and Trademark Office publication, *Patenting Trends in the United States 2000* (USTPO 2001). The USPTO has created a concordance between the U.S. Patent Classification System (USPCS) and a limited number of SIC codes. For the two industries under evaluation, patent data are available at the 3-digit SIC level.

Lawnmower engines are part of SIC code 3524, which is available at the 3-digit resolution (352) in the *Patenting Trend* database. Aircraft coolant systems are part of SIC code 3724, which is available at the 3-digit resolution (372) in the *Patenting Trends* database. Data from the last five years were summed to arrive at the total number of patents in the last five years (1996 to 2000, inclusive). This was done to indicate the current “supply” of relatively recent innovations in the most closely affiliated industry.

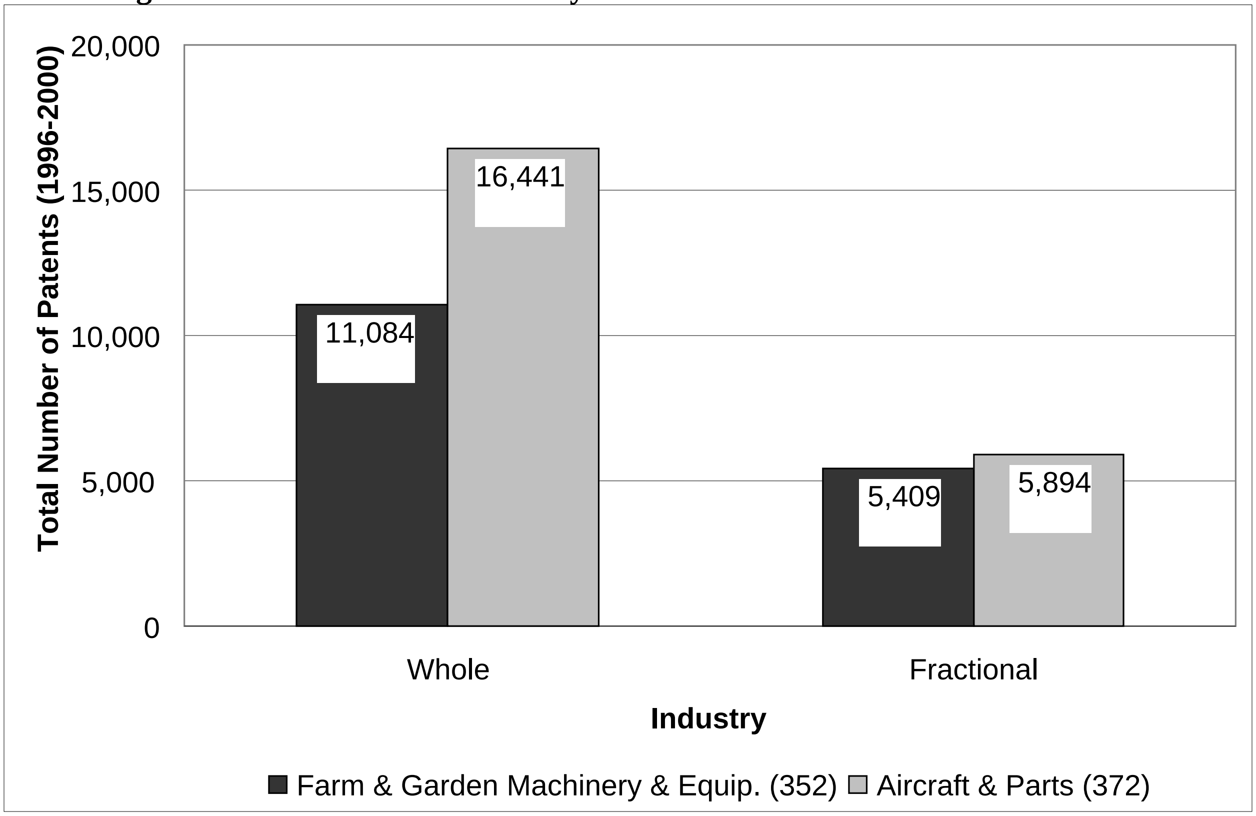
Figure 8 shows the whole and fractional patent counts for Farm and Garden Machinery (SIC 352), and Aircraft and Parts (SIC 372). The whole and fractional counting methods were described in Chapter 2 (section 2.2.1). The Farm and Garden Machinery industry has only two-thirds as many patents as the Aircraft and Parts industry, under the whole patent counting method. Under the fractional counting method, both industries have a similar number of patents.

Appendix B displays the whole and fractional patent counts in the manufacturing sector industries with SIC codes 30 to 39. Both lawnmower and aircraft engine manufacturers are in industries with a moderate level of patent activity. A substantial number of industries have worse performance.

[19] The Census data do not indicate the length of patent maintenance during the 5 year summary.

This indicator reveals a preference for the lawnmower case study candidate using the whole patent counting method, and supports the selection of the lawnmower industry. Under the fractional patent counting method, it does not show a clear difference between the two candidates, and therefore does not lend support to either.

Figure 8. Farm/Garden Machinery and Aircraft Patents Issued 1996 to 2000



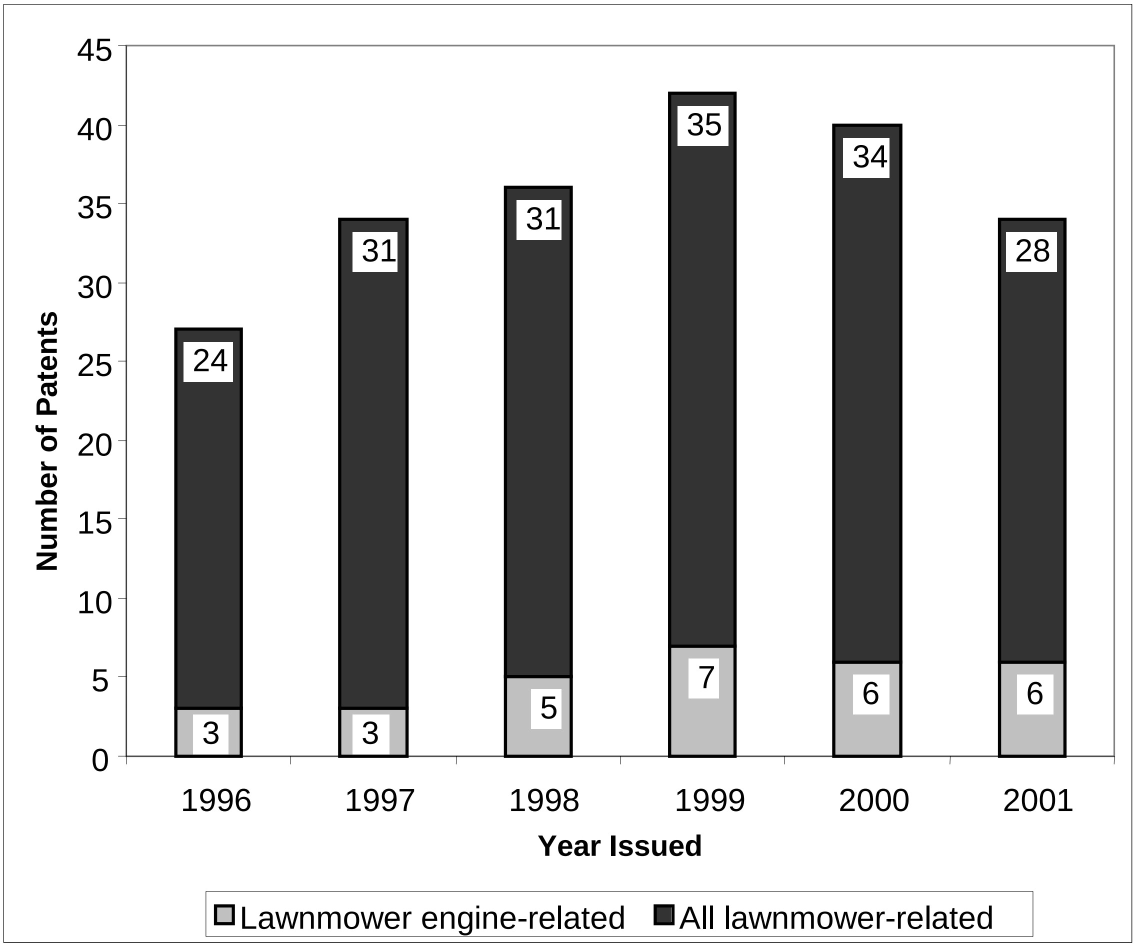
Source: USTPO (2001).

The USPTO provides guidelines for manually constructing patent counts at a higher resolution. These guidelines involve searching for text that matches the selected product or industry in the patenting system Internet database. After collecting all relevant patent classification numbers, the number of patents in each of these categories can be collected.

A multi-year survey period reflects the supply of innovations available for "supply-push" adoption in a particular industry. Narrowly defined data on patents related to lawnmowers were obtained from the USPTO database and then sorted into two categories: patents relating to lawnmower engines and patents relating to lawnmowers in general.[20] Both types of patents are included because some lawnmower manufacturers make their own engines. The results over the past 6-year period are shown in Figure 9.

[20] USTPO Web site, www.uspto.gov/patft/index.html

Figure 9. Lawnmower-Related Patents Issued 1996–2001



Source: USTPO Web site.

Figure 9 shows that over the last six years, lawnmower-related patents increased from 24 to 35 per year, then declined to 28. The number of engine-related patents increased from 3 to 6 per year. From 1996 to 1998, 11 patents were issued. The next three years, 1999 to 2001, saw 19 patents issued. Reasons for this increase could include new emissions regulations, which are discussed in following sections. The figures for 1999 to 2001 indicate a recent increase in the technology "supply" available to lawnmower engine manufacturers. That increase supports the observation that suppliers of new technology target applications toward industries with high technology demand and low supply. In this case, Extrude Hone (which developed the FCM technology for automotive applications) could apply the FCM technology in an industry (such as the lawnmower industry) with a demand for improved engine technology. This is an example of a new "crossover" application for a previously developed technology.

3.3 Research Joint Venture Indicator

The analysis of the number of RJVs in an industry is used to indicate the "supply" of innovation available to that industry. In this study we are concerned with the possible adoption of a specific technology (the FCM technology). All else being constant, the fewer the number of RJVs, the fewer the number of resulting technologies. It follows that fewer competing technologies enhance the likelihood of any one technology innovation being adopted. Specifically, given demand for technology, if there are few innovations, then a new innovation has a greater chance of adoption than if there were numerous innovations.

This section describes the source of the RJV data and the application of the RJV as an indicator of technology innovation supply to both lawnmower and airplane engine manufacturers. Then the likelihoods of technology adoption by the two different industries are compared.

RJV data were obtained from the Collaborative Research (CORE) database.[21] This database includes the SIC code of each RJV filing in the *Federal Register*, by date.[22] Up to two SIC codes (at the 2-digit level) are available for each joint venture. We constructed a whole count and a fractional count, following the procedure outlined in the section on patents. A whole count adds up each occurrence of an SIC code—i.e., a RJV reporting two SIC codes would be counted once in each classification. A fractional count adds only one-half to each SIC code when the RJV reports two classifications. Appendix C shows RJV formation for all manufacturing industries at the 2-digit SIC level.

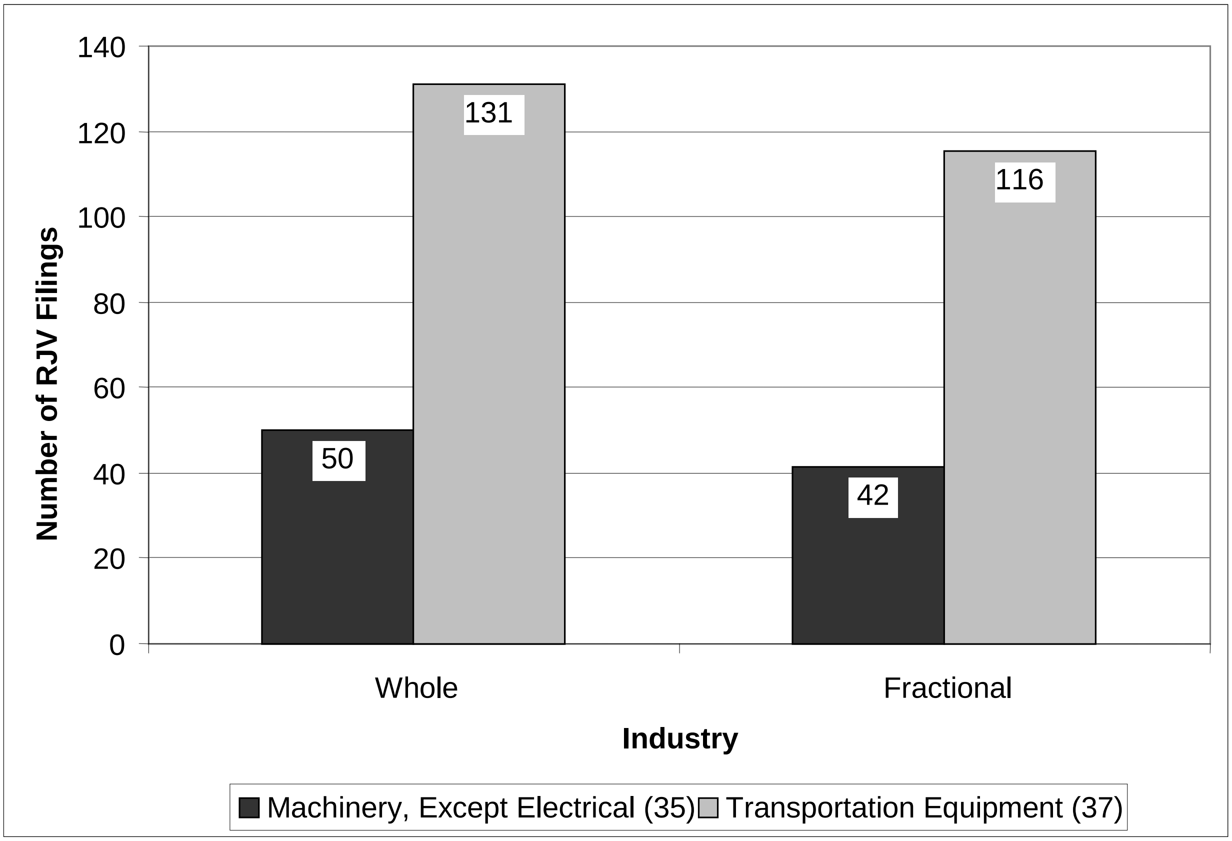
Lawnmower engines are included under SIC 35, "Machinery, Except Electrical." Aircraft engines are included under SIC 37, "Transportation Equipment." As shown in Figure 10, the RJV indicator reveals that SIC 35 (50 and 42) has substantially fewer RJVs than SIC 37 (131 and 116), using the whole and fractional RJV counting methods, respectively.

Given highly aggregated data at the 2-digit level, this information may not be directly applicable to narrow industries, such as lawnmower engines. Nevertheless, this TAI reveals that the industry that includes lawnmowers is comparatively underserved by RJVs. The RJV indicator therefore supports the selection of the lawnmower industry. More narrowly defined TAI data on RJV formation by lawnmower manufacturers could not be found, but future case studies may be able to utilize narrowly defined RJV data.

[21] Collaborative Research (CORE) database, 2001. The CORE database is funded by the National Science Foundation (NSF) and maintained by Dr. Albert Link of the University of North Carolina.

[22] The current CORE database contains 8,185 records, of which 763 report SIC codes. Unfortunately, identification of the target SIC code is not required by the *Federal Register*. The coding of each filing was done manually after the fact.

Figure 10. Number of RJV Filings, Whole and Fractional



Source: Collaborative Research (CORE) Database, 2001

3.4 Public Policy

Comparing government regulation across industries presents conceptual complexities. Public policy, such as government regulation, tends to have unique impacts and effects on industries. The impact of a regulation depends on, among other things, the type of regulation and its severity. Some regulations mandate changes in a currently marketed product, and they differ in the degree of change required in the product; other regulations effectively prohibit certain product innovations. Perhaps due to these conceptual hurdles, there is currently no broad attempt to measure regulation across industries. Regulation effects need to be examined on an industry-by-industry basis.

In this study, we found that the lawnmower manufacturers were constrained by pending Environmental Protection Agency (EPA) regulations intended to reduce small-engine emissions by 59% by 2007. The EPA Phase 1 and Phase 2 regulations are described in detail in Appendix A. The EPA expects that its regulations will cause all remaining side-valve (SV) engines used in lawnmowers to be converted to overhead-valve (OHV) engines. Some existing OHV engines used in lawnmowers will also require improvements to meet the standards. No pending regulations affecting technology adoption by aircraft engine manufacturers were identified.

In the above case, the EPA regulations will, by their design, strongly encourage small-engine manufacturers to make engine innovations and to adopt new emissions-reducing technologies, but it may not be clear in some cases what level of effort is required by the firms to meet the regulations. This illustrates the difficulties encountered when trying to make cross-industry comparisons of the effects of regulations on adoption. Many regulations, such as the above regulations on lawnmower emissions, contain text listing explicit goals mandated (e.g., number of lawnmowers with lowered emissions), providing the needed data for more detailed intra-industry analysis of the regulation's effect on technology adoption.

3.5 Historical Adoption Trends

The SCP model takes into account historical, industry-specific trends for all TAI measures, and includes the history of past technology adoption. There is no standardized way to account for past technology adoption across industries. Each analysis requires both specific interpretations of what constitutes technology adoption and time-trend data on those observable characteristics.

In the case of lawnmowers, EPA Phase 1 emissions regulations in effect as of 1997 led to the replacement of some SV engine configurations with cleaner OHV engine configurations. The market penetration of the more sophisticated engine technology—such as OHV engine configurations—may be used to proxy technology adoption.[23] The Power Systems Research OELink database (Power Systems Research 2001) provides data from 1992 to 1999 on engine kW rating, stroke, valve cam, valves per cylinder, cycle, cylinders, displacement, configuration, and torque, all of which are subject to technological improvement. We use these data to analyze technology adoption trends for the lawnmower engine industry.

Figure 11, using yearly production data from Power Systems Research, shows the decrease in SV engines and increase in OHV engines, and indicates that lawnmower manufacturers adopted OHV engine technology coincident with Phase 1 emissions regulations. It is likely that Phase 2 EPA regulations will have a similar effect, increasing the adoption of new engine technology.

3.6 Conclusion

On the whole, TAIs based on the structure-conduct-performance model show that lawnmower manufacturers are more likely than aircraft manufacturers to adopt the FCM technology spillover from the automotive industry. The broadly defined TAIs are summarized in Table 1, and the narrowly defined, industry-specific TAIs are summarized in Table 2.

[23] The technology adoption is likely due to new EPA regulations.

Table 1. Summary of Findings Using Broadly Defined TAIs

TAI Measure	Lawnmower Engines	Aircraft Engines
CR4 (Appendix D) and CR8	Not optimal size for adoption	Not optimal size for adoption
HHI	Optimal size for adoption	Not optimal size for adoption
Patents	Moderate level of patents indicates less competition; FCM adoption more likely	High level of patents indicates more competition; FCM adoption less likely
RJVs	Moderate level of RJVs indicates less competition; FCM adoption more likely	High level of RJVs indicates more competition; FCM adoption less likely
Public policy/regulations	No broad measure	No broad measure
History of technology adoption	No broad measure	No broad measure

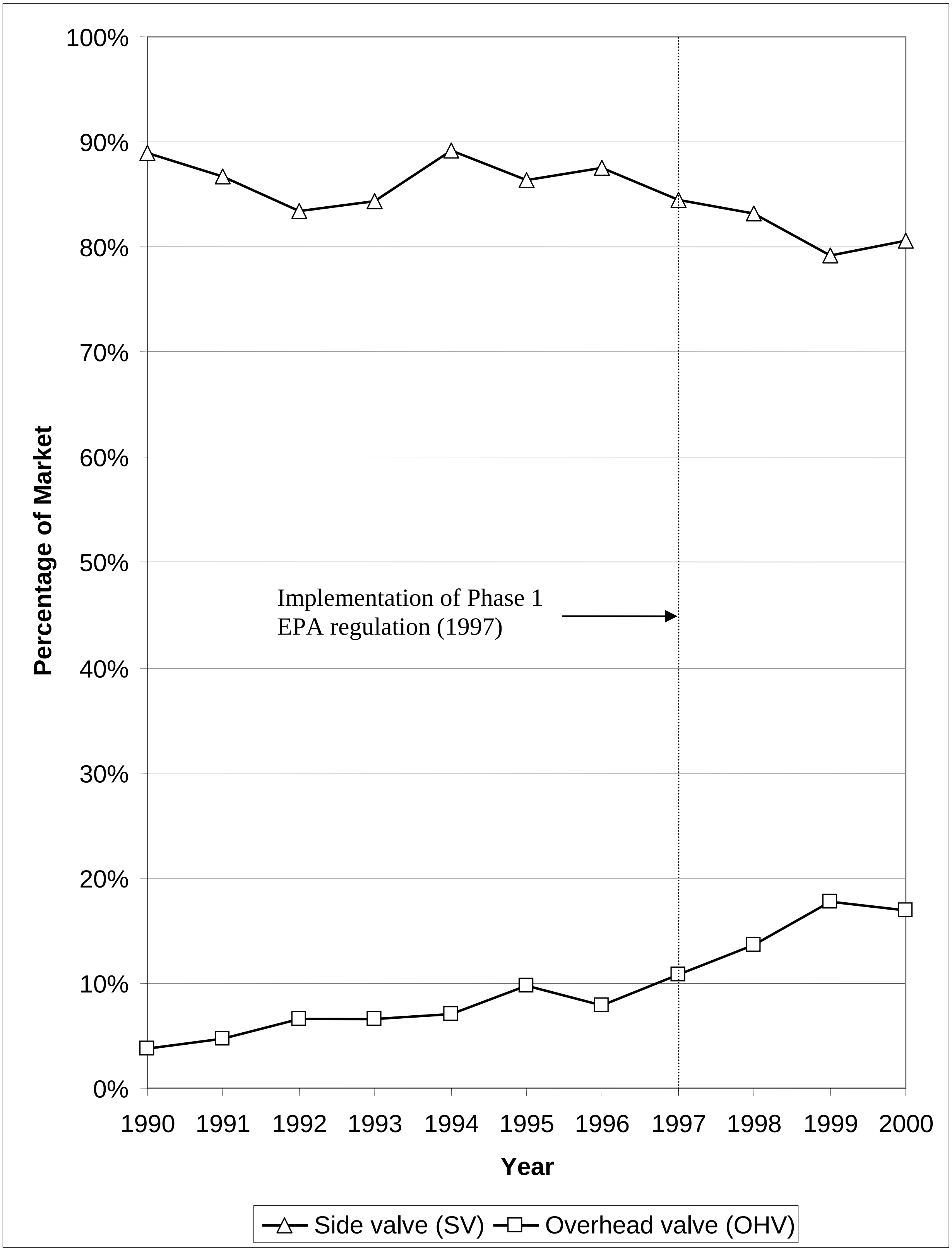
Table 2. Summary of Findings Using Narrowly Defined Data on Lawnmower Manufacturers

Measure	Lawnmower Engines
CR4 and CR8	Too concentrated to adopt
HHI	Optimal size for adoption
RJVs	No specific data
Patents	Recent slight increase indicates some adoption, probably due to regulation
Public policy/regulations	High likelihood of adoption due to major new regulation
History of technology adoption	Indicates some adoption, probably due to regulation

Overall, the TAI analysis suggests that the likelihood of adoption by the lawnmower industry is strong. The broadly defined market concentration indicators show a clear preference for the lawnmower manufacturing application over aircraft engine application. The narrowly defined lawnmower industry data show that, according to the four- and eight-firm concentration ratios, the lawnmower industry is too highly concentrated to adopt technology. However, the Herfindahl-Hirschman Index, which is a more comprehensive measure than the CR4 and CR8, supports technology adoption by the lawnmower industry. The broadly defined patent TAI supports the selection of either the lawnmower industry or the airplane engine industry. The broadly defined research joint venture TAI shows that the lawnmower industry was underserved by RJV formation, compared to the airplane industry, suggesting an opening for an external, new technology. The narrowly defined TAI data on patents, public policy, and historical technology adoption show that Environmental Protection Agency regulations are likely to encourage the lawnmower manufacturers to adopt new engine technology.[24]

[24] Regulations can drive an industry to adopt technology not previously targeted to that industry. The need to meet the emissions regulation required an evaluation of all engine technology innovations, including those originally targeted at automobile engines.

Figure 11. Side-Valve and Overhead-Valve Market Penetration, 1990 to 2000



Source: Power Systems Research (2001).

4. Case Study of the FCM Technology Applied to the Lawnmower Manufacturing Industry

Over 15 million gas-powered lawn and garden mowers, trimmers, and other tools are sold each year, about half of which are walk-behind and riding grass mowers. This equipment produces significant amounts of hydrocarbons (HC), including nonmethane hydrocarbons (NMHC),[25] which lead to ozone, the principal component of smog; oxides of nitrogen (NOx), which contribute to the production of acid rain; and carbon monoxide (CO), a colorless, odorless, and poisonous gas which affects infants and people with respiratory and heart problems.

Since 1990, the EPA has been attempting to decrease emissions from lawnmowers and other equipment that use small spark-ignition engines (SSIEs). Phase 1 regulations were implemented in 1997. The Phase 2 emissions limits are shown in Table 3. (Phase 1 emissions limits are not directly comparable to Phase 2 limits due to a change in testing methodology.)

Table 3. Emissions Limits under Phase 2 EPA Regulations

Engine Class	Emission Type	Emission Limit (g/kW·h)				
		2001	2002	2003	2004	2005 and later
I [A]	HC + NOx	-	-	16.1	16.1	16.1
	NMHC + NOx	-	-	14.8	14.8	14.8
	CO	-	-	610	610	610
II	HC + NOx	18.0	16.6	15.0	13.6	12.1
	NMHC + NOx	16.7	15.3	14.0	12.7	11.3
	CO	610	610	610	610	610

[A] Class I engine families initially produced on or after August 1, 2003, must meet the Phase II regulations when introduced. Preexisting engine families must meet Phase 2 regulations by August 1, 2007.

Source: Code of Federal Regulation.

The Extrude Hone Corporation identified lawnmower engines as an application of the FCM technology. The company conducted a series of tests of FCM technology on a stock OHV engine from a major manufacturer of lawn and garden equipment to assess whether FCM technology would bring a conventional engine into compliance with the EPA requirements for 2007. This engine has a 24 mm carburetor and is marketed as an 8.2 kW (11 horsepower, HP) lawn and garden engine. Three-way comparisons were made between the original engine, an engine that applied FCM to the carburetor (to enhance surface attributes, not to increase the size), and to an engine that applied FCM to the carburetor, intake pipe, and cylinder head. Extrude Hone's engineering tests confirmed that the FCM technology can meet Phase 2 emissions requirements.

[25] Small spark-ignition engines produce about 10% of U.S. mobile source HC emissions.

Extrude Hone engineers also provided detailed data on the costs of applying the FCM technology to the full range of lawnmower engines. These tests show FCM could reduce emissions competitively with the conventional technologies evaluated by the EPA.

In this section we investigate the economic feasibility of lawnmower engine manufacturers using the FCM technology to meet the new EPA regulations. We did this by computing and comparing cost data. Then we present the results of a comparative economic impact analysis of this new technology versus the conventional technologies evaluated by EPA, by using the cost data in a dynamic macroeconomic model of the U.S. economy.

4.1 Fixed and Variable Costs of Meeting Phase 2 Regulations Using Conventional Technology Compared to FCM Technology

The FCM technology is a newly available option for decreasing emissions to Phase 2 levels. To assess its feasibility and potential benefit over other options, we compare the cost of using FCM to the cost of using conventional technology. The EPA's analysis of costs of bringing conventional equipment in compliance, using incremental improvements in existing technology, are reported in *Phase 2: Emissions Standards for New Nonroad Nonhandheld Spark-Ignition Engines At or Below 19 Kilowatts* (EPA 1999). Cost analyses from this report are then compared with estimates prepared by Extrude Hone engineers of the cost of implementing the new FCM technology in existing conventional equipment.

The lawnmower engine industry consists of four market segments, each of which we subjected to a separate comparative analysis. The market segments are defined by two engine sizes and two engine technologies. Engine size is measured by cylinder displacement volume measured in cubic centimeters (cc).[26] Small engines, those below 225 cc of displacement, are called "Class I." Larger engines, those with displacement greater than or equal to 225 cc, are called "Class II." The two engine technologies are side-valve (SV), and overhead-valve (OHV). Side valve engines are defined in the *Code of Federal Regulations* (GPO 2000) as a ". . . four-stroke engine in which the intake and exhaust valves are located to the side of the cylinder, not within the cylinder head . . ." Overhead-valve engines are defined in the *Code of Federal Regulations* as a ". . . four-stroke engine in which the intake and exhaust valves are located above the combustion chamber within the cylinder head. . . ."

The EPA report indicated that engine manufacturers would likely meet the Phase 2 emissions standards largely by changing their engine technology in one of two ways. First, Class I and II SV engines would be replaced by improved OHV engines.[27] Second, existing Class I and II OHV engines would be improved through better piston rings, intake, and combustion. The EPA analysis provided cost estimates of SV and OHV changes and the numbers of engines and engine families to which they would be applied.

The four market segments are referred to in this report as segments A, B, C, and D. Market segment A consists of Class I SV engines. In the EPA analysis, to meet Phase 2 using

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[26] Throughout this report, the abbreviation "cc" is used to denote cubic centimeters (cm^3). The use of "cc" is standard industry practice when measuring the displacement of engines, and is therefore followed in this report.
[27] Vaporizing carburetion could be used to improve side-valve engine technology, but it has found limited use.

conventional technology, the SV engine would be converted to an OHV engine.[28] Market segment B consists of Class I OHV engines. In the EPA analysis, to meet Phase 2 using conventional technology, the OHV engine would be improved. While there are many conventional technologies that may be used to improve the OHV engine, the EPA report bases its analysis on "piston and piston ring improvements," and "improved combustion and intake system." Market segment C consists of Class II SV engines. In the EPA analysis, to meet Phase 2 using conventional technology, the SV engine would be converted to an OHV engine. Market segment D consists of Class II OHV engines. To meet Phase 2 using conventional technology, the EPA assumes that the combustion and intake system, pistons, and piston rings would be incrementally improved. For our analysis, the FCM technology is compared with the conventional technology.

The EPA report assumes that, within a market segment, there is no variation in the application of technology to meet the EPA Phase 2 regulation across the segment. In other words, all affected SV engines adopt the same conventional technology (conversion to OHV). Similarly, all affected OHV engines adopt the same conventional technology (piston and piston ring improvements, and improved combustion and intake system). Our report similarly assumes that there will not be a mix of conventional and new (FCM) technology applied within a market segment, but rather full adoption of FCM or full adoption of conventional technology.

The fixed and variable costs of each scenario—the use of the EPA-assumed conventional technology, and the adoption of the FCM technology—are shown in Tables 4 and 5.

Table 4. Unit Costs of Meeting Phase 2 Standards Using Conventional Technology, in 2002 Dollars

	(1)	(2)	(3) = (1) ÷ (2)	(4)
	Fixed Cost ($1,000's/family)	Average engines/family	**Fixed Cost ($/engine)**	**Variable Cost ($/engine)**
Class I:				
A. SV to improved OHV	18,276	634,105	**28.82**	**14.91**
B. OHV to improved OHV	659	47,676	**13.83**	**2.45**
Class II:				
C. SV to improved OHV	20,096	45,244	**444.16**	**23.98**
D. OHV to improved OHV	659	90,625	**7.28**	**2.45**

Source: EPA (1999).

The variable costs shown in column 4 of Table 4 are taken from the EPA report and converted to 2002 dollars. The fixed costs in column 3 of Table 4 are derived from information in the EPA report, as summarized in columns 1 and 2. Column 1 shows the lump-sum fixed cost to convert an entire engine "family" (line of similar engines) into compliance with Phase 2 standards. Column 2, the average number of engines per family, is computed by dividing the total number of engines by the total number of engine families, both of which are contained in the EPA report.

[28] The SV engine is converted to an OHV engine, which incorporates necessary improvements to meet Phase 2. It is identical to the "improved OHV" in market segments B and D.

Fixed cost in column 3 is derived by dividing the fixed cost per family (column 1) by average engines per family (column 2).

The variable and fixed costs of using FCM technology on the same quantity of lawnmower engines, based on data provided by Extrude Hone engineers, are shown in Table 5. Extrude Hone provided cost estimates for meeting the EPA regulations on both OHV and SV engines.

Table 5. Unit Costs of Meeting Phase 2 Standards Using FCM Technology, in 2002 Dollars

	(1) Fixed Cost ($/cell)	(2) Engines/cell	(3) = (1) ÷ (2) **Fixed Cost ($/engine)**	(4) **Variable Cost ($/engine)**
Class I:				
A. SV using FCM	310,000	37,406	**8.29**	**17.50**
B. OHV using FCM	309,000	49,875	**6.20**	**14.00**
Class II:				
C. SV using FCM	310,000	37,406	**8.29**	**17.50**
D. OHV using FCM	309,000	49,875	**6.20**	**14.00**

Source: Extrude Hone.

The basis for the Extrude Hone cost estimates is a single production cell, consisting of a single FCM machine and its associated equipment (such as electrical connections and mounts for lawnmower engines), operating on the cylinder head of a lawnmower engine. The base price of a single FCM machine is $300,000. Estimates of installation cost ranged from $8,000 to $10,000. For this report, the midpoint value of $9,000 was used. The total fixed cost per FCM machine, set up for OHV engines, is estimated to be $309,000. Fixed cost for an FCM machine set up for SV engines requires a more complex clamp estimated to cost an additional $1,000. The fixed cost for the FCM machine set up for SV engines is $310,000.

The fixed cost per FCM machine for each type of engine is summarized in column (1) of Table 5. Each FCM machine can process 37,406 SV engines or 49,875 OHV engines per year. These yearly production capacities are shown in column (2). Fixed cost in column (3) is derived by dividing the fixed cost per machine (column 1) by the number of engines that can be processed per machine (column 2). Extrude Hone also estimates that variable costs incorporated expected efficiency improvements in material handling, quality control, cleaners, supervisors, operators, and infrastructure. Variable costs are summarized in column (4) of Table 5.

4.2 Total Cost Per Year of Using Conventional Technology Compared to FCM Technology

In this section we show the total costs to the industry of the Extrude Hone FCM process when compared with the conventional costs of meeting the EPA Phase 2 regulations, as estimated by the EPA. The total industry cost estimates are phased in according to the timing of the phased-in compliance with the regulations. The EPA Phase 2 regulation holds Class I and Class II engines to different standards, implemented in different years. Class I engines are analyzed over the years 2007 to 2009, and Class II engines are analyzed over the years 2002 to 2007.

Using the EPA market assumptions regarding the number of affected engines and the number of affected engine families, year-by-year cost estimates (shown in Tables 6 and 7) were developed.[29] These total industry costs were derived by summing two components, the total industry variable cost and the total industry fixed cost. The unit variable cost is multiplied by the total production of compliant engines manufactured, by year. Fixed costs are incurred only in the year in which an engine family needs to be modified to meet Phase 2 requirements. The fixed cost per family (column 1 Table 4) is multiplied by the total number of engine families that are converted to meet the Phase 2 emissions requirements, by year.

Using this method, we developed time paths of industry costs, shown in Tables 6 and 7. In market segments A and B (Class I), the time path is from 2007 to 2009. All Class I engines were assumed to be converted in 2007, incurring both fixed costs and variable costs. Two additional years (2008 to 2009) of variable costs were included to show the ongoing costs of production. In market segments C and D (Class II), the time path is from 2002 to 2007. All Class II engines were converted over the period between 2002 to 2005, according to the phase-in requirements of the regulation. Two additional years (2006 to 2007) of variable costs were included to show the ongoing costs of production. These schedules of yearly industry costs were used as inputs in a macroeconomic model.

[29] The EPA used estimates provided by Jack Faucett Associates in *Small Nonroad Engine and Equipment Industry Study* (December 1992).

Table 6. Total Industry Cost of Meeting Phase 2 Standards Using Conventional Technology Compared to FCM Technology in Class I, in Thousands of 2002 Dollars

	Market Segment A: Class I SV		Market Segment B: Class I OHV	
	Conventional technology	FCM technology	Conventional technology	FCM technology
2007	$305,022	$179,871	$6,210	$7,703
2008	103,988	122,065	935	5,340
2009	103,988	122,065	935	5,340

Source: EPA (1999) and Extrude Hone Corporation.

Table 7. Total Industry Cost of Meeting Phase 2 Standards Using Conventional Technology Compared to FCM Technology in Class II, in Thousands of 2002 Dollars

	Market Segment C: Class II SV		Market Segment D: Class II OHV	
	Conventional technology	FCM technology	Conventional technology	FCM technology
2002	0	0	882	1,830
2003	63,542	3,500	222	1,269
2004	130,338	9,376	1,104	3,099
2005	306,290	23,460	2,208	6,198
2006	24,949	18,211	889	5,075
2007	24,949	18,211	889	5,075

Source: EPA (1999) and Extrude Hone Corporation.

The schedules of yearly industry costs for the conventional and FCM technology applied to the four market segments are shown graphically in Figures 12 to 15.

In market segment A (Class I SV), the FCM technology is significantly less expensive than the conventional technology in 2007. As shown in Tables 4 and 5, fixed costs are concentrated in that year, and the FCM technology has lower fixed costs. However, the FCM technology has slightly higher variable cost on an ongoing basis. It is possible that the lower cost in 2007 might make FCM attractive to lawnmower manufacturers.

In market segment B (Class I OHV), the FCM technology is always more expensive than the conventional technology.

In market segment C (Class II SV) the FCM technology is always the lower cost option compared to the conventional technology. This is because, as we have already shown in Tables 4 and 5, both the fixed costs and the ongoing variable costs of the FCM technology are lower compared to the conventional technology.

Lastly, in market segment D (Class II OHV) the FCM technology is always more expensive than the conventional technology.

The biggest cost savings from the FCM technology comes when it is applied to SV engines (in market segments A and C) that would otherwise have to be converted to OHV engines (other things being equal). Market segment C will definitely benefit from meeting Phase 2 regulations with the FCM technology. Additionally, market segment A might benefit from meeting Phase 2 regulations with the FCM technology, given its lower fixed costs in 2007. We conducted a macroeconomic impact analysis for these two market segments: A (Class I SV) and C (Class II SV) to quantify the economic impact to the nation of using the FCM technology on lawnmower engines rather than the conventional technology assumed by the EPA to meet Phase 2 regulations.

Figure 12. Market A: Class I SV Costs

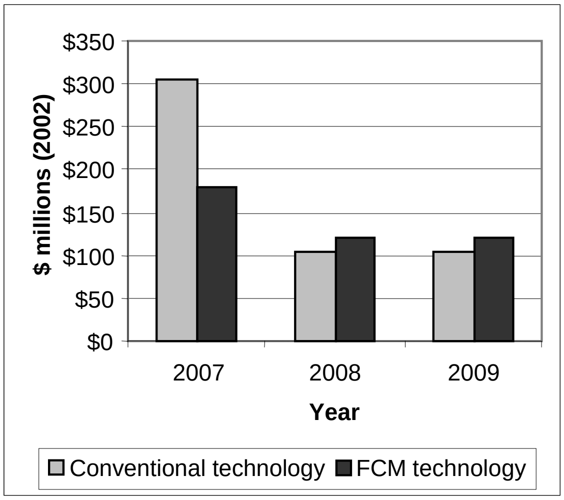


Figure 13. Market B: Class I OHV Costs

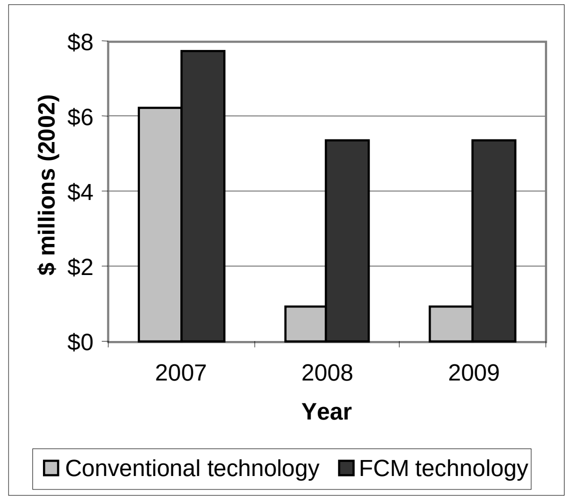


Figure 14. Market C: Class II SV Costs

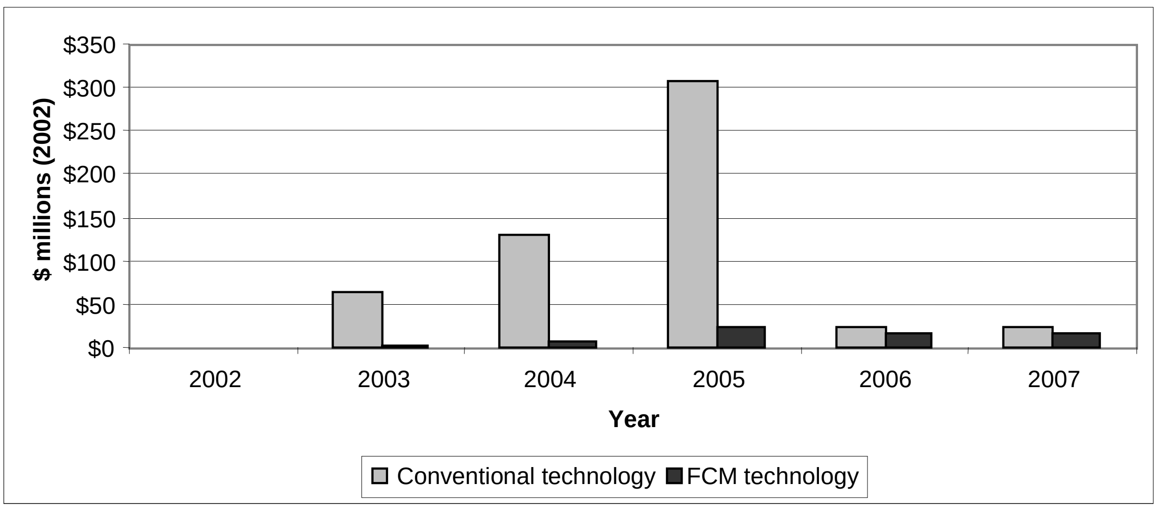
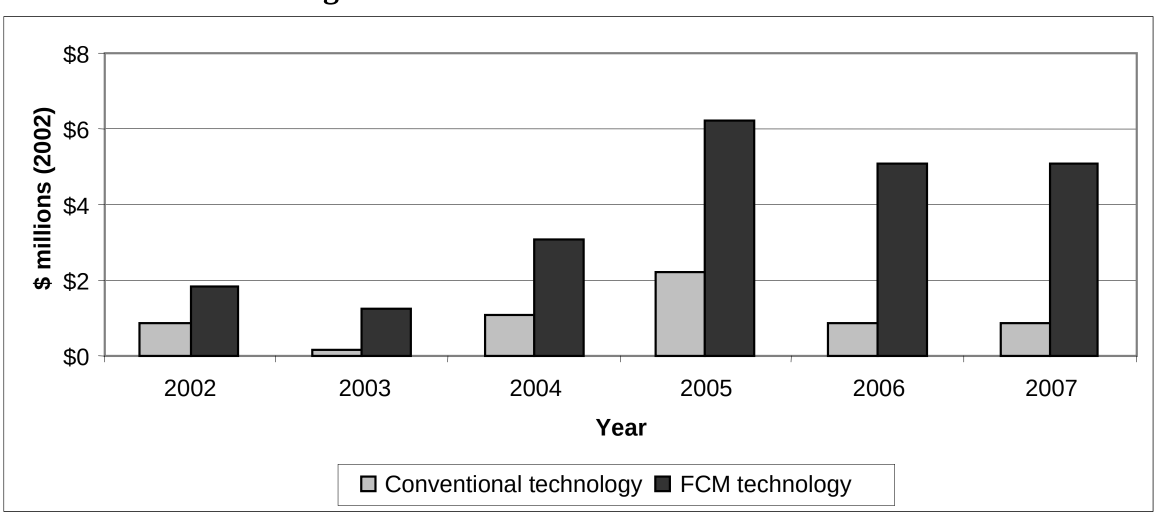


Figure 15. Market D: Class II OHV Costs



4.3 Introduction to the REMI *Policy Insight* Macroeconomic Impact Model

Several macroeconomic models are available for simulating the total national economic impact of changes to specific industries (in our case, the lawnmower engine industry).[30] We used the REMI *Policy Insight* model of the U.S. economy because of its ability to handle a series of nonuniform economic shocks.[31]

The REMI model was developed for analysts who need to estimate the impact of economic changes in the U.S. economy. In general, the model computes the total effect over time on all sectors of the U.S. economy resulting from a change to one or more sectors of the U.S. economy. The model is based on economic theory, input-output (I/O) accounting, and econometrically-estimated, time-dependent relationships between components of the economy.

As summarized in Figures 12–15, fixed and variable costs of production will increase for all four market segments (A through D). Use of either the conventional technology or the FCM technology to meet the emissions requirements of the Phase 2 EPA regulations will increase the production costs of lawnmower engine manufacturers. In market segments A and C, use of the FCM technology will increase costs less than the conventional technologies (SV-to-OHV conversions and OHV improvements) and therefore can be considered economically viable for adoption by these segments, but not segments B and D.[32] We therefore focused our REMI analysis on market segments A and C. We estimated the total industry production cost increase from each technology for market segments A and C, used REMI to estimate the direct and indirect impacts of each segment on the national economy, and compared the impacts.

The simulation performed with REMI indicates that an increase in production costs in the lawnmower industry will cause an increase in the selling price of lawnmowers. This will cause a decrease in the number of units sold. As production costs rise, firms that seek to maintain current profit levels must increase their selling prices and/or reduce other production costs, including the costs of labor and capital (machinery). Decreased sales and cost cutting reduces employment in the industry and in industries that supply parts and services to it, thereby reducing aggregate income and the broad set of purchases this income supports (such as for purchasing cars, homes, services, and travel).

Although REMI models the impacts for dozens of national economic impact variables, we selected three of the most comprehensive measures for this report: GDP, change in national employment, and change in personal income. GDP measures the value produced by labor and capital (such as machinery), and is computed as the sum of all sales of goods and services

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[30] These include the REMI *Policy Insight* (Regional Economic Modeling, Inc., Amherst, MA), the DRI*WEFA Macroeconomic Model (Global Insight, Waltham, MA), and IMPLAN (Minnesota IMPLAN Group, Stillwater, MN).
[31] Using REMI, we were able to use discrete production cost increases in specific years within a single forecast.
[32] If the EPA were to implement a "Phase 3" regulation on small nonroad, nonhandheld engines, this conclusion could change.

produced in the country minus material costs.[33] For example, the GDP of just the lawnmower engine industry would be the sum of all lawnmower engine sales minus the cost of the parts used to produce the engines. What remains is the cost of the labor and capital used to produce the engines; these "returns" to labor and capital are the measure of the contribution of the lawnmower engine industry to GDP. Change in national employment is the change in the total number of people employed in the country, and change in personal income is the change in income received by the employed.

4.4 Macroeconomic Impact of the Costs of Conventional Technology Compared to FCM Technology, in Market Segments A and C

In this subsection we compare the macroeconomic impacts of using conventional technology versus the FCM technology, and present the impacts on GDP, national employment, and personal income.[34] Detailed year-by-year graphs are in Appendix D.

As a result of the EPA regulation, GDP, employment, and personal income will fall. In each market segment, we estimated the economic impact of using the FCM technology, and the impact of using conventional technology. For two market segments, A and C, the decrease in GDP is smaller with FCM technology than with conventional technology. For ease of interpretation, we illustrate the difference in the reductions in GDP or personal income from using the FCM technology instead of the conventional technology in markets A and C as a savings in GDP or personal income.

Figure 16 shows that, in market segment A over the analysis period 2007 to 2009, the FCM technology saved $262 million in GDP. In market segment C, over the analysis period 2003 to 2007, the FCM technology saved $982 million in GDP.

Figure 17 shows that, in market segment A over the analysis period 2007 to 2009, the FCM technology saved $243 million in personal income. In market segment C, over the analysis period 2003 to 2007, the FCM technology saved $879 million in personal income.

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[33] The Bureau of Economic Analysis (BEA) defines GDP as "the output of goods and services produced by labor and property located in the United States" (www.bea.gov). Sales, in contrast to GDP, is not a measure of everything actually created in this country.

[34] It is important to note that although we are considering only costs of the EPA Phase 2 regulation by two approaches, our analysis represents a full benefit-cost analysis. Both the conventional and the FCM technologies perform similarly regarding reductions in pollution and fuel consumption. In this case study, we are comparing the impact of the two technologies that meet the same objectives. Therefore, we do not offset the economic costs by the benefits (pollution reduction and fuel savings). The negative economic impacts on GDP, employment, and personal income of the conventional and the FCM technologies are estimated and compared in this study. We provide an estimate of the impact of each and net impact of one choice versus the other, represented as cost savings.

Figure 16. Savings in GDP from Using the FCM Technology Instead of the EPA-assumed Conventional Technology to Meet Phase 2 Regulations, in Market Segments A and C

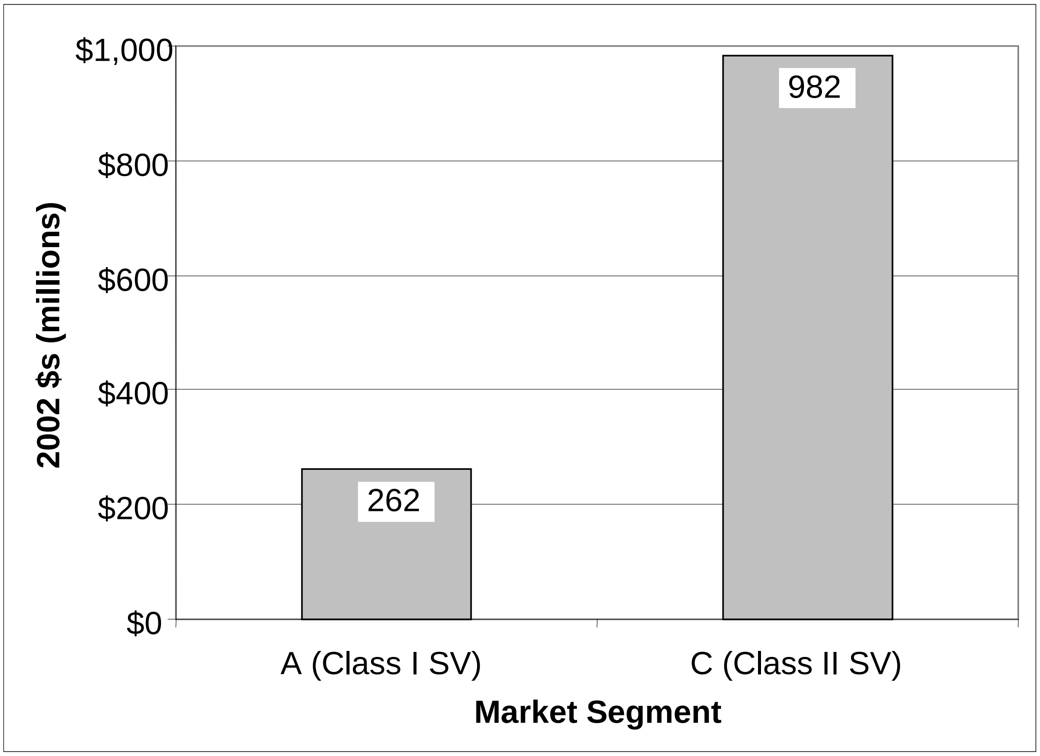
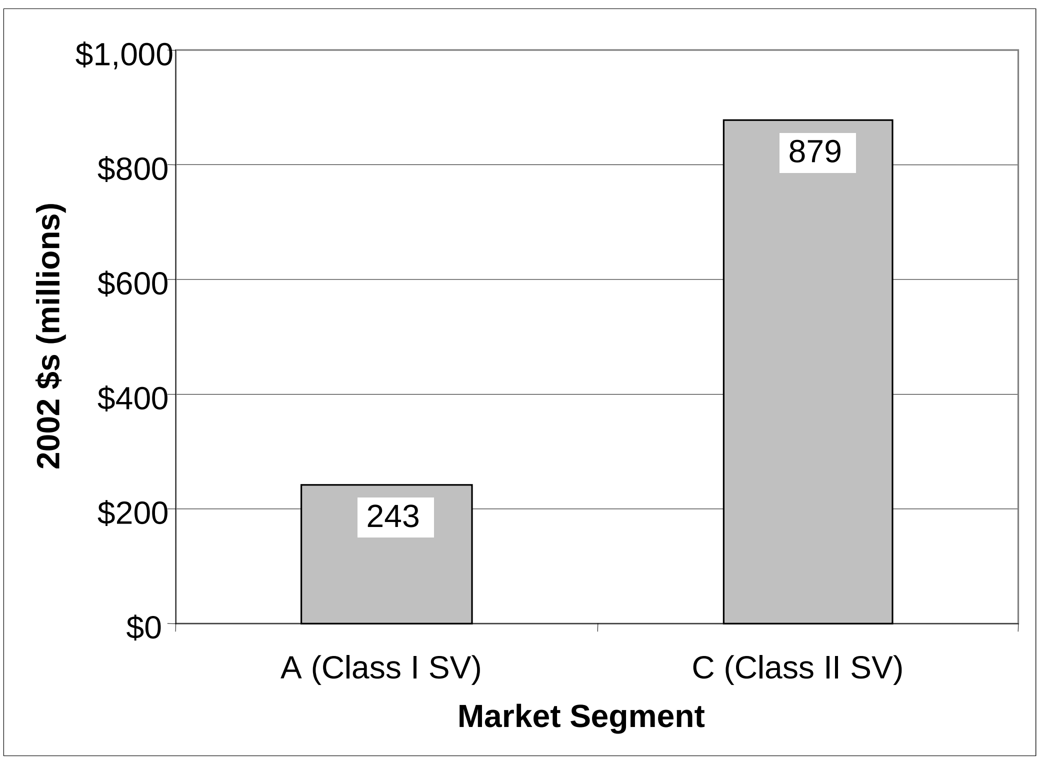


Figure 17. Savings in Personal Income from Using the FCM Technology Instead of the EPA-assumed Conventional Technology to Meet Phase 2 Regulations, in Market Segments A and C



Section 5. Summary and Conclusions

An economic case study of the potential adoption of the Flow-Control Machining (FCM) technology in lawnmower engines was used to develop and demonstrate the use of technology adoption indicators (TAIs). Extrude Hone, the developer of the FCM technology, initially identified lawnmower engines and aircraft engines as two potential uses of the FCM technology. The TAIs were developed to facilitate a systematic comparison of the likelihood for technology adoption in each industry.

5.1 Development and Interpretation of the TAIs from the SCP Model

The SCP framework guided the development of the TAIs. The framework asserts (and supports through extensive research) that the structure of a market (e.g., the number of buyers and sellers) influences the conduct of firms in that market, which ultimately determines the market price, quantity, and other performance attributes. In addition (and as it turns out, crucial to our assessment of the lawnmower industry), government regulations and more generally public policy can affect the structure or conduct of the market. Public policy and regulations belong in the standard set of TAIs, but require customized development from specific information about the industry of interest. We recommend that any study of a particular industry's likelihood to adopt should include an assessment of current government regulations affecting that specific industry.

The broadly defined—using 4-digit SIC and 6-digit NAICS industry classifications—TAIs of industry concentration (CR4, CR8, and HHI), as well as patents and RJVs, were used to compare the likelihood of technology adoption in two industries: the small engine and airplane engine industries. (The four- and eight-firm concentration ratios, along with the Herfindahl-Hirschman Index, were introduced in 2.1.)

For lawnmower manufacturers, almost all the measures (including the narrowly defined public policy information specific to the lawnmower industry) support the conclusion that the lawnmower industry is likely to be more receptive than the aircraft engine industry to new technology. (The broadly defined CR4 and CR8 are unable to support the selection of either industry.)

We extended the case study analysis based on the broadly defined TAIs to narrowly defined TAIs using data specific to the lawnmower industry. The CR4, CR8, and HHI were calculated based on private data available specifically for the lawnmower engine industry. The patent measure was calculated manually using searches of the USPTO database. Specific instances of regulations and the history of technology adoption in the lawnmower industry were also analyzed.

The narrowly defined lawnmower industry data show that, according to the CR4 and CR8, the lawnmower industry is too highly concentrated to adopt technology. The HHI, a more comprehensive measure of concentration, supports technology adoption by the lawnmower industry. The narrowly defined TAI data on patents per the HHI measure, public policy, and historical technology adoption show that the lawnmower industry should be receptive to new engine technology. The EPA regulations are likely to provide a market pull.

5.2 Economic Analysis of the FCM Technology

We assessed the economic benefits from using the FCM technology by estimating the national economic impacts of using the conventional emissions-reducing technologies assumed by the EPA, or alternatively the FCM technology, and then comparing the two. Four lawnmower engine market segments, determined by engine displacement volume (Class I and Class II) and engine technology (SV and OHV) were identified.

In each market segment, we estimated the cost increase from using conventional technology to meet emissions requirements. Over the period of analysis, the cost of the FCM technology was somewhat lower in market segment A, Class I SV engines, and significantly lower in market segment C, Class II SV engines. We extended our analysis to national economic impacts for those two segments where FCM appeared cost competitive with the conventional technology.

We modeled the national economic effects of use in market segments A and C using the REMI macroeconomic model of the U.S. economy. For both the conventional technology and the FCM technology, the additional production costs cause lawnmower engine sales prices to rise, GDP and sales to decrease, employment in affected industries to decrease, and total personal income to decrease, but these effects are greater for the conventional technology.

In market segment A (Class I SV engines), the FCM technology has significantly lower initial fixed cost but slightly higher variable cost than the conventional alternative. The reductions in GDP, employment, and income initially are quite a bit smaller for the FCM technology compared to the conventional technology. Using the FCM technology rather than the conventional technology saves $261 million in GDP over the three years 2007 to 2009, and saves $244 million in personal income.

In market segment C (Class II SV engines), the FCM technology exhibits lower fixed and variable costs of production. The FCM technology is cost advantageous for market segment C and results in significant savings in GDP, employment, and personal income. Overall, the FCM technology saves 93% of GDP, employment, and personal income that would have been lost by using the conventional technology. Using the FCM technology rather than the conventional technology saves $982 million in GDP and $878 million in personal income over the five years 2003 to 2007. The advantage of the FCM technology in market segment C is obvious.

5.3 Application of TAIs

The TAIs are a useful framework for assessing whether a particular industry will adopt new technologies.[35] There are widespread differences across U.S. industries in size and distribution

[35] We envision the TAI framework to be useful guidance in a methodological investigation of industry characteristics affecting technology adoption. In this case study the public policy TAI, in the form of an EPA regulation, turned out to be a decisive factor indicating the adoption of the FCM technology. Other case studies may not have such a decisive factor.

of firms, in patents, in research joint ventures, and in the use of new technologies. Increased understanding of the relationships between these variables will help ATP encourage research proposals from those sectors of the economy that are likely—or have the potential—to adopt new technology, and assess the potential economic impact of the proposed projects. There are four uses of the TAIs. First, they can be used to identify promising case studies for project evaluation. Second, the TAIs offer a consistent and effective methodology for conducting prospective case studies of economic benefits of ATP projects. Third, the TAIs can assist in evaluating business plans of ATP proposers. Fourth, the TAIs can be used to advise ATP awardees on which industries are more likely potential adopters of their technologies.

The TAI methodology provided valuable insight into industry characteristics affecting technology adoption, and, after the analysis of all TAI measures for the two industries, leads us to conclude that the lawnmower industry exhibits the stronger case for likely adoption of the FCM technology. Analysis of the potential impact of the FCM technology using the REMI Policy Insight macroeconomic model suggests substantial benefits to the U.S. economy.

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Appendix A
EPA Phase 1 and Phase 2 Regulations on Nonroad Nonhandheld Small Engines

Under the Clean Air Act (1990), the Environmental Protection Agency was directed to study and regulate the emissions of nonroad engines (engines used in vehicles not driven on roadways). The EPA found that nonroad engines contributed significantly to pollution, emitting nitrogen oxides (NOx), hydrocarbons (HC), nonmethane hydrocarbons (NMHC), carbon monoxide (CO), and particulate matter (PM). Subsequently, under Phase 1 in 1997, lower emissions were required for new nonroad engines less than 19 kW (25 HP). In March 1999, the EPA finalized Phase 2 emissions standards for new nonroad non-handheld spark-ignition engines at or below 19 kW that phase in between 2001 and 2007.[36] The Phase 2 emissions standards also addressed handheld engines (such as those used in leaf blowers and lawn-and-garden-type trimmers and edgers). The EPA plans to propose regulations for nonroad engines in recreational uses as well as nonroad engines larger than 19 kW (25 HP) in 2001.

The Phase 2 emissions limits are defined by engine displacement class. Displacement categories, measured in cubic centimeters (cc) for engine classes I and II, are shown in Table 8.[37] Most walk-behind lawnmowers use engines that fall into engine Class I, and the remaining larger mowers fall in engine Class II.

Table 8. Definitions of Engine Class I and II

Engine Class	Displacement is greater than or equal to . . . (in cubic centimeters, cc)	. . . and displacement is less than (in cubic centimeters, cc)
I	100	225
II	225	no limit

Source: Code of Federal Regulations (GPO 2000).

In 1997, Phase 1 emissions standards addressed the total hydrocarbons and oxides of nitrogen (HC + NOx) exhaust emissions in engine classes I and II. Phase 1 standards were applied to a newly manufactured engine. New Class I engines were allowed to emit up to 16.1 g/kW·h of HC + NOx, measured at a steady state. Class II engines were allowed to emit up to 13.4 g/kW·h or HC + NOx, measured at a steady state. Classes I and II were not to exceed carbon monoxide (CO) emissions of 519 g/kW·h.

[36] The March 1999 Phase 2 emissions standards are detailed in the *Code of Federal Regulations Title 40: Protection of Environment Volume 14,* which includes *Section I: Environmental Protection Agency, Part 90,* "Control of emissions from nonroad spark-ignition engines," dated July 1, 2000 (GPO 2000). Part 90 has 13 subparts, A through M, that address different aspects of the regulation. The sections numbered 90.1 through 90.7 fall under subpart A, those numbered 90.103 through 90.126 fall under subpart B, numbers 90.201 through 90.220 under subpart C, and so on, culminating with subpart M, containing sections 90.1201 through 90.1249. Part 90, in its entirety, requires 129 pages in the Federal Register (pages 166 to 294 in Title 40 Volume 14).

[37] Throughout this report, the abbreviation "cc" is used to denote cubic centimeters (cm^3). The use of "cc" is standard industry practice when measuring the displacement of engines, and is therefore followed in this report.

Phase 2 regulations added new emissions test limits using a new test method. Tests are to be done after the engine's service accumulation period (based on the engine's useful life) so that emissions are stabilized. Engine Class I was subject to Phase 2 regulations in 2003 and 2007, as shown in Table 9. Limits on emissions of nonmethane hydrocarbons plus oxides of nitrogen (NMHC + NOx) are applied only to engines fueled by natural gas, and take the place of the limits on HC + NOx emissions. Regulations on Class II engines were phased in from 2001 to 2005, as shown in Table 10.

Table 9. Phase 2 (1999) Emissions Regulations for Engine Class I

Engine Class	HC+NOx	NMHC+NOx	CO	Effective Date
I	16.1 g/kW·h	14.8 g/kW·h	610 g/kW·h	2003 or 2007 [A]
[A] Engine families initially produced on or after August 1, 2003, must meet the Phase 2 regulations when introduced. Pre-existing engine families must meet Phase 2 regulations by August 1, 2007.				

Source: Code of Federal Regulations (GPO 2000).

Table 10. Phase 2 (1999) Emissions Regulations for Engine Class II

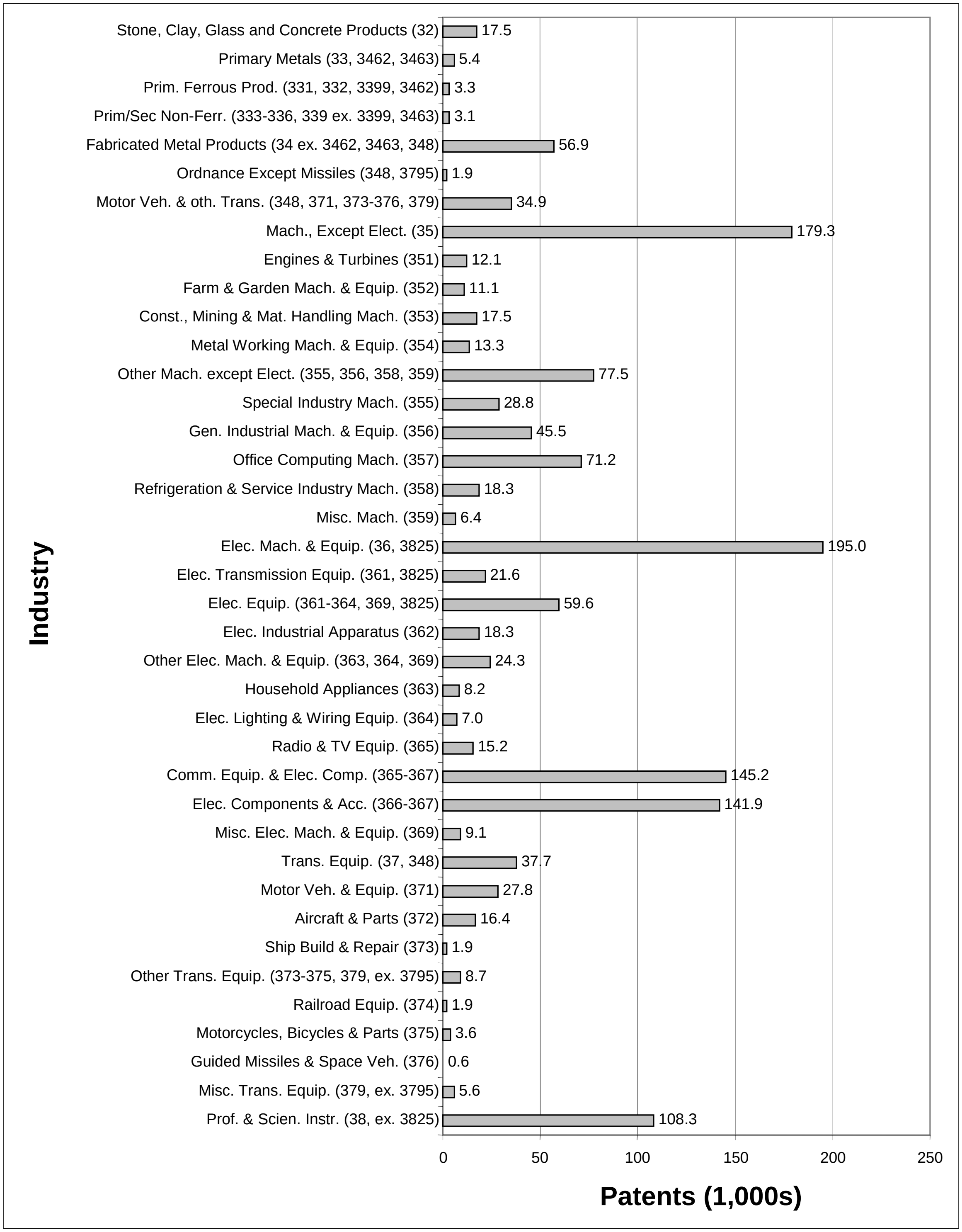
Engine Class	Emission Requirement	2001	2002	2003	2004	2005 and later
II	HC + NOx	18.0	16.6	15.0	13.6	12.1
	NMHC + NOx	16.7	15.3	14.0	12.7	11.3
	CO	610	610	610	610	610

Source: Code of Federal Regulations (GPO 2000).

In their Phase 2 economic analysis, the EPA proceeded under the assumption that SV engines would be converted to OHV engines. At the time of the report, manufacturers did not indicate to the EPA that there existed any conventional technology that could be applied to SV engines to reduce their emissions to Phase 2 levels. Some existing OHV engine families also required improvements to meet Phase 2.

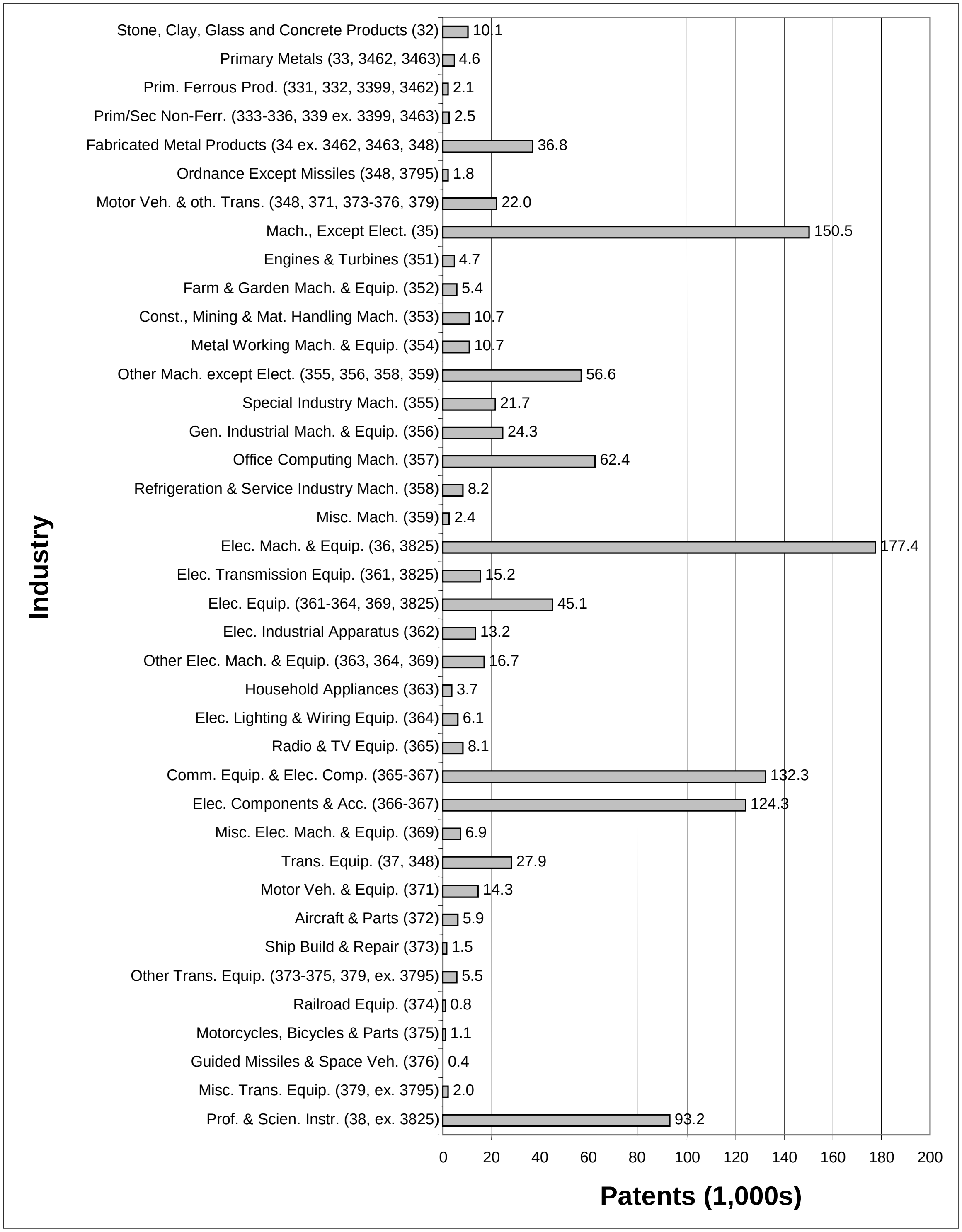
Appendix B
Patents Issued by SIC Code

Figure 16. Thousands of Patents Issued (Whole Count) for 1996 to 2000, by SIC Code



Source: USTPO (2001).

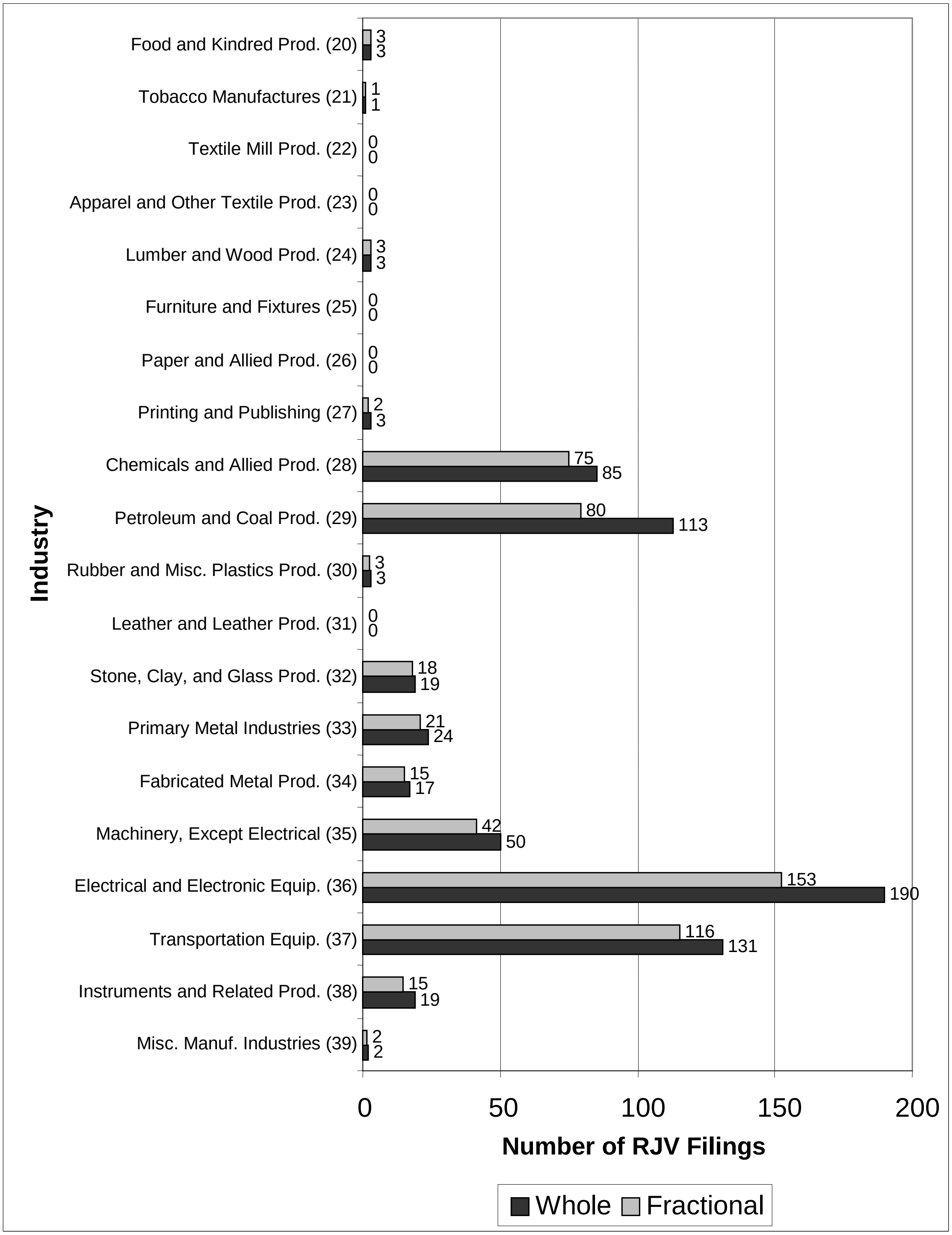
Figure 17. Thousands of Patents Issued (Fractional Count) for 1996 to 2000, by SIC Code



Source: USTPO (2001).

Appendix C
Research Joint Ventures by SIC Code

Figure 18. Research Joint Venture Filings, by SIC Code



Source: CORE Database, 2000.

Appendix D
REMI Forecast Detail

In Figure 19, the first bar in year 2007 shows that the conventional technology would reduce GDP by $1,120 million. The second bar shows that the FCM technology would reduce GDP by $660 million. Therefore, in market segment A, the FCM technology would save $460 million (= 1,120 – 660), or would reduce the cost of meeting the regulation by 40% in terms of GDP compared with the conventional technology in 2007, the first year of analysis. Figure 20 shows the estimated reductions in employment. Using the FCM technology would save 5,826 jobs in 2007 (jobs saved cannot be combined between years). Figure 21 shows the estimated reductions in personal income. Using the FCM technology would save $356 million in personal income in 2007. Over the analysis period (2007 to 2009), total savings would be $261 million in GDP and $244 million in personal income.

Figure 19. Market A (Class I SV): Estimated Reductions in GDP

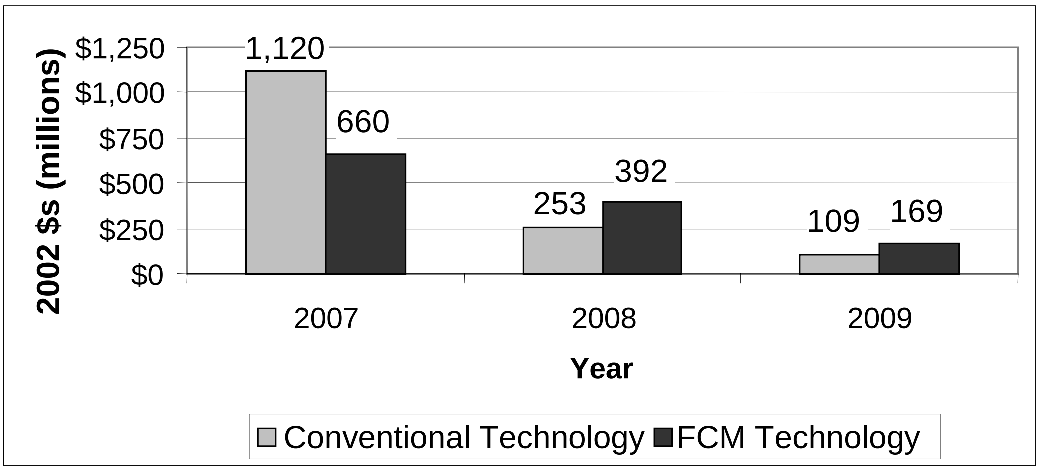


Figure 20. Market A (Class I SV): Estimated Reductions in Employment

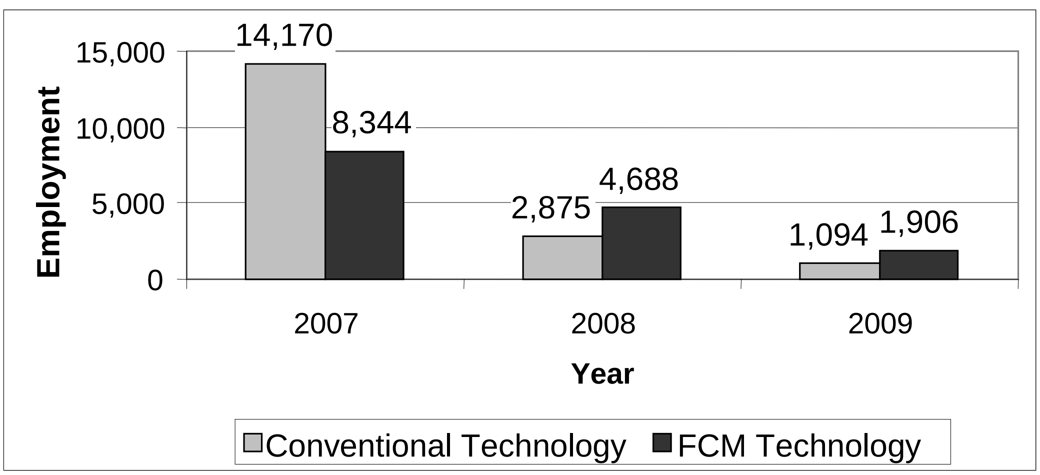
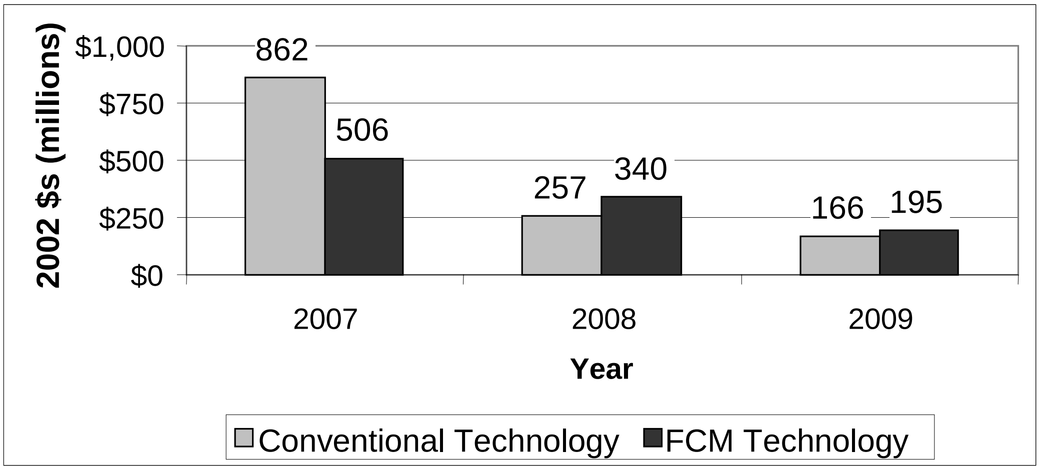


Figure 21. Market A (Class I SV): Estimated Reductions in Personal Income



The estimated reductions in GDP, employment, and personal income are then shown for market segment C in Figures 22, 23, and 24. In 2005, the year with the biggest impact from using FCM technology, $415 million in GDP would be saved, 5,594 jobs would be saved, and $350 million in personal income would be saved. Over the analysis period (2003 to 2007), total savings would be $982 million in GDP and $878 million in personal income.

Figure 22. Market C (Class II SV): Estimated Reductions in GDP

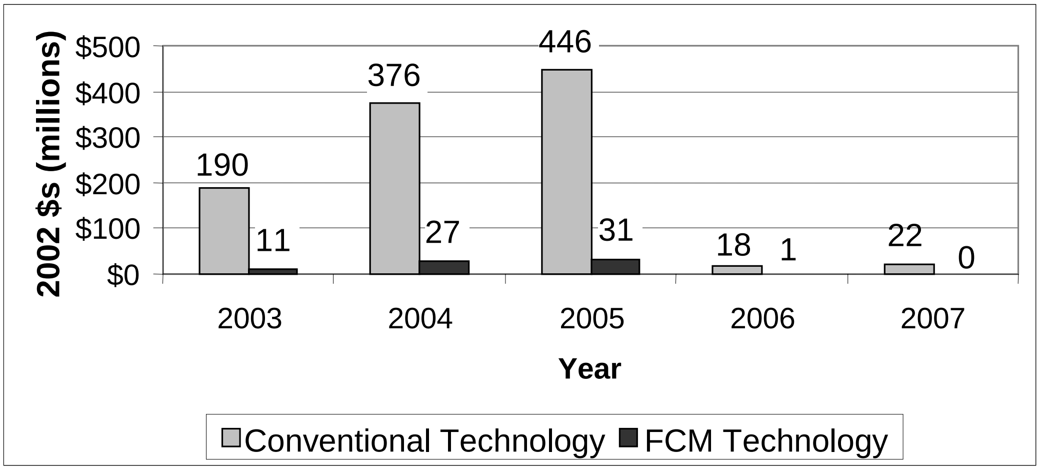


Figure 23. Market C (Class II SV): Estimated Reductions in Employment

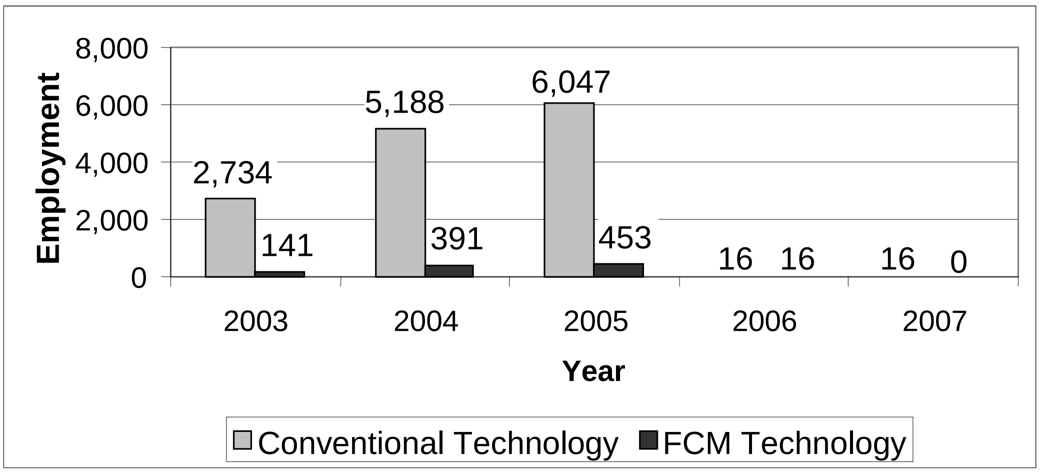
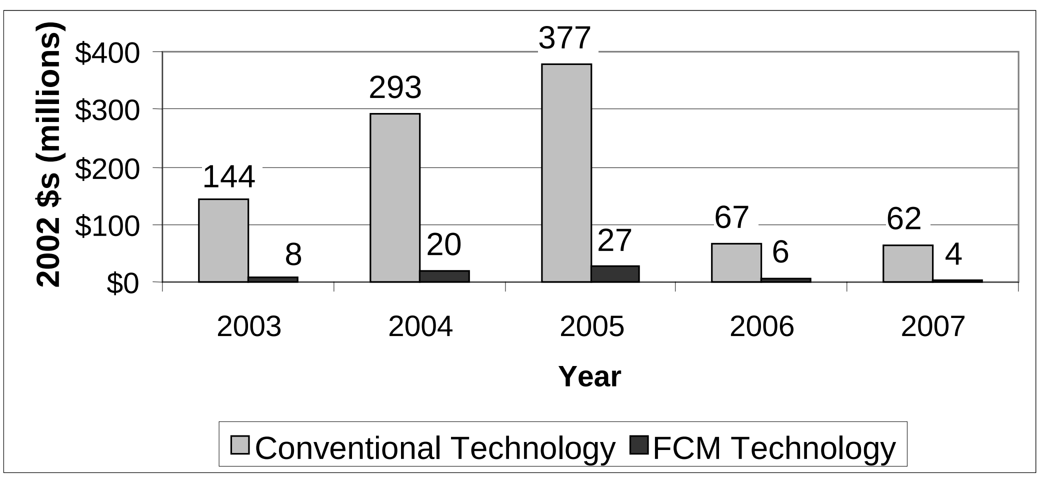


Figure 24. Market C (Class II SV): Estimated Reductions in Personal Income



ABOUT THE ADVANCED TECHNOLOGY PROGRAM

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