

Intel's XL Permit: A Framework for Evaluation

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Abstract

The paper develops a framework to evaluate permits granted to firms under the Environmental Protection Agency's Project XL -- with emphasis on the novel air permit granted to the Intel Corporation. We describe the permit, the process that created it, and the types of costs and benefits likely to arise from this type of "facility-specific" regulatory arrangement. Among other things, the paper describes the permit's impact on environmental quality, production costs, transaction costs, and Intel's strategic market position. The paper also considers how an estimate of the costs and benefits -- both to Intel and society -- might be estimated. While facility-specific regulation typically conjures images of production cost savings as processes are re-engineered and low-cost abatement strategies pursued, the Intel case highlights perhaps a more important source of benefit: flexibility in the form of streamlined permitting. Flexibility in this form allows for accelerated product introductions, with potentially significant benefits to the firm and possibly to society.

Key Words: Project XL, tailored regulation, environmental regulation, cost-benefit analysis

JEL Classification Nos.: L51, Q38, L63, K32

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James Boyd, Alan J. Krupnick, and Janice Mazurek*

Quick or Dead -- Intel Company motto

I. INTRODUCTION

The maxim, "time is money," is particularly apt as a description of the design and manufacture of high-performance microprocessors, the brains inside personal computers (PCs). While no one knows for sure, some managers posit that production delays can cost Intel a million dollars in lost revenue each day. While Intel is designed for speed, it must engage in a regulatory process that often moves at a snail's pace. Regulation penalizes firms such as Intel that must frequently change their emissions stream. In general, any production change that modifies air or water emissions requires a new permit or formal review. It is in this context that Intel sought a new kind of permit under EPA's Project XL program -- a permit that would allow Intel to change processes, and therefore, emissions, frequently, without having to submit a new permit, as long as it kept its emissions below what federal regulations require.

The purpose of this paper is to develop a framework to estimate the private and social costs and benefits of this type of regulatory arrangement, emphasizing the novel issues posed in defining and measuring the public and private benefits of reduced time to market. Thus, this exercise is relevant not only for microelectronics manufacturers but for the increasing number of businesses that seek to respond more rapidly to competition and changing market conditions.

The analysis is also pertinent to ongoing statutory initiatives such as the proposed "Innovative Environmental Strategies Act of 1997" (the so-called Lieberman Bill).¹ The proposed Act is aimed at providing a legislative foundation for flexible, facility-specific, environmental regulation. The Intel-XL agreement is one of the first examples of this type of regulation. Our analysis of the permit emphasizes the importance of issues also reflected in the pending legislation, such as the definition of baseline, environmental performance and transaction costs associated with stakeholder negotiation. The Act itself endorses the need for a study such as ours, calling for ongoing evaluation of this innovative form of regulation.

The following report is divided into eight sections. Section two provides an overview of Project XL and of some key economic and environmental features of microprocessor manufacture. Section three develops a framework for evaluation. Section four examines Intel's XL permit, and market, industry, and manufacturing issues pertinent to the assessment of the

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¹ S. 1348, 105th Cong., 1st session.

costs and benefits of the permit. In sections five and six we apply the evaluation framework to identify sources of static and dynamic costs and benefits. Section seven discusses measurement and data issues and section eight offers conclusions.

II. OVERVIEW OF THE XL PROGRAM

Traditional command and control regulation holds firms to a uniform set of standards. The growing belief within EPA that this gives firms too little flexibility in complying with pollution regulations led to the creation of Project XL (Ayres and Braithwaite, 1992, p. 39). Project XL was to be an exercise in case-by-case regulation, with negotiations between EPA and the regulated firm driving the outcome but subject to stakeholder agreements. Although the goals of the project were many (see Table 1, below), in general EPA was agreeing to give up "letter of the law" compliance with all applicable regulations in return for environmental performance exceeding what traditional regulation could bring. Because this experiment involves negotiation, it was understood that initial transaction costs to industry, regulators, and public participants would be high to all parties, but the hope was that the benefits in cost reductions accorded by increased compliance flexibility would more than make up for the delays and costs of negotiations. Project XL architects also hoped that transaction cost would decrease over time as additional facilities and firms adopted XL programs.

Table 1. Project XL Goals

1. Environmental results
2. Cost savings and paperwork reduction
3. Stakeholder support
4. Innovation/multi-media pollution prevention
5. Transferability
6. Feasibility
7. Monitoring, reporting, evaluation
8. No shifting of risk burden

Source: EPA 1996c.

In practice, few firms have sought such flexibility because the legality of Project XL is not assured (Ginsberg and Cummis, 1996). In the absence of explicit statutory authority, firms out of compliance with status quo standards are vulnerable to both EPA enforcement action and citizen lawsuits. Legal problems also have resulted in Project XL participation rates lower than EPA originally envisioned. While EPA had originally hoped to admit 50 firms into Project XL, EPA since 1995 has approved only two other XL plans, known as final

project agreements (FPAs), both of which are currently underway.² An additional 23 projects are in various stages of development or negotiation; and 20 proposals have been withdrawn or rejected (EPA, 1997, p. 3).

In November 1996, Intel became the first major U.S. manufacturer approved for Project XL, the "crown jewel" in the Clinton administration's efforts to reduce the cost and increase the effectiveness of environmental regulations. Intel's XL effort is a comprehensive plan that governs air, water, and waste issues at the company's newest semiconductor manufacturing plant near Phoenix. The agreement also contains non-environmental features, such as a commitment on the part of Intel to donate computer equipment to schools and libraries. While it forms just one part of the XL package, we focus on the air permitting portion of Intel's XL agreement because it represents the greatest source of regulatory flexibility. The XL air permit relieves Intel from certain basic permitting provisions in the Clean Air Act Amendments (CAAA), which requires manufacturers to notify regulators, and in some cases seek approval from regulators, in order to make routine process changes. Permit notification and review processes can impose delays of weeks, months, or even years. In the presence of competition, delays threaten to erode slim technological and marketing leads. In addition to imposing potential delays, environmental regulations that require manufacturers to notify regulators each time a production change occurs also impose considerable paperwork requirements and permitting fees.

Intel had a lot to gain. As the world's largest microprocessor manufacturer, Intel routinely doubles the number of transistors on a thumbnail-sized slice of silicon every 18 to 24 months and typically must construct new, billion-dollar fabrication plants to craft a new product (Hatcher, 1994; Sheppard, 1995). To achieve refinements and optimize its production process Intel must constantly modify process chemistries and equipment. However, the manufacturer's ability to make refinements in a timely manner is threatened by permitting provisions introduced by Congress in 1990 to help states better control conventional and hazardous air pollution (Sheppard, 1995; Hatcher, 1994).

In contrast to a traditional XL project, Intel's permit is tailored to fit the unique characteristics of a microprocessor manufacturer, where production and pollution control methods vary not only among facilities but at an individual facility *over time*. Intel's five-year XL Project agreement covers operations at the company's 720-acre Ocotillo site near Phoenix in Chandler, Arizona. The site is home to Fab 12, the company's newest Pentium® microprocessor fabrication facility. The agreement contains a separate, fully-enforceable air permit that approves, in advance, routine production changes at Fab 12, one of the world's largest microchip production facilities. In exchange, Intel commits to a set of plant-wide emissions limits, or caps, for conventional and hazardous emissions released from Fab 12.

² One approved project involves a permit that consolidates all federal, state, and local environmental requirements into one document for a Florida citrus juice processor. Consolidating permits eliminates the requirement of preparing multiple applications, a benefit that could save the company several million dollars. Another agreement, signed in January 1997, aims to reduce pollution impacts from a Weyerhaeuser pulp and paper manufacturing plant on the Flint River in Georgia.

The caps are more stringent than those required by federal law. Under the permit, Intel also can construct a second fabrication facility -- referred to here as "Fab X" -- to craft microprocessors at least two generations ahead of the current products made at Fab 12, provided that emissions from both facilities combined remain below levels specified in the XL air permit.

This paper develops a framework for considering the basic question the public should ask about any policy initiative: does it deliver benefits to the public that outweigh its costs. If the answer is no, then, in general, the policy should be dropped or altered. In addition, we are interested in whether the policy offers the private sector benefits which exceed its costs of participation. Private costs and benefits are relevant to predictions of whether or not firms in the future will find participation in such programs appealing.

The Intel case encourages analysis of an issue that has received relatively little treatment in the literature: the public and private benefits of reduced regulatory delay. While the effects of reduced delay are relevant in any sector and for any firm, the enormous value of time to Intel makes this investigation particularly compelling.

III. THE FRAMEWORK FOR ANALYSIS

Our framework identifies the benefits and costs of Intel's XL permit. In doing so, we take care to distinguish between private and social benefits and costs. By private benefits we mean the increase in profits to Intel associated with the permit; these can result from lower production costs, lower abatement costs, or lower transaction costs in negotiating over permits. Private costs are those associated with increased production, abatement or transaction costs arising as a result of the permit. By social benefits (or costs), we mean the improvements (reductions) in social welfare associated with the XL permit. There may not be a close relationship between profitability at Intel and social benefits; to paraphrase a General Motors executive: *What may be good for Intel is not necessarily good for the U.S.* In particular, we are concerned with "incremental" benefits and costs. That is, what are costs and benefits under the XL permit compared to those under the alternative, traditional emissions regulation? This is the most relevant question when comparing the performance of the XL permit to the status quo.

The definition of the status quo, or "baseline," is an important and complex issue. The baseline primarily refers to the levels of pollution control required by traditional regulation. First, the meaning of "traditional emissions regulation" is far from clear. There are a number of studies that catalogue the inflexibility and slow pace of permit decisions. But in recent years EPA has initiated a variety of initiatives to reform this process. Project XL is only one such program. Moreover, there are other avenues open to a firm that wishes to push the traditional permit process to its limit. It can negotiate with the local and state authorities for particular permit terms, for instance. Thus, the baseline is at best an educated guess, given the variety of regulatory requirements that can emerge from a relatively broad palette of regulatory programs.

Second, the baseline extends beyond regulatory matters. For instance, Intel provided computers to the local community to help build goodwill for its new plant. Would it have done so if an XL agreement, with its requirement that local stakeholders be involved, not been on the table? If the computer donation is linked to the agreement, the computers should be viewed as an "above baseline" social benefit of the agreement. Otherwise, the computers should be viewed as part of the firm's baseline performance, and thus not count as a benefit of the XL agreement.

Evaluation of XL permits also involves the definition of baseline costs, as well as benefits. As an example, consider abatement equipment decisions. If Intel planned on installing and operating high performance abatement equipment irrespective of the XL process, then these abatement costs should be considered as part of the baseline.

These baseline issues have important policy significance because if the baseline is defined too tightly (e.g., is defined as a particularly high level of emissions abatement), a firm may have no incentive to participate in the program. This is undesirable if participation, given a "lower" standard of baseline performance, would still result in environmental improvements. On the other hand, if the baseline is defined too loosely (e.g., requires too low a hurdle), "superior environmental performance" -- a requirement of XL agreements -- may not occur.

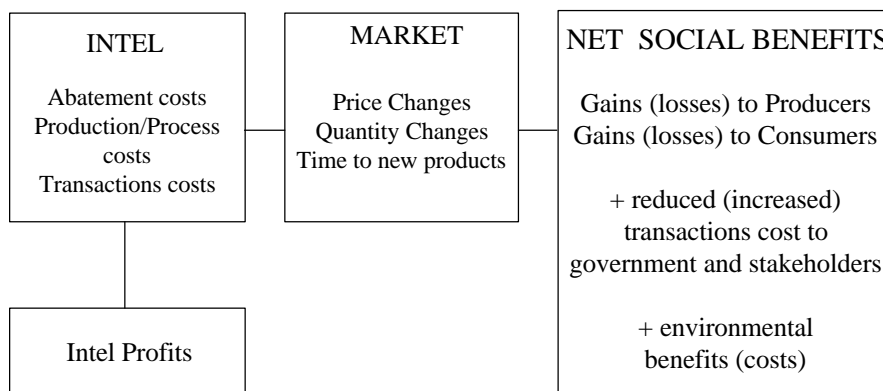
Our overall framework is illustrated in Figure 1 (below), where the various types of costs and benefits are identified, along with who benefits and whether they are private or social *net* benefits (i.e., benefits minus costs). The costs and benefits to Intel are registered in three categories. The permit can lead to changes in the company's abatement costs, it may lead to changes in production processes (and, most importantly, in the speed at which these processes are changed), and in what economists term transaction costs. The basic idea behind XL is that the firm can save abatement costs (and improve the environment) by being subject to a permit on its emissions that accords it more flexibility to reduce its emissions. Examples might include (i) more than meeting emissions limits for a very toxic pollutant in exchange for slightly violating emissions of a much less toxic pollutant, and (ii) meeting plant wide aggregate emissions limits but not limits for each waste stream. As we shall see, in Intel's case, abatement costs may have actually increased with the XL permit, but there are other ways in which costs can fall. The XL permit also may help Intel by giving it the flexibility to change production processes rather than relying entirely on installing abatement technologies.

The main benefit to Intel is likely to be a reduction in the time it takes to bring a new product to market. In Intel's case, where production processes are changing rapidly during a one-year chip development process, the firm faces the prospect of costly delays every time it had to modify its production process. From a cost perspective, savings arise from reduced interest costs for the huge capital investments necessary to produce a new generation of chip. Cost savings create competitive advantages for Intel, leading to increased market share and profits.

The process of obtaining the XL permit and meeting various on-going stipulations concerning the permit may also lead to a different level of "transaction costs" than in a traditional permit situation. Transaction costs include time and money spent to conduct the

transactions associated with the policy. To obtain an XL permit requires the applicant to engage in extensive negotiations with EPA and stakeholders. For Intel, these are particularly large because the negotiation process had yet to be defined or constrained. As defined, negotiation costs would be zero for a conventional permit. However, there are also on-going costs to administering the permit; these costs may be larger in a conventional permitting situation than for XL because each process change would lead to some costs under the conventional approach. At the same time, the XL permit may include greater than normal reporting requirements, special monitoring, and other stipulations that are meant to assure all parties that these relatively innovative agreements are being kept. These are additional transaction costs of an XL permit. Ultimately, these costs must be subtracted from cost reductions achieved by the company in order to gauge the net private benefit arising from the XL permit.

Figure 1. Net Social Benefits



Moving to consideration of changes in social welfare, there are three categories: transaction costs to government and other stakeholders, benefits to the environment, and benefits conferred through the market for computer chips and, indirectly, computers.

Consider transaction costs. The costs to the government are entirely in the nature of transaction costs. If the regulators assigned to the negotiation have to give up other activities, this is a cost to the public, along with travel expenses, etc. Similar costs may be incurred by various stakeholders participating in the process, which is chalked up as a cost to society.

The environmental benefits are the incremental benefits to health and the environment, expressed in terms of the public's willingness to pay for such improvements (relative to the

gains from conventional permitting). Benefits assessments have been carried out for a wide variety of pollutants, with the most focus and success coming from projects which link air pollution changes to health effects and associated economic values.

The final category consists of economic benefits (or costs) realized through the market for products affected by the XL permit. Benefits are realized by consumers if they purchase new software or hardware faster or at a lower price than they would otherwise be able to.

Benefits to the industries affected may also be realized. But this issue is complicated. The benefits to Intel of speeding up production have to do with maintaining market leadership or dominance. Yet, these benefits may come at the expense of other firms in the industry, which may mean that there is not net increase in profitability in the industry. In addition, the market dominance enjoyed by Intel may eventually result in prices higher than they would otherwise be.

Another, less tangible, benefit is worth mentioning, though we will not address it further. It is possible that a firm's participation in an XL project, particularly in the early phases of the program, will earn it "goodwill" with the EPA or other regulatory agencies. The existence of this goodwill is by no means certain, and in any event is difficult to measure. Nevertheless, a firm may feel that its participation is consistent with efforts to be a good environmental citizen and may be rewarded in future interactions with regulators.

IV. THE INTEL CASE STUDY

To gain further insight into the firm's motivations for seeking a novel air permit, we describe Intel's XL package in greater detail. We then provide an overview of Intel's unique market position and some key industry and manufacturing features to illustrate how traditional air permits increase the risk of costly delays.

1. Intel's XL Agreement

Intel's final project agreement was signed in November 1996 by EPA Administrator Carol Browner. Akin to the other two XL efforts underway, the Intel effort is designed to reduce the need to prepare multiple permit applications, but is distinguished by provisions to address local environmental concerns, as well as recognize the time-sensitive nature of the microprocessor industry. To capture these disparate elements, the final project agreement contains three distinct, but related, provisions: a five-year air permit; a permit from the city of Chandler that governs water treatment issues; and a set of regulatory and voluntary performance features primarily geared toward local concerns (EPA, 1996e). For each element, Intel voluntarily commits to control more pollution than required by federal, state, and local laws and guidelines.

For example, from the start, Chandler residents were concerned with the plant's impact on the region's relatively scarce freshwater supplies and deteriorating air quality (Coombs, 1996). In response, the company pledged to minimize freshwater consumption by using treated effluent water for cooling, and use stormwater retention basing to control runoff,

instead of dry wells.³ The firm made a set of other desirable commitments. They agreed to provide a setback of 1,000 feet from any manufacturing building to the closest residential property, even though the legally required distance is 56 feet. They agreed to prepare an integrated electronic emergency response plan for responding to accidental spills of hazardous waste. In addition, Intel pledged to recycle large volumes of solid and hazardous waste from the Ocotillo site. Finally, the agreement contains non-environmental commitments including a plan to promote Intel's involvement in community educational efforts and pledges on behalf of the manufacturer to donate computers and equipment to schools and libraries (EPA, 1996e).

As originally envisioned, the final project agreement would have allowed Intel to consolidate permitting and reporting into a single document administered by the State of Arizona, rather than ten separate agencies (Intel, 1996c). Intel was unable to vest permitting and reporting requirements with a single agency because Maricopa County Environmental Services Department (MCESD), the local agency responsible for air pollution control, refused to relinquish its permitting authority and oversight to the State of Arizona. MCESD's work is partially financed through fees levied on pollution sources such as Fab 12 for each permit application filed. The county permitting authority perceived the consolidated proposal as a potential loss of revenue.

For Intel, the sources of flexibility in the agreement are contained primarily in the air permitting portion of the final project agreement. While air permitting requirements may not pose much of a problem to firms whose equipment and chemical processes are stable, new requirements established by Congress in 1990 fail to account for the time-sensitive requirements of leading-edge chipmakers. The New Source Review provisions under the 1990 Clean Air Act Amendments, (CAAA) require each state to develop a comprehensive, federally-enforceable operating permit program for all major stationary sources of air emissions.

"Major sources" refer to facilities or individual pieces of equipment that emit more than a 100 tons per year of the six "criteria" pollutants and specified levels of pollutants defined as hazardous (HAPs), which are suspected to trigger adverse health effects in much smaller amounts (Quarles and Lewis, 1990). Minor sources, such as Fab 12, emit fewer than 100 tons of criteria pollutants and 25 tons of hazardous pollutants per year. Unlike major sources, minor sources are not required to undergo lengthy regulatory review. However, some states still require that minor sources notify regulators each time a routine production change occurs.

Of particular concern to Intel, which operates fabs in Arizona, Oregon, California, New Mexico, Ireland and Israel, is the potential for state and local agencies to develop permit programs that subject routine process change to review. Reviews can impose delays of several days or several months, depending on whether regulators require public notice and comment (which themselves can take up to 60 days) (Hatcher, 1994, p. 12). Shortly after

³ It is worth noting that one oft-cited example of the agreement's superior environmental performance is dubious. EPA billed Intel's construction of a \$28 million dollar reverse osmosis facility as a way of saving water under part of the XL agreement. In fact, the plant needs highly purified water. Moreover, the facility was constructed before Project XL was even announced as a program.

Congress approved the New Source Review provisions, Intel cautioned that lengthy state review would cause the company to "seriously question whether it could remain committed to the construction and expansion of our U.S. sites" (Hatcher, 1994, p. 4).

To illustrate the degree to which the manufacturer is willing to avoid permit-related delays, consider that, in response to the 1990 amendments, Intel adopted a corporate policy of structuring almost all of its U.S. facilities to emit pollutants below threshold limits that trigger major source permitting. One exception is an older facility in Oregon, where Intel subsequently worked with EPA and state regulators to develop an air permit that would become the blueprint for Project XL.

There are three categories of benefits to Intel, stemming from flexibility in the air permit crafted under the XL agreement.

Advanced approval of production changes: Under a traditional permit, an Intel facility would be required to file up to 28 permit notifications per year.

Plant-wide emissions caps: The permit replaces some individual emissions limits with aggregate limits. Caps give the firm greater flexibility to modify substances and equipment.

The ability to expand operations without re-permitting: Intel may add a second wafer fabrication facility at the Ocotillo site without securing additional air permits--a process that can take anywhere from six months to a year.

In exchange, Intel commits to a set of emissions limits for current and any additional operations that are more stringent than what federal law requires (see Table 2, below). To meet such ambitious goals, Intel planners and engineers must design next-generation equipment and processes so that not one, but potentially *two*, fabrication facilities release less than what is typically allowed for a single facility to remain a minor source. Viewed from this perspective, the XL permit will deliver environmental benefits at Fab X regardless of where Intel elects to locate the plant. As part of the XL air permit, Intel also commits to testing and public notification provisions beyond those required under a traditional permit.

The XL air permit is good for five years and is attached to the XL FPA as a separate document to make it enforceable. Other permit features, such as best available control technology (BACT) requirements, will mirror those contained in a traditional air permit. Under the XL permit, emissions of some conventional pollutants such as nitrogen oxide (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) exceed 25 tons per year, so the site must continue to comply with Maricopa County's BACT controls. For example, BACT for boilers includes the installation, operation, and maintenance of low NO_x burners. VOCs from manufacturing operations must be vented to a VOC control device. BACT requirements under XL thus significantly reduce a potential source of operational flexibility.

Table 2. Current Law and XL Emissions, Fab 12 and 16

Pollutant (tons/per year)	Current Federal Requirements for Minor Sources	Project XL Permit Fab 12 + Fab X*
Carbon Monoxide	<100	49
Nitrogen Oxide	<100	49
Sulfur Dioxide	<250	5
PM-10	<70	5
Total Volatile Organic Compounds	<100	40
Hazardous Air Pollutants (HAPs)	<25 aggregate; 10 for any individual HAP	10 Total Organic 10 Total Inorganic

Source: EPA 1996b.

Notes: Hazardous air pollutants (HAPs) are those listed in Section 112(b) of the federal Clean Air Act as amended; the 10 ton per year limits for total organic HAPs and total inorganic HAPs assume that more than one HAP will be emitted from the site. If a single HAP is emitted from the site, the emissions limit is 9.9 tons per year; based on Intel's modeling exercise and Arizona Ambient Air Quality Guidelines (AAAQG), the permit establishes a separate limit for phosphine, at 4 tons per year, and sulfuric acid at 9 tons per year, to be included in the aggregated combined inorganic HAP emissions plant site emissions limit; While Intel has not officially announced plans to construct a second fab at the Ocotillo site, the emissions levels under the XL permit column are for two fabs.

2. Market Position

To identify the private and social impacts of the XL air permit, it is necessary to know something about Intel's current market position and how it got there. For leading edge chip manufacturers profitability is closely tied to their ability to release new technologies ahead of competitors.

Intel is currently the leading supplier of microprocessors, controlling between 80 and 90 percent of the U.S. market alone. Advanced Micro Devices (AMD) and, until recently, Cyrix Corp., are the other leading market contenders. Founded in 1968, Intel secured an early lead by inventing the world's first microprocessor in 1971. Microprocessors, differentiated primarily by power as measured in megahertz, combine memory, logic, and certain discrete functions onto a single piece of silicon. The microprocessor took integration of circuits to a higher plane because it combined the functions of a computer -- logic, memory and certain discrete functions -- onto the space of a single chip. Within three years of the introduction of the 4004, Intel released the 8008, an eight-fold improvement.

Since the microprocessor's invention, technical breakthroughs in chip design and manufacture have enabled Intel to roughly double the number of transistors on a single slice of silicon roughly every 18 months. While Intel's earliest chips contained several thousand

transistors, today's may hold more than five million. Such advances require compressing transistor size and space between them. Shrinking the channel width between transistors, measured in microns some 200 times smaller than the human hair, enhances chip speed by reducing the distance that a signal must travel. During the past decade, channel widths, which measure the distance between circuits have dropped from ten micron widths apart to just .35 micron widths. Fab 12 currently manufactures circuits 0.35 micron widths apart and is converting to a process to make 0.25 micron width circuits. The conversion could yield up to twice as many chips as today's 0.35 micron processes. Following this logic, the space between circuits is expected to further shrink to less than 0.07 microns by 2011.

For Intel, such advances have historically been profitable because the doubling in density was not accompanied by a commensurable jump in manufacturing cost. The alchemy of the chip manufacture is such that it combines relatively inexpensive elements such as silicon, oxygen, solvents, and metals to forge a product that is worth far more than its weight in raw materials. As engineers determine how to add more transistors, the average cost per circuit element falls. Indeed, for every new chip breakthrough, the manufacturing cost per transistor has traditionally been cut in half, owing primarily to the ability to sandwich more transistors onto silicon. Such advances also benefit consumers because the price per transistor falls as supply increases. For example, the microprocessor which sells for \$500 today will cost consumers about \$10 in five years and about ten cents ten years from now. In ten years, today's chips will be cheap enough to provide everyday household objects like lightbulbs with the intelligence of today's desktop computer. This phenomenon, the so-called "Moore's law," was first formalized in a 1965 essay penned by a former Fairchild scientist, Gordon Moore, who with Robert Noyce founded Intel in 1968.

An important aspect of innovation is the ability to match a product with other, complementary products. To realize their value, microprocessors must have a product application. In 1979, International Business Machines started to manufacture a PC and sought a 16 bit microprocessor to power it. At the time, Intel and Phoenix-based Motorola were the two industry leaders. To win the deal, Intel launched "Operation Crush" to out-design and outsell the competition (Wiegner, 1992). Motorola never regained its market position. A young, Harvard dropout -- William Gates -- helped to further insure Intel's success when he structured the disk operation system (DOS) for IBM's personal computer around the capabilities of Intel's 8088 microprocessor. Applications for Intel microprocessors expanded as IBM licensed PC design to makers of computer "clones" such as Compaq.

3. Industry Features

Despite Intel's seemingly secure market position, continuous technological innovation and integration into downstream industries does not assure market dominance. Stiffer international competition and spiraling capital costs have prompted Intel in recent years to adopt a business strategy unique from most other semiconductor firms. Intel is one of the few firms that continues to build costly new manufacturing facilities. Intel therefore seeks to avoid delays associated with bringing entirely new facilities on-line.

Until the late 1970s, U.S. firms accounted for roughly 85 percent of all breakthroughs in chip technology (Morris, 1990). By the mid-1980s, most U.S. firms, including Intel, had abandoned memory chip manufacture to Japanese producers, who were able to erode market share by selling superior products at a much lower cost than U.S. companies. Between 1985 and 1986, Intel experienced cumulative losses of \$250 million and laid off 6,000 employees (Wiegner, 1992). The majority of U.S. companies responded to increased foreign competition either by agreeing to share technology and manufacturing lines with competitors or dispense with manufacturing altogether. In 1997 more than 60 chip companies located in the U.S. obtained at least 75 percent of their chips from outside sources known as "foundries" (FSA, 1997).

Both strategies are fueled by the rising cost of wafer fabs. In 1996, the price tag for new fab construction was \$2 billion per plant and climbing. By 2000, some observers expect the cost of a single facility, roughly the size of two football fields, to reach at least \$5 billion (Hutcheson and Hutcheson, 1996). Of this cost, about 75 percent is for fabrication equipment such as photolithography tools that determine the smallest features that can be placed upon a wafer (Hutcheson and Hutcheson, 1996). After five years, fabs are converted to craft less technologically advanced products such as memory chips or communications devices instead of microprocessors.

In contrast to most other firms, Intel continues to independently build and operate new wafer fabs. In 1996, Intel spent \$5 billion on capital projects and research and development. According to company reports, Intel operates roughly twelve to thirteen fabs while its closest competitor AMD operates about six. Cyrix Corp., Intel's other chief U.S. competitor, was recently sold because the "fabless" company, using third-party suppliers for production, was consistently unable to match Intel's volume.

4. Manufacturing Issues

Intel's business strategy helps product planners and engineers to rapidly introduce new products and ensure that sufficient manufacturing capacity exists to produce them. However, the potential for delay persists because manufacturing microchips in high volume is an uncertain process. There is no preset formula for crafting successive generations of microprocessors, a process which can involve over 300 different manufacturing steps. Instead, each new chip generation is achieved through continual experimentation and refinement. Product fine-tuning often calls for frequent equipment and process chemical changes. Process chemicals are used both to place transistors on silicon and to insure chip cleanliness, the leading source of device failure.

In addition to process chemicals, a single mega fab may use more than 2 million gallons of deionized water, 2,500,000 cubic feet of high purity nitrogen, and 240,000 kilowatt hours of electrical power each *day*. While manufacturers are reluctant to report on materials used to manufacture chips, one industry expert estimates that successfully manufacturing one six-inch wafer requires 20 pounds of chemicals; and more than 3,200 cubic feet of gases (MCC 1993).

To further guard against contamination, the most sensitive manufacturing processes take place inside sterile "clean rooms," where workers clad in masks and white, head-to-toe coverings known as "bunny suits" usher chips through a maze of stations which contain clusters of costly production equipment or "tools." Computer-controlled robots typically conduct operations on the wafer. As a further precaution, air in the average Class 1 clean room is continuously filtered to the point of just one half-micron particle per cubic foot of air, half a million times cleaner than the average operating room. Temperature, barometric pressure and humidity are tightly controlled to keep contaminant levels to an absolute minimum.

In five years, an average Intel facility using the latest process technology would introduce at least two new generations of technology; make 30 to 45 process chemical changes *per year*; and install five to 15 new equipment types and/or new processes (Hatcher, 1994, p. 7). To put the dizzying pace of such requirements into perspective, consider that *Chemical & Engineering News* reports that the average process at a chemical plant may last up to 15 years, and the plant itself up to 75 (Kirschner, 1995, p. 14).

Intel estimates that for all new product introductions, roughly one-third require entirely new sets of process chemistries and equipment (Hatcher, 1994, p. 7). Typically, the company crafts a new multi-billion dollar fabrication facility every nine months for each new major product breakthrough. For example, Fab X will likely produce chips at least two generations removed from the 0.35 micron products currently manufactured at Fab 12. Fabs typically manufacture two advanced product generations and become obsolete for leading-edge manufacture after about five years.

Due to the highly experimental nature of wafer fabrication, output tends to follow a fairly predictable trajectory, referred to as the "learning curve effect" (Dick, 1991). Initially, output, as measured by the number of good chips per wafer is low as chipmakers "learn" to eliminate duds by modifying chemical processes and equipment configurations. Output then rises over the 18 to 24 month product cycle and production costs concomitantly fall. Output falls when the next generation of chips are released, and the cycle starts anew. While output, or wafer yield is a closely-guarded trade secret, today's fab may produce more than 30,000 eight-inch wafers per month. Each wafer may yield between 250 and 400 individual chips, depending on the product and its intended use.

5. Permitting and Manufacturing Delays

Federal air permit requirements increase the potential for manufacturing delays in both existing product lines, such as chips made at Fab 12, and fabs that remain in blueprint form. The potential for delay to existing processes persists because Intel engineers do not always know in advance how to combine processes and equipment to maximize output. The potential exists for permit delay -- problems that can stall manufacturing for several days or several months. Permit delay also results from the sheer number of emission sources and rarefied manufacturing conditions inside clean rooms. The number of tools, combined with the antiseptic atmosphere makes it difficult and costly to precisely pinpoint how much pollution

individual tools emit. Filtration makes it difficult to measure at any moment how much pollution is created from the manufacturing process and concentrated in the air.

The threat of delay to plants where chips are already in production is reduced somewhat in regions where regulators have interpreted the 1990 requirements to recognize the constant upgrades required for chip manufacture. For example, Maricopa County, where the Ocotillo site is located, does not require pre-change review as part of its traditional permit program, only notification. Rather than require notification each time a change occurs, the county also allows Intel to file more than one notice of modifications at the same time.⁴ According to a set of case studies that Intel prepared on existing facilities in Maricopa County, during the first eight months of 1994 Intel made 28 revisions to an operating permit at an older facility. The revisions were accomplished by filing the 28 notifications in three batches (Hatcher, 1994, p. 10).

The potential for estimation problems -- and delay -- is greater for new fabs because Intel often designs facilities and secures permits for them years in advance of full operation. Securing a permit for an entirely new facility such as Fab X could require up to six months to process through the county (Wampler, 1996). In order to obtain permits for wafer fabs years away from shipping chips, Intel engineers develop estimates based on comparable processes at other fabs. It is not unusual for the firm to commence experimental production before equipment that meets exact product specifications is available. For example, Intel applied to the Maricopa County Environmental Services Department (MCESD) for an operating permit for Fab 12 in 1993, three years before the facility actually began shipping Pentium[®] microprocessors. Because Fab 12 was not yet in operation at the time of the initial permit application, Intel engineers developed estimates that showed the facility would emit 5.5 tons of hazardous air pollutants per year (MCESD 1994). As it turned out, this estimate significantly underestimated actual emissions. In what follows, we show how this need to estimate emissions in advance can complicate the permit process. It also complicates the identification of an appropriate emissions baseline.

V. STATIC COSTS AND BENEFITS

In this section we consider the various types of "static" costs and benefits registered as part of the Intel's XL permit. These categories include environmental benefits, abatement costs, and transaction costs. They exclude the "dynamic" benefits to Intel (and society) associated with reducing permit-based delays in production and discussed in the next section. Overall, the XL agreement could raise abatement costs for Intel and increase environmental benefits over a standard permit baseline, although there is ample room for debate over both of these conclusions. The agreement's effect on transaction costs is unclear.

⁴ This exemption from pre-change review is a benefit to Intel over a pre-change review program. But it is standard practice in Maricopa county and its benefits to Intel fall well short of those in its XL agreement, allowing for a one-time review of the air permit for both Fab 12 and Fab X.

1. Environmental Benefits

Environmental benefits are the improvements in human and environmental health associated with lower emissions arising as a result of the XL agreement. These benefits may range from fewer respiratory problems to better visibility on a hot summer afternoon. As benefits may be directly (if not linearly) related to emissions, changes in emissions are a more convenient, if more limited) way of measuring benefits. Note that the calculation of these benefits requires definition of a "baseline" level of emissions associated with conventional regulation. Unfortunately, since Fab 12 is a new facility and Fab X only exists on paper, the site lacks an emissions history with which to craft a baseline, or base case to determine emissions absent the XL permit.

This baseline issue was further clouded by Intel's original, overly optimistic, assessment of the feasibility of reducing emissions of certain air pollutants. Intel's pre-XL 1994 air permit limited the plant to aggregate emissions of about 5.5 tons per year of total inorganic and organic HAPs. Under its Project XL plan, Intel proposed to emit 10 tons per year of organic and 10 tons per year of inorganic HAPs, or a total of 20 tons per year of HAPs. Thus, it appears that the XL permit represents a four-fold *increase* in hazardous air pollutants. Intel engineers cited two reasons for the increase: First, while manufacturer's specifications show that scrubbers would remove up to 90 percent of VOCs, tests at low inlet concentrations showed that the equipment only removed between 20 and 30 percent of pollutants. The lower-than-expected scrubber efficiency levels are due to decreasing VOC emissions into the scrubbers. (The efficiency rate decreases concomitantly with the pollutant concentration.) Second, subsequent to the 1994 permit, Intel added significant amounts of methanol (a hazardous air pollutant) to the manufacturing process (EPA, 1996a, pp. 2-3).⁵ The underestimation of HAP emissions in the 1994 air permit raised concerns among some community members in the XL air permit workgroup about the accuracy of the information Intel provided (EPA, 1996a, pp. 2-3).

This baseline issue was addressed by EPA and Intel XL project stakeholders when they decided that, absent historic data, the theoretical maximum under the 1990 Clean Air Act Amendments of 100 tons of conventional and 25 tons of hazardous pollutants were appropriate baselines (Table 3, below). Other groups outside of the formal stakeholder process maintained(see, for example, NRDC, 1996) that Intel's original 1994 operating permit provided a more appropriate yardstick. The XL participants and EPA countered that the emissions levels in the 1994 operating permit were artificially low because they only covered experimental phases of production. In contrast, the XL permit emissions levels apply to a fully operational Fab 12. Moreover, the XL limit is a combined limit that covers both Fab 12 and Fab X, should it be built. According to the official baseline, then, the environmental benefits of XL represent the difference between emissions levels under the XL permit and the

⁵ While larger than originally forecast, however, the 20 ton per year level of HAP emissions still qualifies the plant as a "minor source" facility.

theoretical maximum allowed by federal law (or columns three and one). For example, the XL permit reduces carbon monoxide and nitrogen oxide each by 51 tons per year.

Table 3. Minor Source Limits, 1994 Permit Levels, and XL Permit Levels

Pollutant (tons/per year)	Current Federal Requirements for Minor Sources	1994 Fab 12 Permit	Project XL Permit Fab 12 + Fab X*
Carbon Monoxide	<100	59	49
Nitrogen Oxide	<100	53	49
Sulfur Dioxide	<250	10	5
PM-10	<70	7.8	5
Total Volatile Organic Compounds	<100	25	40
Hazardous Air Pollutants (HAPs)	<25 aggregate; 10 for any individual HAP	5.5	10 Total Organic 10 Total Inorganic

Source: EPA 1996b.

Notes: Hazardous air pollutants (HAPs) are those listed in Section 112(b) of the federal Clean Air Act as amended; the 10 ton per year limits for total organic HAPs and total inorganic HAPs assume that more than one HAP will be emitted from the site. If a single HAP is emitted from the site, the emissions limit is 9.9 tons per year; based on Intel's modeling exercise and Arizona Ambient Air Quality Guidelines (AAAQG), the permit establishes a separate limit for phosphine, at 4 tons per year, and sulfuric acid at 9 tons per year, to be included in the aggregated combined inorganic HAP emissions plant site emissions limit; While Intel has not officially announced plans to construct a second fab at the Ocotillo site, the emissions levels under the XL permit column are for two fabs.

Measuring the benefits of the HAP portion of the air permit is more complicated because HAPs may cause more localized health problems, and trigger them at smaller doses, than conventional pollutants. Furthermore, HAPs typically possess unique exposure thresholds, pathways, and properties once released into the environment. That is, some are extremely toxic in small amounts, while others require much larger doses; some act through exposure on contact, some on inhalation; others disperse rapidly in air, while some persist in soil or water.

The terms of the HAP portion of Intel's XL air permit contain a number of safeguards to ensure that emissions levels provide protection equal to that afforded by traditional permits. To insure that hazardous emissions levels under the XL permit sufficiently protect human health, Intel agreed to perform fate and transport modeling to determine whether predicted emissions will be consistent with Arizona's Ambient Air Quality Guidelines (AAAQGs), a set of risk-based parameters for roughly 400 chemicals. The XL permit establishes 10 ton aggregate limits each for organic and inorganic HAPs (20 tons per year total). Intel based its modeling exercise

on the conservative assumption that each individual HAP would be emitted at a rate of ten tons per year, rather than the 10 ton aggregate caps for organic and inorganic HAPs.

Intel's analysis showed that emissions of all but two pollutants, phosphine and sulfuric acid, would be at or below Arizona's Ambient Air Quality Guidelines, a set of risk-based parameters for roughly 400 chemicals. Based on the results of Intel's modeling exercise, the XL permit establishes a separate limit for the inorganic hazardous air pollutants, phosphine, at 4 tons per year, and sulfuric acid at 9 tons per year, to be included in the aggregated combined inorganic HAP emissions plant site emissions limit. The XL permit requires Intel to conduct similar analyses in the future before *any* new regulated chemical or currently unregulated compound is emitted from the facility.

Despite Intel's commitments, lingering uncertainties regarding the potential effects of HAPs on humans and the environment have prompted the Natural Resources Defense Council (NRDC), Silicon Valley Toxics Coalition (SVTC), and several others to question whether the HAP caps provide benefits that are "superior" to those under a traditional air permit. For instance, NRDC pointed out that the caps for phosphine and sulfuric acid originally stipulated in the draft FPA sent out for public comment would have exceeded the AAAQGs. As part of the FPA, Intel committed to satisfying the AAAQGs not only at the fence-line, but also within the facility. NRDC also expressed concern that the permit contains no provisions to prevent Intel from using increasingly hazardous substances over time, or from emitting pollution "spikes" at different intervals (NRDC, 1996). EPA countered that emissions levels under the XL permit for Fab 12, as well as for any additional facility, were sufficient to protect human and environmental health because they were well within "minor source" designations under the Clean Air Act (EPA, 1996f). EPA did not dispute NRDC's observation that XL permit contains no provisions to prevent emissions from the plant from becoming more toxic over time, but maintains Intel's conservative modeling exercises showed that even if the manufacturer released ten tons of a single hazardous pollutant, the levels remained well within voluntary state guidelines (EPA, 1996f). For HAPs then, the state guidelines form a baseline for comparison. To estimate benefits, HAP levels under the XL agreement could be compared with voluntary levels set under the Arizona Ambient Air Quality Guidelines. Analysts could then estimate benefits according to the array of health and environmental effects associated with each HAP.

2. Abatement Costs

Abatement costs of the XL permit are the incremental costs associated with reducing emissions below the baseline from traditional permits. Abatement costs will vary depending on whether or not the calculation applies simply to Fab 12 or to Fab X as well. Assuming that Intel builds Fab X at the Ocotillo site, costs to Intel to design equipment and select process chemistries will likely be much higher than if the air permit levels apply to Fab 12 alone.

While abatement costs for conventional and hazardous pollutants may be larger than under conventional regulation, abatement costs associated with best available control technology (BACT) requirements are unlikely to change. The XL permit requires Intel to

continue to seek approval for changes that trigger a BACT analysis for conventional pollutant emissions in excess of 25 tons per year. For example, BACT for boilers includes the installation, operation, and maintenance of low NO_x burners and VOCs from manufacturing operations must be vented to a specific control device. Thus, air abatement and analysis costs for NO_x, CO, and VOCs under the XL permit are likely to be similar to those under a standard Maricopa County permit.

Indeed, any higher abatement costs to Intel resulting from emissions levels lower than what federal laws require may be offset somewhat or entirely by permit provisions that allow the firm to trade HAPs and VOCs under a cap. Intel may use up to 90 different chemicals and dozens of specialized tools to craft one type of chip. Under a traditional permit, Intel would be required to meet separate emissions limits for each individual HAP. For example, the 1994 Intel air permit for Fab 12 set both daily and annual emissions limits on both individual conventional and hazardous air pollutants. For example, the 1994 permit limits carbon monoxide emissions to 59 tons annually and limits emissions of boron trichloride and diborane to 500 pounds and 50 pounds, respectively (MCESD, 1994). The XL permit replaces individual emissions limits for hazardous air pollutants with aggregate caps. The caps allow the firm to select among a greater mix of potential abatement technologies and combine them in order to minimize costs. While many chemicals generate the same classes of pollutants (for example, VOCs and HAPs), abatement costs vary by chemical and by process. Permits that contain emissions limits for individual chemicals and equipment lists ignore variations in abatement cost. Thus, the cap provision, to the extent it would not have been part of the standard permit, provides significant flexibility to Intel in fashioning its abatement strategy.

So far, we have largely assumed that chemicals and emissions changes are independent of equipment modifications. A more realistic scenario is one in which equipment choice affects chemical inputs and abatement technologies. While Intel modifies chemicals more often than production technologies, it is likely that the ability to make routine equipment modifications without triggering permit notification is a greater source of economic benefit. This follows since equipment is much more costly than chemicals.

Intel has to modify its equipment because it develops product specifications before it develops the equipment to meet these specifications. In addition, manufacturing wafers is an art that requires much trial and error with equipment and chemicals. Both of these types of adjustments can trigger permit problems. To illustrate, recall that HAP emissions in Fab 12's 1994 operating permit increased four-fold shortly before the facility began shipping chips because the original estimates were specifications developed by the scrubber manufacturer. Once equipment that exactly met specifications for Fab 12 was developed, engineers found that the abatement technology, in this case scrubbers, was less effective at removing pollution at low inlet concentrations than originally forecast.

Consider a traditional permit that places limits on individual chemical emissions and specifies what type of controls the firm must use. With a traditional permit, manufacturing uncertainties, such as lower than originally forecast scrubber efficiency rates, could require the firm to reduce emissions from the process to meet permit levels, even if there was a way to

achieve the reductions elsewhere in the facility. In contrast, the XL permit gives Intel the flexibility to select the least costly abatement method, including forms of abatement associated with other pollutants, as long as aggregate emissions remain under the permit caps. Because Intel typically upgrades equipment to either make more product or to make a superior product, flexibility to introduce machinery also may reduce the firm's average costs, or cost per unit of output, by allowing the firm to introduce processes to increase output or wafer yield.

3. Transaction Costs

In contrast to static costs associated with production and abatement, consideration of transaction costs requires moving beyond the factory floor to examine institutional features. The transaction costs of an XL permit refer to time and money spent to negotiate, report and monitor the permit. Our primary interest is in the incremental transaction costs of an XL permit, i.e., the transaction costs associated with this permit minus the transaction costs associated with a standard air permit, or in Intel's case, a series of permits needed for each change in Intel's production process.

A priori, this incremental cost may be positive or negative. The costs of an XL permit are bound to be high, both because the XL program is in its infancy and because of the requirement to involve all affected parties and stakeholder groups -- a requirement absent in standard permitting. Project negotiation required over nine months, 100 official meetings, and dozens of other informal conversations (Coombs, 1996; Mohin, 1997). On the other hand, the standard permit would need to be renewed each time the production process changed. Thus, there would be on-going costs of such a permit, in contrast to virtually no on-going cost to a XL permit. The following discussion describes different categories of costs borne by Intel, government and non-governmental organizations and public participants.

Transaction Costs Borne by Intel

EPA gave Intel six months to develop and negotiate a final project agreement (FPA), which set out the terms and conditions of how the facility would operate under the initiative. As required by EPA, Intel assembled 23 official representatives from ten different government agencies and from the local community to negotiate the XL final project agreement.

Shortly after EPA accepted Intel into Project XL, participants established separate working groups to examine the following issues: air permitting, recycling, legal topics and regulatory streamlining. Each group was comprised of regulators, public representatives, and Intel employees. According to Angela Boggs, an Intel employee charged with public outreach, at least five Intel employees spent between 80 to 100 percent of their time attending official and informal meetings, fielding inquiries, and disseminating information about the entire FPA. To negotiate the air permitting portion of the agreement, Intel estimates that each employee worked anywhere from 40 to 60 days. The figure includes time devoted to working group meetings, as well as conducting one public hearing.

In addition to Intel labor costs, the company also hired third parties to facilitate the FPA negotiations. For example, Intel secured a facilitator to supervise and assist work groups developing the FPA. The firm also used outside legal counsel to help develop the final project agreement, including the air permit. Isolating external legal fees for the air permit from other portions of the Intel agreement is too complicated for confident estimation.

In addition to labor costs, transaction costs to develop the permit include materials, travel, and communication costs to assemble those affected by the agreement. For example, Intel posted 20,000 notices in Chandler, Arizona to encourage the public to participate in Project XL. The company also created a web site to inform the public about XL meetings.

Given the aforementioned factors, it is likely that Intel spent more to negotiate the XL air permit than to negotiate a traditional permit. However, the greatest source of cost savings to Intel -- outside of the reduced permitting time -- is likely to be lower transaction costs associated with administering the XL permit. The XL permit's preapproval features lump all fees and preparation costs that would otherwise occur each time the producer makes a production change into a one-time, up-front cost. In addition to filing fees levied for each separate notification, other costs associated with permit notifications include sampling, analysis, and reporting. Due to the highly rarefied environment of wafer fabs, emissions from individual sources are difficult and costly to pinpoint. In addition to analysis, permits require preparation time.

The magnitude of transaction cost reduction associated with preapproval partly depends on whether or not Intel decides to construct Fab X. As discussed in the case study section above, securing an operating permit for a entirely new facility may take up to six months to process through the county. If Intel decides to build Fab X at the Ocotillo site, the XL permit eliminates the need for the manufacturer to secure an additional operating permit for the facility.

Data from an existing Chandler facility developed by Intel illustrate some of the potential cost savings associated with permit preapproval. According to the Intel study, the facility filed with MCESD 28 permit notifications during the first eight months of 1994. In 1993, the site had 32 equipment modifications processed under the Section 100(a)(2) provision with 5 separate notifications. In 1992, the site made 50 revisions to its permit to operate with five different notifications (Hatcher, 1994, p. 10). The data are derived from another Intel facility in operation before Fab 12. However, assume that an average Intel facility prepares 50 notifications per year and files them with Maricopa County in batches of five. As a first step to estimate savings associated with a permit that approves equipment and emissions levels in advance, county filing fees, individual tool or chemistry analysis, and permit preparation costs can be multiplied by five. By this method, over five years the XL permit replaces the cost of 25 separate notifications filed throughout the permit life. In theory, at least, the transaction costs associated with XL permit preparation and filing should be roughly one-25th as expensive as the cost of a traditional MCESD permit. Obviously, refining crude benefit estimates requires developing factors more appropriate for Fab 12, as well as knowing what Intel actually spent to prepare and file the XL air permit with MCESD.

Offsetting potential savings in administrative cost to Intel are several features that are not required under a traditional permit. For example, to insure that pollution loadings (as opposed to the composition of those loads) do not exceed output, the permit requires Intel to develop a measure with which to insure that emissions do not increase proportionally more than production. Furthermore, to insure that hazardous emissions under the XL permit are sufficiently low to protect human health, Intel commits to conduct fate and transport modeling to determine whether predicted emissions will be consistent with the AAAQGs.

The reporting provisions under the XL air permit are likely more stringent than a traditional permit, which only requires companies to report once a year. In contrast, Intel agrees to prepare and release *quarterly* emissions reports based on the flow of materials and energy into and out of the fab. Such flows are estimated using emissions factors that consider, for example, fuel use and the type of equipment generating the pollution.

Transaction Costs Borne by Government Agencies

The Environmental Protection Agency (EPA), Arizona Department of Environmental Quality (ADEQ) and Maricopa County Environmental Services Department (MCESD) are the three major government agencies involved in the air permit portion of the Intel effort. As is standard practice, we assume that the time and other resources put into the negotiations by government agency personnel are diverted from other activities with an opportunity cost equal to the wage. The following discussion briefly describes transaction costs that were likely to be borne by EPA, ADEQ and MCESD.

EPA administered the Intel effort from its Region 9 office in San Francisco as well as through a small core of staff members in a policy office in Washington D.C. Ultimately, however, the air permit and the broader FPA also drew in staff from the administrator's office down through the agency's various air, water, and waste program offices. As in the case of Intel, apart from time spent in meetings and conference calls, it would be difficult to isolate how much agency time was directly devoted to the air permit. At least one Region 9 employee was devoted exclusively to the air permit portion of the agreement.

What is clear is that EPA's transaction costs to negotiate the air permit were greater than expected due to the experiment's novelty and duration. For example, a report prepared by the National Academy of Public Administration (NAPA) found that one EPA Region 9 employee was expected to divert about 20 percent of his time away from job duties such as "wetlands management" to develop the Intel agreement. In fact, the employee ended up working on XL full-time (NAPA, 1997, p. 91).

The NAPA report also describes other categories of transaction costs, including communication and travel expenses. For example, EPA staff from Washington and San Francisco conducted frequent conference calls and traveled to the Chandler facility. One Region IX employee spent \$14,000 alone for frequent treks from San Francisco to Intel's Ocotillo facility.

It is difficult to discern from the XL air permit and the XL final project agreement what the costs to EPA of permit administration will be. Since the agency obviously has an

interest in the project's outcome, involvement is likely to extend beyond negotiation. Because Intel was unable to vest air permitting authority with the State of Arizona, it is unclear whether the state will bear transaction cost to administer the XL air permit.

In contrast to EPA, the staff from Arizona DEQ and MCESD were largely drawn from individual program offices, rather than from across agencies. That is, analysts charged with administering the federal Clean Air Act at the state and county level worked on the air permit portion of the Intel agreement. While the state devoted staff and resources to the negotiation, it is likely that the county office charged with air permit administration bore the lion's share of negotiation costs. Furthermore, since Intel was unable to vest permitting authority with the State of Arizona, it likely that MCESD will similarly bear most of the transaction costs to administer the XL permit.

Maricopa County was required to incur both traditional permit development costs as well as costs of the XL negotiation because the county insisted that the XL air permit appear as a separate, enforceable document to the FPA. As a result, MCESD was required not only to participate in the nine month negotiation but also to follow all relevant administrative procedures, including providing for public notice-and-comment. In contrast to a traditional permit, which typically draws little public response, the highly visible XL effort attracted formal comments from groups nationwide, in particular, from scientists and lawyers at Washington D.C.-based non-governmental organizations (NGOs). MCESD was required to respond to as least a dozen lengthy, detailed comments.

The XL permit also contains supplementary administrative features. For example, the XL air permit stipulates that Maricopa County officials may inspect the facility and require the plant to verify the data in the firm's quarterly emissions, whereas regulators in the past reviewed paperwork and were not required to visit the site. The XL permit also could represent a revenue loss to MCESD, which normally levies fees each time a manufacture seeks to modify a permit. However, this revenue loss is Intel's gain, so one would not want to count this transfer as a social loss or gain.

Transaction Costs Borne by Non-governmental Organizations (NGOs)

In addition to official participants, a number of unsolicited outside actors such as Non-Governmental Organizations (NGOs) sought to influence the negotiation late in the process. NGO representatives prepared detailed and often, highly visible objections to the air permit portion of the Ocotillo agreement. Several environmental groups questioned whether the emission levels contained in the XL permit were consistent with XL's original goal of delivering environmental performance superior to a traditional air permit (EPA, 1996f).

While they were not considered official participants in the negotiation, a number of non-local organizations including the NRDC, SVTC, and the Good Neighbor Project also invested time and resources to study and comment on the Intel XL air permit. In some cases, NGO involvement consisted of letter-writing campaigns and petitions. In others, NGO scientists and legal experts filed exceptionally detailed responses to the air permit's technical features. If NGO expenditures are taken into account, their indirect involvement in the

negotiation both raises the total transaction cost, and raises the cost of official participants in the negotiation. To illustrate the latter, consider that objections to the air permit filed by the NRDC with Maricopa County required the agency to spend time and money to prepare responses. It is unclear at this time whether non-local NGOs will continue to be involved in the administration of the XL permit.

Transaction Costs Borne by Public Participants

While Intel staff, regulators and NGO representatives drew paychecks from their respective employers during the negotiation, five Chandler residents volunteered to participate in the nine-month negotiation. At least one public volunteer worked on the air permit portion of the final project agreement. In addition to attending official meetings, volunteers also participated in informal meetings, telephone conversations and interviews. According to the NAPA report, the public volunteers on the air permit group found it necessary to take home work in order to understand the technically challenging provisions of the air permit (NAPA 1997, 92). Other expenses that were likely borne by public participants to negotiate the agreement include communication, travel and food.

Administration of the XL permit also represents a public transaction cost. In contrast to a conventional permit, the XL permit requires a panel of community advisors to review quarterly emissions statements. Time and expense to monitor, review and report on emissions must be considered as a social cost.

4. Summary

Negotiating the XL permit required Intel, government agencies, and public volunteers to spend more time and money than a traditional air permit. Unexpected involvement from non-governmental groups increased even further the cost and time required of all participants to secure the XL permit. However, costs to administer the permit are likely lower than a traditional permit, since a traditional permit requires the manufacturer to notify MCESD each time a production change occurs. The permit's preapproval provisions may save MCESD money and time as well.

VI. THE DYNAMIC BENEFITS OF REDUCED PRODUCT DELAY

Intuitively, it seems better to bring a product to market sooner, rather than later. But exactly why is that so? And if a single firm achieves a quicker time-to-market, how does that affect other firms and society generally? To answer these questions, we now turn to an economic analysis of the dynamic, or intertemporal, effects of the XL permit.

1. The Benefits of Speeded New Product Introduction

The growth of demand for processing power and features and the rapidity of chip design innovations places a premium on early product introductions. Perhaps more than in any other major industry, delayed semiconductor production translates into significant

foregone profits and (perhaps) consumer benefits. The importance of time-to-market in this industry is illustrated by the fact that in five years, the average Intel chip fabrication plant introduces at least two new generations of process technology (Hatcher, 1994, p. 7). While plants may be upgraded indefinitely, they typically become unfit for fabrication of the most technologically advanced products after five years. Indeed, Intel constructs a new wafer fab roughly every nine months (Kirkpatrick, 1997, p. 62). The rapidity of product and process turnover is reflective of intense competition and rates of innovation in the industry. In such a market environment, delayed product introductions are particularly damaging to a firm's customer relations, competitive position, and profits.

One of the principle benefits to Intel of its participation in the XL program is that the negotiated agreement promises to speed the environmental permitting process, and thus speed Intel's time-to-market. This section develops a way of thinking about the benefits of streamlined permitting, using insights from business and economic theory. Understanding these benefits is necessary in order to evaluate the ultimate performance of the Intel-XL agreement.

What is the value to a firm such as Intel of being able to introduce products more quickly? While the question is simply posed, its answer is surprisingly complex. As will be shown, the value of more rapid product introductions depends, not just on a firm's direct competitors (other chip manufacturers), but also on the firm's own existing and future products, and on the development of complementary products used in conjunction with microprocessors (software applications, computer hardware). These continuously evolving product markets seek to supply a consumer market that itself has complex characteristics. "Platform" effects, such as that which has given Microsoft's operating system its distinct competitive advantage, the relatively capital-intensive nature of a computer system purchase, and differing tastes regarding computational speed and new product applications all complicate demand forecasts and producer strategies. As a consequence, the value of accelerated product introductions cannot be derived via some simple calculation.

In order to sort through this web of issues, the analysis is decomposed into several areas of discussion. In each case, we will analyze the benefits of speeded product introductions to an innovative firm such as Intel. The benefit of more rapid time-to-market affects both a firm's desire to participate in a program such as XL and the scale of environmental performance improvements that can be negotiated in the permit process.

In many cases, the benefit of speeded product introductions can be thought of as producing a social benefit, beyond the private benefit to a particular firm. Consumers are usually made better off by earlier, or more frequent product introductions. This is not always the case, however. When there are competing firms, profit may simply be transferred from one competitor to another, without any net consumer gain. For instance, earlier adoption may give a firm a competitive advantage over rivals that ultimately leads to reduced competition. In this type of case, earlier adoption yields a large private benefit, but could actually create a social cost. We will take care, therefore, to distinguish between the private and broader social effects of speeded product introductions.

The section is organized as follows. We begin by analyzing the ways in which the timeliness of innovation and production affects the decisions and "private" interests of firms. For simplicity, the case of a single-generation product monopolist is considered first.⁶ Even in this simplest of cases, we can identify a rich set of factors that determine the benefit of speeded product introductions. Greater realism then leads us to consider the importance of factors such as multiple generations of products, complementary products, and the firm's competitive environment. The section concludes with an analysis of the ways in which the benefits of streamlined permitting to the participating firm can differ from the social benefits.

2. Benefits of Rapid Introduction in a Non-Strategic Market Environment

We begin the analysis of rapid introduction in the simplest possible environment, that in which production is controlled by a monopolist and not threatened by potential competitors. The assumption of production by a monopoly allows us to temporarily set aside "strategic" issues -- such as the way in which rapid introduction affects the firm's market share and ability to maintain technological leadership.

A. Benefits of Accelerated Introduction to a Single-Generation Product Monopolist

At the outset we will also assume that the firm produces a single-generation product. The assumption of a single-generation product means that we can ignore the effect of acceleration on demand for future products the firm will produce. This assumption will be relaxed in subsequent sections of the analysis.

When trade occurs between a firm and consumers the trade generates what is called a social surplus, or gains from trade. Benefits arise when these gains from trade come earlier in time. Two sources of benefit can be identified, accelerated income and accelerated consumption benefits.

The accelerated income benefit is the benefit to the firm of achieving profits earlier in time. The accelerated consumption benefit corresponds to the gain in utility (satisfaction) consumers experience from being able to consume the product earlier.

Central to a more detailed description of these benefits is the concept of the time-sensitivity of demand.

The time-sensitivity of demand

Most of us are reminded daily that it is desirable to have a product or service sooner, rather than later. The use of credit cards is illustrative. Consumers pay credit card charges, for instance, in exchange for the ability to purchase and consume a product immediately. If a

⁶ Our use of the term monopoly in this report is an analytical convenience only. Intel is most appropriately described as an oligopolist, that is a firm with a relatively small number of competitors.

consumer is willing to pay \$100 in credit charges to have something this year, rather than next, we can conclude that delayed consumption would make them worse off by at least \$100. Eventual use of the product is valuable to a consumer, but the inability to use a product over some period of time generally means that the consumer is worse off than if they could use it immediately.

For this reason, we will think of demand (a product's value to consumers) as being a function of time. Permitting delays can reduce the value of products to consumers by truncating the number of periods over which the product's benefits can be realized.

The time-sensitivity of demand depends on the degree to which consumption in a later period of time is a substitute for consumption in an earlier period of time. Put differently, is a consumer's demand tomorrow independent of whether or not their demand was satisfied today? Consider two polar cases to help illuminate this concept. First, assume that any unsatisfied demand in period 1 is perfectly transferred to period 2. For instance, a couple too busy to go on their honeymoon in year 1 may be just as happy to honeymoon in year two. If so, delay does not make the couple worse off. And the firm supplying honeymoons does not lose the sale, though it is delayed.

The second case is that in which unsatisfied demand in period one is not transferred to period 2. A bride who is unable to buy a wedding dress on her wedding day has no demand for a wedding dress a year after her wedding day (it is hoped). If consumption must be postponed, the value of the wedding dress is completely lost. In this case, the inability to satisfy demand in period one means that revenue from such a sale is not just delayed, as in the previous case, but is foregone altogether.

The relative importance of accelerated income and consumption benefits from more rapid product introductions is a function of demand's time sensitivity. Thus, the estimation of acceleration benefits is not a transparent, straightforward calculation. In addition to estimates of foregone profit and the relevant discount factor (i.e., the time value of money), the firm must estimate the degree to which future consumption is a substitute for foregone present consumption.

B. Benefits of Accelerated Introduction to a Multi-Generation Product Monopolist

Now add an additional degree of realism. As in the case of Intel, a firm often produces successive generations of products. While a firm's new products usually outperform its old ones, to some degree the new and old products are substitutes for each other. That is, the new product replaces, or "cannibalizes" the old. This influences the optimal timing of new product introductions. If a new product is introduced too soon after an old one, there may be too little demand for the new product since consumers have recently purchased the old product. Alternatively, demand for the *older* product may be weak if consumers anticipate the new product, and thus delay purchase until the new product is available. The possibility of both "forward" and "backward" cannibalization influences the optimal timing of product introductions. In turn, cannibalization influences the benefit of an accelerated product introduction.

To deal with the issues presented by multi-generation products, we shift to a somewhat different description of the factors that influence demand. Instead of assuming that demand for a single product is a function of the time of consumption (as above), we now want to depict a product's demand as a function of, not only its own timing, but also as a function of the timing of previous and future "generations" of the product. Consider three generations of a product, produced at times t_0 , t_1 , t_2 . Different product generations are always to some extent substitutes for each other. This means that the demand for any one of the generations will depend not only on its own price and time of introduction, but also on the prices and times of introduction of the other generations. Consider demand for generation 1. To determine its optimal product introduction strategy, the firm will want to know how demand for the generation 1 product is affected by the prices and dates of introduction of its newer generation products. These effects are described by *cross-elasticities*. Cross-elasticities describe the degree to which a change in price of one product affects demand for another. If a new product generation leaves prices of other generations unaffected, the cross-price elasticity is zero. Alternatively, if product generations are substitutes for one another, the cross-price elasticities will be positive. In other words, as the price of the newer generations falls, the demand for generation 1 will fall.

Elasticities typically describe the effect of prices on a product's demand. They can also be used to describe the effect of different introduction times. Several things can be said about the effect of multi-generation timing on demand. First, a greater "spread" in the time between product generations will tend to reduce their substitutability. This is because consumers are more likely to need a new generation even if they purchased the old, or are less able to skip purchase of a generation when generations do not come in quick succession. Therefore, as the time between generations (t_1-t_0 and t_2-t_1) increases, inter-period substitutability decreases (and cross-price elasticities fall).

Second, the demand effect of a change in the timing of another generation's introduction is ambiguous. As noted above, an earlier introduction of generation 1, by increasing the time between generations 1 and 2, would tend to reduce the substitutability of the two generations.⁷ This would be expected to increase demand for product 2. However, an earlier introduction of product 1 can in some cases reduce demand for product 2. The earlier generation 1 is introduced, the more valuable it is (since consumption is not delayed). This leads to more generation 1 purchases and therefore may reduce demand for generation 2. This can be put another way: if a consumer doesn't have to wait for generation 1, they may go ahead and purchase. If, on the other hand, they have to wait for generation 1, they may instead choose to wait a little longer so that they might consume the generation 2 product.

Inter-generational timing must be considered if accelerated income and consumption effects are to be accurately estimated.

⁷ Clearly, the durability of a product is relevant to inter-period substitutability. Non-durable goods have low inter-temporal substitutability.

C. Product Complementarity

Many products are useless unless accompanied by, or integrated with, "complementary" products. Memory chips are a good example since they have no use unless integrated into a larger bundle of computer software and hardware products. Product complementarity means that the value of each product singly is determined by a consumer's ability to make use of the products together. Consider the relationship between software applications and memory. In order to operate at all, Microsoft's software requires minimum levels of computing power and speed. If Intel, or other chip makers, cannot provide this power and speed, Microsoft's operating system and applications are useless. Correspondingly, if Microsoft does not produce applications for which computing power and speed are important, there will be a considerably smaller market for Intel's high-end microprocessors.

This has clear implications for the analysis of accelerated product introduction. We began with a definition of time-sensitive demand. This concept was expanded to address issues associated with multiple product generations. Product complementarity requires further refinement of our framework. In particular, consumer demand is sensitive to the timing of *bundled*, multi-generation product introductions.

Consumers primarily demand computer components that are bundled with other components. This means that demand for one component must be estimated with an understanding of (1) product complementarities and (2) the introduction times of other products in the bundle.

Given product complementarity, there are a variety of possible consequences to accelerated product introduction. For example, complementarity can mean that acceleration has little or no effect on costs. This will be true if the product introductions of other firms' complementary products are scheduled to come even later. If Intel and Microsoft are introducing a bundled product, there is less benefit associated with acceleration at Intel if the timing of Microsoft's product introduction is the "binding constraint", i.e., the factor that limits introduction of the bundled product to market.⁸ On the other hand, if the opposite is true -- introduction of the Microsoft product is waiting on completion of the Intel component -- the benefits of acceleration at Microsoft must be included in assessment of the accelerated income and consumption benefits from faster introduction of the bundled product.

Another example emphasizes the importance of product complementarity. Chips are typically sold as part of a larger computer hardware system. This larger system is a relatively

⁸ An delayed introduction from May to July will be relatively less important if the introduction of complementary products is not expected to occur until September. As an example, chip manufacturers confront a variety of non-regulatory types of delay, such as that for the delivery of manufacturing equipment ("Chips Not Ready to Fall," *San Jose Mercury News*, Dec. 4, 1995). Regulation is in such circumstances not the binding constraint on production times.

durable and capital-intensive investment. Demand for chips is therefore sensitive to the way in which consumers respond to the size and lifetime of an investment in an entire PC system.⁹

The coordinated introduction of complementary products clearly adds another layer of complexity to the estimation of benefits arising due to speeded introduction. We now turn to an additional set of issues arising from the firm's strategic, competitive environment.

3. Benefits of Rapid Introduction in a Strategic, Competitive Environment

Accelerated product introductions are particularly desirable in a competitive market environment. In most commercial settings, monopolies rarely go unchallenged. Even a perennial market leader such as Intel faces persistent competitive threats from firms that may be only months behind it in terms of new product development. In the presence of competition, delay threatens to erode slim technological and marketing leads. Correspondingly, there is great value to the firm in being a technological and market leader.

This section begins with an analysis of the relationship between technological leadership and profitability. By definition, innovative products are unlike any others, at least for some period of time. This uniqueness implies a strategic advantage. Because there are fewer substitutes for innovative products, price competition is relatively weak. Thus, innovation provides a temporary window of monopoly power. Within this window, the prices a firm may charge are relatively unconstrained by competition.¹⁰ While this benefit of leadership may seem self-evident, several other considerations make leadership of the microprocessor market particularly valuable.

A. First-Movers, Market Share, and Entry Deterrence

Empirical research on firm profitability suggests that technological leaders ("first-movers") gain a significant competitive advantage in terms of market share and sustainable price premiums. This is true in a variety of industries and for a variety of reasons (Bond and Lean, 1977; Bain, 1956). Being a first-mover can be valuable because it allows the firm to

⁹ Durable, capital intensive goods (such as cars) have unique demand characteristics. First, consumers will generally not purchase each successive generation of the product. Second, durability implies the possibility of a secondary, or "used," market. Consumers who wish to, may trade up to the latest generation, but in so doing they introduce their used product into the secondary market. Since used products are a substitute for new, demand in the new product market is affected by supply and demand in the used product market.

¹⁰ The pattern for Intel is to be first-to-market, sell at a relatively high price until competitors such as Cyrix or Advanced Micro Devices enter the market, and then innovate again while exiting the older market. In this way, Intel stays ahead of its competitors, but also stays ahead of price competition. For example, a leading-edge Pentium[®] may initially sell for \$1,000. As Intel's output increases and competitors enter the market, Intel will continuously lower the product price until it hovers just over \$200. Such product release and pricing strategies earn the manufacturer gross margins of around 60 percent.

pursue strategies that deter the entry of competitors. Deterred entry means relaxed price competition and higher profits for the leader.¹¹

Two characteristics of the computer chip market -- the predominance of "standardized operating systems" and manufacturer cost savings due to "learning by doing" -- allow first movers to deter competition. These competitive strategies are important to an understanding of the benefits of accelerated product introduction.

Operating system standardization

Intel's chips are integrated technically with a software operating system (Microsoft Windows) that dominates its market. While this dominance is due in part to the quality of Microsoft's and Intel's products, it is also due to some special economic characteristics of computer operating systems. It is to these characteristics that we now turn.

Certain products, including computer operating systems, exhibit what is called a "network externality." This concept describes the situation in which a product becomes more valuable as more consumers use it. The classic example is a telephone network. If only two people can speak to each other on the phone, the network's value is limited. As the network expands, however, each person connected can communicate with a larger and larger group. Thus, the value of a phone network increases as more and more people have phones.

By its nature, a network externality can create a market dominated by a single firm. If consumers value the use of a single, "standard" product, this can undermine a market's competitiveness by deterring rival, non-standard products. This is clearly beneficial to the firm whose product defines the standard.

A formal example will help to illustrate. Let $U(n)$ and $V(n)$ denote the benefits to a consumer of using two potentially competing products. If both products exhibit a network externality, these benefits are an increasing function of n , the number of people that consume them. For simplicity, assume that there are only two consumers. It follows that $U(2) > U(1)$ and $V(2) > V(1)$. Further, assume that $V(2) > U(1)$ and $U(2) > V(1)$. This means that the consumers are strictly better off if they coordinate, and both use the same product. This emphasizes the desirability of a technological standard. Without such a standard, one consumer may purchase the U product, while the other purchases the V product, and both are worse off.¹²

¹¹ Profitability itself has been shown to be positively correlated with market share. This is true holding things like product quality constant (Buzzell and Gale, 1987).

¹² This situation is evocative of the competition between the competing videocassette player formats, VHS and Betamax, in the early 1980s. Before VHS emerged as the standard, video distributors had to choose between supplying tapes formatted for only one standard (which meant lost sales) and manufacturing tapes for both formats (which increased costs). Consumers faced a corresponding dilemma in terms of which type of player to purchase. The lack of a uniform standard resulted in costly duplication, unavailable video titles for many consumers, and investment in ultimately useless products based on the failed Betamax standard.

This example also highlights the strategic benefits of being a first-mover. By setting the standard, a first mover can assure itself of a market free from competition. To see this, assume that if there were agreement on the standard, the U product would be preferred to the V product, i.e., $U(2) > V(2)$. But consider what happens if the V product is brought to market first and is purchased by one of the consumers. The presence of the network externality means that it is in the interest of the second consumer to also purchase the V product. The network externality, combined with V 's first-mover advantage results in V 's emergence as the standard, even though U would have been unanimously preferred (Farrell and Saloner, 1985). In this way, first-movers are able to strategically deter the emergence of a rival standard.

The pervasiveness of the Microsoft operating system (OS) and the problems for Macintosh are due, at least in part, to the successful employment of this strategy. Computer operating systems exhibit a network externality because users value compatibility with other users. Software applications that run on different operating systems are not typically compatible. In turn, this means that documents and databases constructed on one OS cannot be "read" by applications associated with another OS. Moreover, it is costly for users to maintain parallel systems. There are significant "switching costs" involved with moving between operating systems. These include hardware costs (since different operating systems typically have different hardware needs) and the need to learn how to use the second operating system (a daunting proposition for many users). Microsoft's open architecture and focus on market share has led to the emergence of its operating system as the market standard. Given switching costs and the presence of a network externality, Microsoft is in a strong position to deter and stifle rival operating systems.

What is the implication for Intel of Microsoft's standardization strategy? To answer this question it is important to note the almost symbiotic relationship between Microsoft and Intel. From a purely technical standpoint, Intel's hardware and Microsoft's software are integrated in the design phase in order to maximize the ultimate performance of the bundled product. Successive software product generations are matched with successive hardware (chip) improvements. Intel has contributed to Microsoft's market dominance by providing it with the hardware innovations necessary to the performance of Microsoft software innovations. In turn, Microsoft's ability to dominate its market translates into strong, consistent demand for Intel's products.

Microsoft enjoys significant market power via its possession of the dominant operating system standard. Intel shares in that market power because of its technical integration with Microsoft's products. This has two, conflicting implications for the benefits of accelerated product development. Even if a competitor were to be first to market with an innovative chip, Intel would likely be insulated from the threat due to its integration with the OS standard. This is true since innovations which are not integrated with the standard OS platform will tend to be resisted by consumers. However, this insulation is likely to be effective only in the short term. Should a competing chip manufacturer consistently beat Intel to market, Microsoft would undoubtedly seek product integration with the competitor. Also, continued integration with the Microsoft OS is very valuable to Intel. Accelerated product

introduction enhances the firm's ability to remain in innovative lockstep with Microsoft, and thus profit from the dominance of their bundled product.

Integration of its microprocessor products with the Microsoft OS platform is highly valuable to Intel due to Microsoft's dominant market position. Accelerated product introduction improves the likelihood that this integration will continue and be a source of value to Intel.

Computer markets, and particularly the market for OS software, exhibit economic characteristics that create market power for technological leaders. Intel's status as a leader, and the complementarity between its products and the market's standard operating system, implies some insulation from price competition. While an important source of profitability, this advantage is constantly threatened by firms seeking to supplant Intel's position as technological leader. Accelerated product development for any firm in this industry is a source of significant competitive advantage, and thus value.

Learning by doing

The previous section described how a characteristic of computer demand (the network externality) provide a competitive advantage to first movers in the market for computer operating systems. This section describes a similar first-mover advantage, but one that arises from the manufacturing side of the market.

In early production stages, the manufacture of technologically complex products is fraught with difficulties. As a firm produces more and more of the product, however, it learns to produce it more efficiently and with higher levels of quality. Production experience leads to the rationalization of processes, reduced waste, and greater labor force expertise. Average production costs decrease over time and with increases in the firm's cumulative output.¹³ This effect is referred to as the "learning curve" or "learning by doing."

Learning by doing raises entry barriers by creating a persistent cost advantage for first-mover firms. This cost advantage may deter the entry of competitors. Any initial first-mover cost advantage increases market share. In turn, this leads to even greater learning, cost reductions, and competitive advantage.¹⁴

There is a pronounced learning curve associated with the manufacture of computer chips. Consider the "yield rate," or ratio of usable to chips to total chips on a wafer. This yield rate has been shown in several studies to be an increasing function of production experience. Unusable chips are costly, so as the yield rate improves, the average cost of usable chips falls. Gruber (1994) finds evidence of firm-specific learning by doing in the

¹³ Airframes and Ford's Model T are classic examples.

¹⁴ For economic analyses of learning by doing and its competitive implications see Arrow (1962), Spence (1981) and Fudenberg and Tirole (1983).

semiconductor industry.¹⁵ Flamm (1994) considers the question of whether learning takes place primarily within a given product line, within a given firm, or across different firms. Using statistical techniques, he finds that learning-based cost reductions are best explained by facility-specific experience.¹⁶

Given learning by doing, speeded product introduction clearly benefits a firm such as Intel. By enhancing its ability to be a first mover, speed allows for the capture of initial market share. This triggers the virtuous circle of lower manufacturing costs, greater market share, even more learning by doing, lower costs, etc. The end result of this cost advantage is the ability to aggressively price and/or sustain healthy profit margins.

Speeded product introductions allow Intel to move down the manufacturing "learning curve" more quickly than its competitors. This leads to significant cost advantages that strengthen the firm's competitive position.

This section has highlighted the desirability of being a technological leader. Speeded product introductions allow producers to capture large initial shares of their markets. The economics of the computer market make this a very valuable situation. Because of consumers' desire for standardization and the existence of manufacturing learning effects, firms that capture initial market share possess a distinct, and valuable, strategic advantage.

B. Appropriability

The design and development of new products requires investment in new scientific, technical, and manufacturing knowledge. Because these investments are costly, they will be made only if the firm expects some competitive reward for doing so. This reward may take the form of reduced production costs, which increase profit margins or allow the firm to undercut competitors' prices. In the case of a firm such as Intel, the reward comes from producing a product with unique characteristics -- a "differentiated" product. As discussed in a previous section, differentiated products are ones with no close substitutes. The lack of close substitutes means relatively weak price competition, or a kind of temporary monopoly. The promise of such a monopoly, even if it is only brief, motivates innovation.

The benefits of innovation are significantly reduced, however, if one's competitors can copy, or *appropriate*, the innovator's new ideas. If new ideas are appropriated, the uniqueness of the innovator's product is undermined. While this enhances competition, it correspondingly reduces the profitability of the new product.

By rewarding innovators with a temporary (usually 17-year) monopoly on their ideas, the patent system guards against the threat of appropriability. In this way, patent protection

¹⁵ He also develops a theoretical model to explore the effect of learning by doing on firm profitability in the industry. The model confirms the value of being a first mover by showing that profits are decreasing in the order of entry into the market.

¹⁶ For another empirical examination of learning by doing in the industry see Dick (1994).

stimulates the incentive to innovate. In some situations, however, patents are an imperfect means of guarding against appropriation. First, some ideas cannot legally be patented. Second, even if a patent is granted competitors may be able to "innovate around" the patent using slightly different techniques. Third, patenting requires the innovator to publicly reveal the substance of its new idea. Together, these problems can undermine the patent system's ability to assure an innovator of adequate rewards. Evidence of the rapid dissemination of semiconductor technologies suggests that patent system protections in this industry are weak (Lamond and Wilson, 1984, p. 46).

Because of weaknesses in the patent system, innovators must often rely on there being a delay in their competitors' ability to appropriate innovative ideas. Imitation, while much easier than innovation itself, may nevertheless be difficult. New ideas, jealously guarded by their originators, must be acquired. Engineering personnel must educate themselves regarding the new ideas and designs and production processes must be altered. This creates an "imitation lag," or a window of time during which the original innovator can expect to be in sole possession of the fruits of its innovation. Innovation lags are important in the semiconductor industry, but are also vanishingly brief. Intel's two to three month lead on its closest competitors is illustrative.¹⁷

Speeded product introduction is particularly valuable in a market environment in which imitation lag times are short. Speeded introduction lengthens the period of time during which the innovator's product is unique within the marketplace, and thus not subject to competitive pricing pressures. Appropriation can begin to occur long before a product comes to market. If imitation begins with the development of new designs, for instance, a delay in manufacturing will not delay imitators, it will simply reduce the time span over which the innovator can market its unique (and thus relatively profitable) product.

Know-how relating to production techniques and design characteristics is under constant threat of appropriation by competing firms. Speeded product introduction helps preserve profits threatened by appropriation.

Appropriability can reduce the barriers to entry described in the previous section. Timely appropriation can reduce a first-mover's lead time and thwart its attempt to gain the market share necessary to capture strategic learning or network benefits.

4. The Social Versus Private Costs of Delay

The previous sections have described several sources of benefit to a firm that can accelerate product introductions. Analysis of these benefits assists the evaluation of Intel-XL-type agreements. However, it is important to emphasize the following distinction: the existence of economic benefits to Intel need not imply economic benefits to society generally.

¹⁷ Appropriation, while ethically problematic, is an inescapable reality in all industries. The discussion in this section, however, should not be taken to suggest any specific allegations of appropriation by Intel's competitors.

Even if speeded product introductions unambiguously benefit an innovator, and even if environmental implications of the regulatory agreement are left aside, a more cautious declaration of improved social welfare is required.

While a given innovator may benefit from speeded product introduction, the social benefits of greater speed are more difficult to demonstrate.

First, economic analyses suggest that competition in innovation can lead to excessively *early* adoption of new technologies. Fudenberg and Tirole (1985), for instance, develop a model in which firms choose the optimal timing for new product adoptions. One of the strategies explored in the model is for a technological innovator to "preempt" its rival by adopting an innovation sooner than it otherwise would. How can early adoption be undesirable? It is most realistic to assume that earlier adoption is more costly than later adoption. Thus, the costs of innovation may be too high if firms find it in their interest to adopt early. Because part of the benefit of being a first-adopter comes at the expense of rival firms, the private benefit of early adoption exceeds the social benefit of early adoption. As a result, competition can result in earlier (and more costly) adoption times than would be optimal for the industry as a whole (including consumers).

Second, analyses of product variety (Scherer, 1979; Spence, 1976) suggest that some markets may produce too much product variety. If we draw an analogy between product variety and multiple product generations, this type of result suggests that computer manufacturers may introduce product upgrades too frequently. A monopolist may deter rivals by offering a range of products to fill niches that would otherwise invite entry. The value of filling such niches is higher to a monopolist than to its competitors since the monopolist does not face competitive price pressures. As a consequence, brand proliferation or excessively frequent upgrades can be a sustainable, entry-detering strategy.¹⁸

Third, analyses of first-mover behavior suggests that market power can be created and that such power has ambiguous effects on social welfare. By definition, firms with market power can sustain price levels that exceed production costs. On one hand, market power rewards, and thus stimulates, innovation. Without this reward innovation may never occur. On the other hand, market power by definition creates a loss to society associated with stifled competition. This tradeoff is directly reflected in the design of the patent system. Patents grant market power for a period of years in order to reward innovation. Market power is not granted indefinitely, however, so that consumers can eventually benefit from competition.

Theoretically, then, product introductions can be too early, too numerous, and lead to anti-competitive outcomes. While this does not suggest that the government should actively seek to delay product introductions, it does suggest that the effect of speeded product

¹⁸ See also Gilbert and Newberry (1982). They demonstrate that a monopolist's incentive to innovate and remain a monopoly is greater than an entrant's incentive to innovate and become a duopolist (i.e., one of two leading firms), since competition reduces the industry's aggregate profits.

introductions on social welfare is complex and not equivalent to the private benefits enjoyed by innovating firms.¹⁹

VII. MEASUREMENT OF THE XL PERMIT'S BENEFITS

This analysis has developed a structure to classify the benefits and costs to Intel, and the benefits and costs to society, of Intel's XL permit. The framework defines categories of costs and benefits that must be measured (or estimated) if we are to evaluate whether or not, on balance, the XL permit improves social well-being relative to the status quo -- traditional command and control regulation.

Using our framework as a guide, the first conclusion to be drawn is that exhaustive, precise measurement of the permit's incremental effects is likely to be difficult, if not impossible. This is due in part to the site-specific nature of the XL permit. It is also due to the complex effects that any form of regulation -- including command and control -- can have on the private sector. But while it is difficult to be precise, analyses of these effects can proceed and can provide suggestive evidence on the social welfare effects of the agreement. We emphasize, as well, that measurement issues should not be used as an excuse to avoid experimentation with regulatory flexibility. Our framework suggests that on conceptual grounds alone, the benefits from flexibility can be substantial.

This section begins by highlighting the types of data required to do a comprehensive measurement of benefits and costs. It concludes with a prescription for the way in which measurement issues should be confronted by regulators and analysts. The key to the prescription is to distinguish between the social effects of a new permit and the private costs and benefits to the permitted firm.

1. Measuring Intel's Private Costs and Benefits

Our framework has highlighted a set of ways in which the XL permit will affect Intel's costs and benefits. In the discussion of static costs and benefits we described how regulatory flexibility can lead to technical flexibility. In turn, this technical flexibility -- whether it comes from the ability to use different inputs or install different capital equipment -- can reduce the firm's production costs. Note that the information necessary to calculate the savings from this type of flexibility is extremely technical and highly specific to the site and product being produced. Estimating private benefits associated with flexibility under the VOC and HAP caps is challenging because of the sheer number of potential chemicals, proportions, and process changes. Changes will be made from over 300 manufacturing steps.

¹⁹ It is also worth noting that semiconductor manufacture is an internationally competitive industry. There is evidence, for instance, that Japanese firms are particularly adept at optimizing the production process (i.e., learning by doing effects are significant). In one study, (OECD, 1985, 35) the average yield rate on chips was twice that of U.S. firms in the first two years of a product cycle. Global competitive threats strengthen the desirability -- domestically -- of accelerated product introductions but the benefits from a world perspective are not necessarily positive.

One hopeful possibility, however, is that firms may be able to generically identify the most common chemical and equipment changes. This perhaps would allow for use of probabilistic engineering models to estimate changes in abatement costs. With Intel's cooperation, transactions costs could be easily estimated.

In the discussion of dynamic costs and benefits we described the complex consequences of reduced manufacturing delay. Consumer demand for products, market share, and technical interrelationships with complementary products are all profoundly affected by the timing of product introductions. These strategic considerations translate into the long-term success of the firm, and therefore define categories of benefits that should be estimated. Again, however, these are complex issues and specific to the product and business.

Moreover, in estimating both technical and strategic benefits the necessary data, particularly on strategic benefits, may be understandably, but jealously, guarded by Intel. Data on market strategies and opportunities and on the technical layout of production facilities is commercially sensitive. Therefore, estimating a dollar value for Intel's benefits to participation in the XL project is nearly impossible, at least for parties external to the firm, unless the firm fully cooperates. Having said that, our conceptual analysis suggests that accelerated product introduction is likely to translate into a sizable economic benefit. While some quantitative "flesh" can be put on these conceptual "bones," a precise estimate of strategic benefits is likely to be impossible.

2. Measuring Social Costs and Benefits

To discuss measurement of social costs and benefits, consider three categories that have been delineated in the analysis: environmental costs and benefits, transaction costs, and market-level costs and benefits.

A. The Environmental Baseline

Of particular concern to many is whether or not the Intel permit will lead to greater environmental quality than would have occurred with command and control regulation. The first step in answering this question is the definition of baseline emissions under the traditional system. This is a non-trivial challenge.

The estimation of environmental benefits or costs requires a clear definition of the baseline, such as one defined by a status quo "control facility" against which to compare XL permit emissions at the Intel facility. While Intel operates fabs in other states with some processes comparable to Fab 12's, the other fabs fail to serve as adequate controls both because they are not identical to Fab 12 and also because minor new source permitting provisions vary among states. The ideal control would be a twin facility in Chandler constructed at the same time with identical output as Fab 12 and a traditional minor new source air permit issued by MCESD. In practice, it may be possible to simulate a control by collecting data through surveys or interviews with engineers at comparable Intel facilities in

order to construct a composite. One possibility is to examine a comparable facility operated by AMD, or, until recently, Cyrix foundries, IBM microelectronics and SGS Thomson.

In order to develop such a profile it is necessary to know exactly what type of product Intel crafts at Fab 12. According to trade reports, the product is a P55C with multimedia or MMX technology (Slater, 1996). If true, comparable products include Cyrix's M2 chip and AMD's K6. In the unlikely event that Intel's competitors would agree to provide data with which to construct a control, it will be necessary to first define air permitting provisions comparable to those in Maricopa County. Other, more sensitive data include wafer starts and yield in order to more accurately compare Fab 12 emissions and production with a control.

In addition to Fab 12, the XL permit covers the proposed Fab X facility, which currently exists only on paper. If Intel decides to construct Fab X at the Ocotillo site, it also will be necessary to develop a baseline for that facility as well. This will create an even greater challenge, given that the facility remains in the planning stage. Put crudely, how is it possible to know what emissions would have been from a fab that has not yet been built? To some degree, it may be possible to survey engineers at Intel's advanced design facility to determine "how much more" pollution their processes must control as a result of Intel's participation in Project XL. The task will be easier if Intel or its competitors plan to construct facilities comparable to Fab X. It also may be possible to create a historic emissions profile from other Intel facilities to forecast what emissions from Fab X would have been in the absence of Project XL.

A simpler method, mentioned in Section 4, would be to use major source permitting limits under the Clean Air Act as the baseline. If federal levels are used to indicate what Intel would have emitted in the absence of XL, it is much easier for Intel and regulators to calculate changes arising from the XL permit.

Regardless of the baseline chosen, facility-specific regulation creates challenges for measurement. When emissions are shifted from one chemical to another, environmental benefits will change. Risk assessment and valuation of changing risks are needed to appropriately account for the effects of these shifts. These issues are complicated, but not insurmountable. Finally, tailored regulation, by moving to cap-based limits, poses new challenges for emissions monitoring. Movement away from technology-based standards means movement toward more difficult forms of compliance monitoring. There is sufficient reason to believe that these challenges will be worth the effort.

B. Transaction Costs

Our framework has distinguished between transaction costs associated with development and negotiation of the XL permit and those associated with the permit's future administration. The former can in principle be measured retrospectively, while prospective administrations costs can only be estimated. Certainly, "ballpark" estimates of these costs can be obtained.

Development of the XL permit involved, by all accounts, significant social transaction costs borne by the EPA, the State of Arizona, and Maricopa County.²⁰ A retrospective measurement of labor time and materials is complicated, however, because the initiative is not required by law. Without statutory authorization, there is no isolated budgetary paper trail for Project XL. One alternative possibility is that labor time required of regulatory agencies, public participants and Intel could be determined retroactively through surveys or interviews of time commitments. This could be combined with knowledge of prevailing market wages and salaries for respective job titles to approximate the aggregate opportunity cost of labor time devoted to the agreement. The incremental cost due to XL is this cost minus the cost of labor devoted to establishing a conventional permit. Materials costs will be more difficult to capture but may similarly be identified through interviews or surveys.

Ongoing permit administration costs require a different form of estimation. First, it is necessary to define differences in administration between the two forms of regulation. Our analysis has highlighted some of these differences. For instance, the XL air permit replaces approximately 25 individual notifications with one. Presumably, fewer review requirements represent potential savings to Maricopa County in employee time devoted to permit review. For this benefit, there are also offsetting costs. The XL permit requires Intel to prepare quarterly emissions reports and chemical screening models that would not be required by a standard permit. Also, a traditional MCESD permit requires annual site inspections. Under the XL permit, regulators may be required to visit the site with some frequency. How does this frequency compare to that in a standard permitting situation?

C. Market-Level Effects

This report has identified several possible effects of the permit on the larger markets in which Intel competes. Production line cost savings can translate into lower consumer prices for chips, which in turn improve consumer well-being. Timelier product introductions mean that consumers can enjoy a product's benefits sooner. And cheaper, quicker production translates into a concrete advantage over international competition. Enhanced competitiveness for a domestic firm is likely to lead to domestic social benefits. These benefits may have a value that is quite high. If so, they should be accounted for in any analysis that attempts to value the incremental benefit of the XL permit.

The central challenge in calculating market-level effects is the need to estimate consumer demand for chips (consumer demand is just a way of saying "the benefits of consumption"). There is a huge body of literature on techniques and applications of these techniques for estimating market demand for a variety of products. This literature could guide the analysis, but several knotty problems would remain.

First, there are baseline questions. Consider the following example. As we have argued, flexible permitting can lead to lower costs which in turn can translate into lower

²⁰ Intel privately bore costs of its own. Estimating costs to Intel will also be challenging in part because the firm does not require employees to maintain timesheets.

consumer prices. But how would this be demonstrated? There is no "higher price" from which the price actually drops. The higher price is speculative -- i.e. the price that would have been charged if production costs were higher. The only other way to estimate the benefit is to assume that prices will fall in direct proportion to reductions in cost. But this requires knowledge of the baseline cost. As we have argued throughout this analysis, that baseline cost is difficult to estimate.

Second, consumer welfare is not just a function of prices, but also of the timing of consumption. What is the value to a consumer of having a product sooner, rather than later? One answer is to see what consumers are willing to pay to have a product sooner. Unfortunately, there is no direct measure of that value, though it might be inferred in some circumstances from price premiums associated with cutting-edge technology. Finally, consumer demand is a function of product substitutes and complements. Estimates of consumer welfare require knowledge of demand effects associated with these other product markets. (For instance, a delayed product introduction may have little effect on consumer welfare if there are readily substitutable products available to consumers.)

It is worth mentioning again one market-level social cost that could arise from an XL-type permit. By providing a single firm with a competitive advantage (see the discussion of first-mover advantages), price competition in that firm's market may be weakened under certain circumstances. Techniques from anti-trust economics could be used to measure the impact on consumer welfare. This estimation, however, is complicated by the dynamic characteristics of the market. While Intel dominates the front-end of its market in a static sense, its prices are disciplined by rivals that in relatively short order enter Intel's market and compete aggressively.

None of this should be taken to imply that the XL-type permitting is anti-competitive. In fact, if flexible permitting is an option open to all firms, then flexibility enhances competition. Rather, the point is made to underscore the ultimate desirability of offering flexible regulation as an option to all firms, rather than one or two market leaders.

3. Measurement Priorities for the Regulator

The most difficult benefits and costs to measure are those that accrue privately to the firm. Their technical nature and proprietary value make them poor candidates for third-party estimation. Fortunately, this type of data is relatively unimportant from the standpoint of a regulator. Presumably, in the long run, firms can be counted on to participate in flexible regulation only if the private benefits exceed the private costs. Consequently, regulators can be confident of a welfare improvement as long as (1) the firm voluntarily agrees to participate and (2) the non-private benefits of the permit are positive. These conditions are sufficient to guarantee a permit that improves social welfare overall. The focus of regulatory evaluation should be on net environmental consequences, incremental transaction costs, and possible anti-competitive effects. Of these, the latter may be the hardest to capture, although we believe that "soft" quantitative estimates can be obtained.

VIII. CONCLUSION

This paper has developed a framework to evaluate Intel's novel XL air permit. Like the permit itself, the evaluation requires new ways of looking at regulatory issues and raises as many questions as it answers. Our analysis takes an economic approach to the problem. Economic analysis allows us to evaluate the complex web of environmental, institutional, and technical issues in a consistent manner. It also focuses the evaluation on a particularly relevant question for society: namely, does this facility-specific form of regulation for a firm like Intel promise net benefits relative to the status quo? With this question as our starting point, the paper outlined a taxonomy of benefits and costs to be considered in determining whether or not the Intel XL permit, and others like it, are likely to improve social welfare.

The framework for evaluation was inspired by the Intel permit itself. However, the exercise is relevant not only for Intel and other microelectronics manufacturers but for the increasing number of businesses that seek to respond more rapidly to competition and changing market conditions. It is also relevant to proponents and detractors of facility-specific regulation. In practical terms, the analysis of the Intel case highlights several challenges to regulatory innovation. It also specifies the potential benefits of this regulatory approach.

Facility-specific regulation typically conjures images of production cost savings as processes are re-engineered and low-cost abatement strategies are favored by a firm who responds to a set of regulations written specifically for them. The Intel case highlights perhaps a more important source of benefit. Flexibility in the form of streamlined permitting allows for accelerated product introductions. As the world economy increasingly shifts to lean, information-intensive production the speed of product development takes on relatively greater competitive importance. More and more, speed is of the essence and the alternatives for the firm are, as Intel says: "quick or dead."

Our analysis emphasizes both the potential benefits of XL-type regulation and several significant challenges that will bedevil firms and regulators operating within this new type of system. Perhaps foremost are the difficulties associated with the definition of environmental baselines. The baselines are crucial to the determination of superior environmental performance. There is an inherent difficulty in defining baselines, however, when the product or process in question is new. Baseline definitions will almost certainly elude tight statutory definition. The Lieberman Bill is illustrative. The Bill acknowledges the unique issues presented by "new or modified" facilities by allowing baselines to be defined not only by applicable regulatory requirements (which are themselves uncertain in the case of new facilities) but also by best industry practices.²¹ Even with this type of acknowledgement, however, there will be an unavoidable challenge in defining best industry practices as they relate to new, innovative products and processes.

Another significant challenge is presented by operation of stakeholder participation processes. The number of parties involved, and diversity of viewpoints likely to be

²¹ Supra n. 1, Sec. 7(c)(4).

represented, raise the possibility of protracted, and thus costly, negotiation. This issue, as well, has been substantively addressed by the Lieberman Bill, which specifies time limits for notice and response, and rules governing participation in stakeholder negotiations.²² The Intel case highlights the importance of this kind of procedural clarity if transaction costs are to be minimized. Even so, a negotiated, stakeholder process is largely untested and is almost certain to prove contentious and difficult.

An issue raised by our analysis that the Lieberman Bill does not acknowledge is the potential impact of facility-specific regulation on competition. Regulation that speeds time to market or that provides cost advantages to specific firms has the potential to skew the competitive playing field, with potentially adverse market consequences. First movers will be in a position to further enhance their competitive position via regulatory flexibility. This has the potential to undermine price and product competition. While the rationale for limiting participation to firms with exceptional environmental records is understandable, the potentially negative welfare effects of regulation-induced competitive advantage should be acknowledged.

Finally, new forms of monitoring must be developed to respond to the new challenges created by site-wide, flexible permitting. And legal reforms must provide a framework so that all parties feel their concerns will be appropriately safeguarded. All of these challenges, however, should not obscure the fact that flexible regulation targeted to specific firms can in principle yield significant economic benefits to the alternative of command and control regulation, and that the latter form of regulation does not even necessarily guarantee better environmental outcomes. Whether facility-specific regulation is superior to sector or economy-wide economic incentive pollution control policies, such as cap and trade systems, is a matter for future research.

²² *Supra* n. 1, Sec 6.

APPENDIX

The Time-Sensitivity of Demand

This appendix depicts the time-sensitivity of demand more formally. From product to product, consumers differ in their tastes for the timeliness of consumption. In the case of microprocessors, business consumers in most cases value timely access to computing speed more highly than do household consumers. Thus, the value of a product can be expressed as a function of both the product's price and the time at which consumers are able to begin using it. Let this value, or consumer demand D , be defined as follows,

$$D(t, \phi, p) = A - \phi t - p.$$

where A is a constant, p the product's price, t the date of consumption, and ϕ a taste parameter. Note that demand is a decreasing function of both price and the length of time before consumption. All prefer access to the product sooner, but high- ϕ type consumers, such as businesses that require high-volume data processing, value timeliness more highly than low- ϕ types, such as households.

Given this framework, what is the benefit of accelerated product introduction? To answer the question assume that the product is either sold immediately ($t = 0$) or is delayed one period ($t = 1$). Also, assume n consumers, a marginal production cost c , and a discount factor δ . Without delay, and assuming for simplicity that the monopolist can extract all consumers' surplus, the firm can set its price so that $p = A$. This follows since $D = A - p$. Profits are therefore $\Pi_0 = n(A - c)$.

Now if the firm is forced to delay the product's introduction, it can only charge a price $p = A - \phi$. And since revenues are earned in the future period, the value of the profit must be discounted. Profits from a sale that is delayed are therefore $\Pi_1 = \delta n(A - \phi - c)$. The difference in profits, and therefore the benefit of accelerated introduction, is

$$(1 - \delta)\Pi_0 + \delta n\phi.$$

This expression depicts both the accelerated income and accelerated consumption benefits. To isolate the accelerated income benefit, assume that $\phi = 0$, so that consumers are completely insensitive to the timing of consumption. Note that even though consumer utility is unaffected by delay, delay still creates a cost. Specifically, the firm is $(1 - \delta)\Pi_0$ worse off than if its product introduction had not been delayed. This is the cost of achieving profits later, rather than sooner. It is equivalent to the financial return that could have been earned on the profits over the period of delay. Thus, irrespective of its effect on consumer utility, acceleration always implies an income-based benefit.

When $\phi > 0$, we see the benefit of accelerated consumption. This benefit corresponds to the gain in consumer utility that arises due to accelerated consumption. To isolate this

benefit, assume no discounting ($\delta = 1$) so that there is no accelerated income benefit. The accelerated consumption benefit is then simply $n\phi$. In extreme cases, where ϕ is large (specifically, when $\phi > A - c$) delay can reduce the product's utility so significantly that the product's market is eliminated altogether.²³ This implies a very large benefit to accelerated introduction.

²³ The earlier example of a market for a wedding dress is illustrative. If wedding dresses cannot be supplied prior to the wedding day, no wedding dress will be sold.

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