**Understanding the Effects of Larger Wafers on the Global Semiconductor Equipment Supply Chain**

By

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BS Electrical Engineering, Utah State University, 2005

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for Degrees of

**Master of Business Administration**
and
**Master of Science in Electrical Engineering**

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# Understanding the Effects of Larger Wafers on the Global Semiconductor Equipment Supply Chain

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## Abstract

This thesis examines how an investment in 450mm wafers might affect capital equipment suppliers in the semiconductor industry and assesses if the 450mm transition is in the industry's best interest. The 450mm transition is currently scheduled for 2012 by the ITRS (International Technology Roadmap for Semiconductors), but the overall industry remains divided on the issue, and without sufficient consensus, a transition is simply not possible. The cost of developing equipment for a new wafer size has increased dramatically over the last few wafer size transitions. Furthermore, producing more efficient tools also decreases the number of tools needed by the semiconductor manufacturers if growth stays flat. These factors have caused reluctance among equipment suppliers to go ahead with a transition to 450mm wafers. However, the largest semiconductor manufacturers contend that more efficient tools will lead to cheaper products and stronger semiconductor growth. They argue that this growth will make up for supplier revenue lost due to efficiency gains.

This thesis analyzes the dynamics of the capital equipment industry. Qualitative factors, such as past performance, recent trends, and the equipment industry's competitive landscape, are considered using Porter's Five Forces model. A quantitative analysis using the author's supplier cost model (SCM), is applied to several potential 450mm transition scenarios, showing that the industry is sensitive to various inputs such as demand variability, tool productivity, and development costs, to name a few.

These qualitative and quantitative analyses are combined to demonstrate that a transition to 450mm is in the best interest of the semiconductor capital equipment industry. The equipment industry is presently in an unhealthy state, with most firms struggling to maintain a reasonable profit amidst the high competition and volatile market conditions. Consolidation will eventually be the key to improving the industry structure, but consolidation will be a long and slow process if the industry remains on 300mm wafers. 450mm will stimulate consolidation throughout the industry, quickly bringing the industry to a more stable and sustainable state. The transition will likely be a painful process, and many equipment suppliers will have to exit the market, but it will allow fewer suppliers to be more profitable and healthier in the long run.

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# 1. Introduction and Overview

## 1.1 Introduction

The rapid emergence of the electronics industry over the last half century has been fueled by the semiconductor industry's ability to innovate and produce ever more powerful devices at increasingly lower costs. Semiconductor devices are manufactured on discs (known as "wafers") made from silicon in large fabrication factories. In order to achieve the low cost to manufacture these devices, semiconductor manufacturers have used two methods to decrease costs: shrinking the device dimensions to make individual chips more compact or more powerful for the same area and increasing the size of the wafer to allow more chips to fit on a single wafer. The former happens more frequently, approximately every two to three years, while the latter has historically happened approximately once a decade. Each cost cutting technique requires a significant amount of upfront investment for development, and the cost of doing these developments is rising fast. These costs are putting financial strain on both device makers as well as the capital equipment suppliers that provide the tools required to make the devices.

The rising development costs have left many wondering if a wafer size transition from 300mm to 450mm wafers is in the best interest of the industry. The 450mm transition is currently scheduled for 2012 by the ITRS (International Technology Roadmap for Semiconductors), but the overall industry is divided on the issue, and without sufficient consensus, a transition is simply not possible. Much of the disagreement throughout the industry is due to a lack of clear information. An accurate outlay of R&D costs and machine capabilities are not yet known, and a detailed analysis of the economic feasibility of transitioning to 450mm has yet to be completed. Furthermore, device makers and equipment makers are hesitant to share the information required to do this analysis for fear of losing their competitive advantage.

In hopes of clearing up some of the disagreement, this report will seek to analyze the 450mm wafer transition from the capital equipment supplier's perspective. Equipment suppliers have argued that the 450mm investment offers little benefit to suppliers, as device makers capture most of the value. It is the author's belief that 450mm is an inevitable stage in the evolution of the semiconductor industry. Furthermore, it is the author's hypothesis that 450mm is an industry aggregate negative net present value investment for equipment suppliers; however, due to consolidation, shifts in market share, and changes to industry structure, many suppliers will find ways to operate successfully and find a positive return on the 450mm investment. For the suppliers that successfully weather the transition, a more healthy and profitable industry will be the reward.

The first objective of this thesis is to analyze the competitive landscape and understand the dynamics that are driving the equipment industry. The second objective of this analysis is to assess the financial impact of the transition on individual equipment manufacturers. The results will shed some light on the health of the capital equipment supply chain as well as offer suggestions for what would need to happen for the capital equipment supply chain to remain healthy.

## 1.2 Thesis Layout

Chapter 2, "Overview of the Semiconductor Equipment Industry," will provide background on the complexities surrounding the issue of moving to 450mm wafers. It will begin with a brief history of the semiconductor industry followed by an introduction to the semiconductor manufacturing process. A more detailed look at the functional areas within a fab and the role of capital equipment in each functional area will be analyzed. Next, a look at historical trends and growth patterns within the industry will be discussed. Chapter 2 will finish with a discussion of the semiconductor industry supply chain and a deeper analysis of the capital equipment industry's competitive landscape.

Chapter 3, "Theory and Economics of Wafer Size Transitions," will discuss in greater depths the benefits of larger wafers. It will begin by looking at the history and trends of past wafer size transitions. Next, a deeper look at the economic benefits of increasing a wafer's size will be discussed. Chapter 3 will conclude with a case study of the most recent wafer size increase, 300mm wafers. The 300mm transition presented a new set of challenges that the industry had not seen in previous wafer size transitions, and implementation of this transition was more problematic than in the past. This section will attempt to make sense of a transition gone wrong in order to learn how to make the next transition successful.

Chapter 4, "Impact of 450mm Wafers on Equipment Manufacturers," will assess the specific challenges that the capital equipment manufacturers may face if the industry makes the 450mm transition. It will start with a general introduction to the problem and the dynamics surrounding the

450mm transition. Next, the Supplier Cost Model will be introduced. The Supplier Cost Model is an Excel based model generated by the author to analyze the most important factors that determine the success of 450mm. After the model has been explained, Chapter 4 will conclude by analyzing the results of six scenarios run through the Supplier Cost Model.

Chapter five, "Conclusions and Next Steps," is the final chapter and will pull together the various conclusions generated throughout the thesis. It will finish by presenting areas where further research would be useful.

# 2. Overview of the Semiconductor Equipment Industry

This chapter will open with a brief introduction of the semiconductor industry's birth, Moore's law, and the remarkable growth performance of the industry. The manufacturing process will then be discussed in order to give a better understanding of the role that capital equipment plays in the semiconductor industry. This will be followed by a more detailed look at the historical economic trends of the past, and more importantly the recent history. Finally, the structure of the semiconductor industry will be discussed, followed by a detailed analysis of the capital equipment industry's competitive landscape.

## 2.1 Birth of the Transistor and Moore's Law

It was the birth of the transistor that has enabled so many great and marvelous technological advancements throughout the latter half of the 20$^{th}$ century. The transistor came into existence on December 23, 1947, when three Bell Labs scientists successfully demonstrated the first working transistor. This device offered the functionality of a vacuum tube, but added the advantages of being solid state (no vacuum), being small and lightweight, and having low power requirements and a long life-time.[1]

The invention of the transistor immediately led to a flurry of activity as scientists and inventors went searching for ways to take advantage of the transistor's many benefits. A string of new patents came into existence, and a progression of discoveries led to Robert Noyce's patent of the planar integrated circuit (IC), a cluster of transistors patterned and connected together on a single substrate. Robert Noyce's discovery became the model for integrated circuits, and it is upon this foundation that all future technological developments within semiconductors came to be.

The semiconductor industry was born, and in 1965, Gordon Moore, then at Fairchild Semiconductor, was assigned the task of predicting what would happen with silicon components over the next 10 years. He was asked to publish his findings in *Electronic Magazine*. Noticing that over the previous six years the number of transistors in a circuit had roughly doubled each year, Moore made the prediction that

[1] (Van Zant, 2004)

this trend would continue for the next ten years. Even Moore was amazed to find that the prediction held true for nine of those ten years. Then in 1975, Moore adjusted his prediction to forecast the doubling of transistors to happen every two years for the foreseeable future, and for more than thirty years now, this prediction, coined "Moore's Law," has held true. In fact, transistor counts have doubled slightly faster than hypothesized (see Figure 1) and have followed a trend of doubling nearly every 18 months.[2]

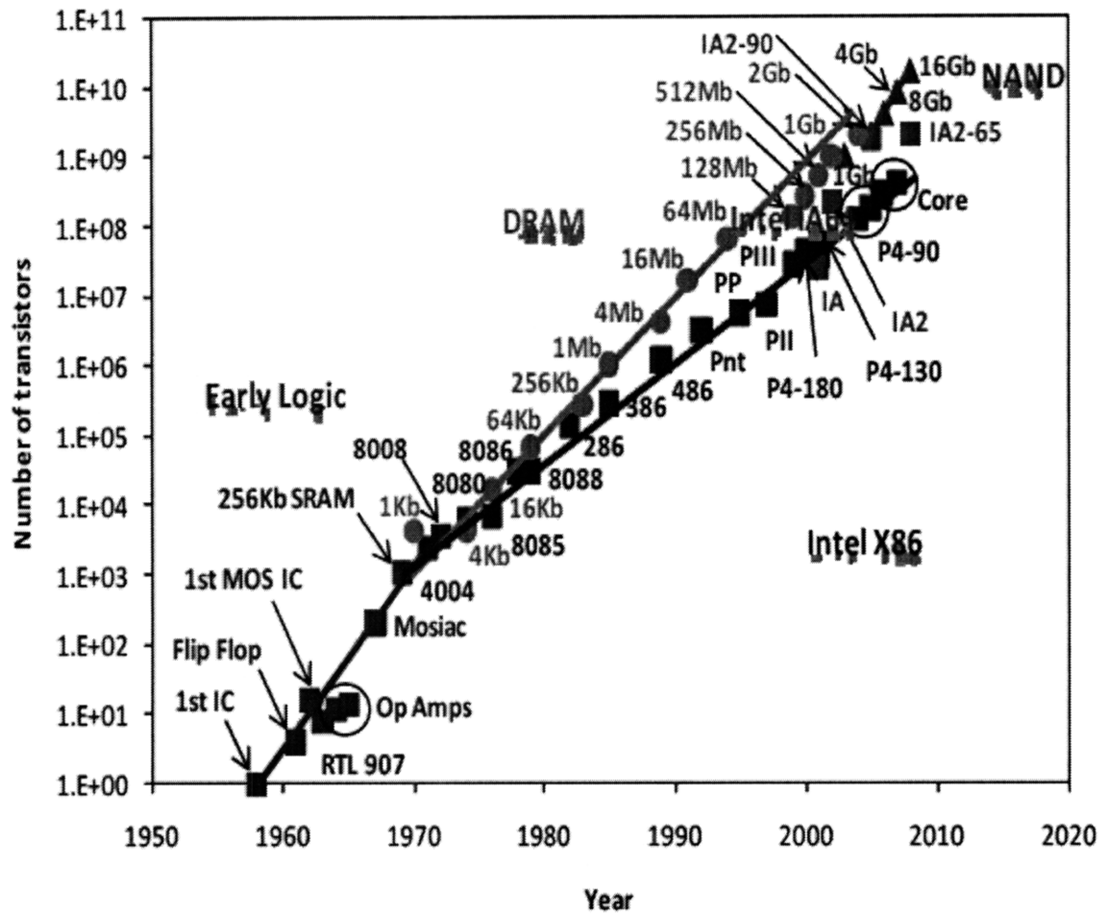


FIGURE 1, TRANSISTORS PER INTEGRATED CIRCUIT[3]

Year after year, skeptics have expressed their doubts about the semiconductor industry and its ability to keep pace with Moore's Law, but year after year these skeptics have been proven wrong. It is truly miraculous the pace at which the semiconductor industry has managed to maintain its growth. All the while, the computer chips have become extremely sophisticated, yet remarkably affordable. As the semiconductor industry moves into the 21st century, the skeptics are out in full force once again. This

[2] (Gordon Moore, 2005)
[3] (ICKnowledge, 2008)

time there is plain evidence to support their doubts. Devices are already being produced at or near the atomic level, and further reductions in scale are becoming increasingly more complicated and expensive to develop. Furthermore there has been a clear slowdown in the industry's growth, and a slowdown in growth directly impacts the industry's ability to fund expensive research and development projects. It is not clear when Moore's law will end, but one thing is for sure, if the semiconductor industry does not continue to increase device performance while simultaneously minimizing manufacturing costs, as they have done for so long, demand growth will continue to slow.

## 2.2 Overview of Wafer Fabrication

While the purpose of this thesis is not to describe in detail the steps and processes involved in manufacturing wafers, a basic understanding of the manufacturing process and the equipment that performs these processes will help make clear the benefits of larger wafers as well as expose any limitations. This section will start with a basic high level overview of the manufacturing process. The remaining subsections will discuss in greater detail the major steps that a wafer must pass through and the role of the capital equipment that is required to complete that step. The final sub section will discuss the implications of upgrading the equipment to 450mm.

### 2.2.1 Basic Overview

Semiconductor chips (also known as "die") are manufactured on silicon wafers. Typically hundreds of die reside on a single wafer in square or rectangular patterns (see Figure 2). Each of the rectangular patterns is identical, and will eventually be cut apart and packaged individually.

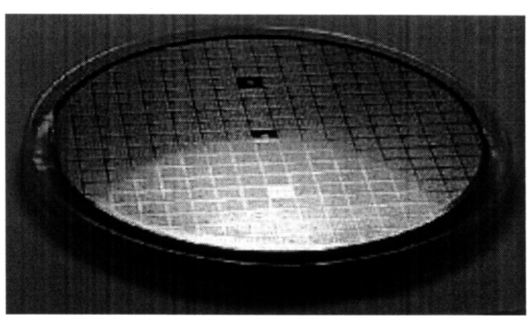

FIGURE 2, FINISHED WAFER

Building a chip, in many ways, can be compared to building a skyscraper – although a very flat skyscraper. Just as a skyscraper has many floors, a microchip has many layers stacked on top of each other. Each of these layers are connected to one another and routed in such a way to give functionality to the device. Likewise, a skyscraper has many elevators, hallways, and doors that align and connect all areas of the building together to best utilize the space of the building. A graphical depiction of what this semiconductor construction might look like is shown in Figure 3.

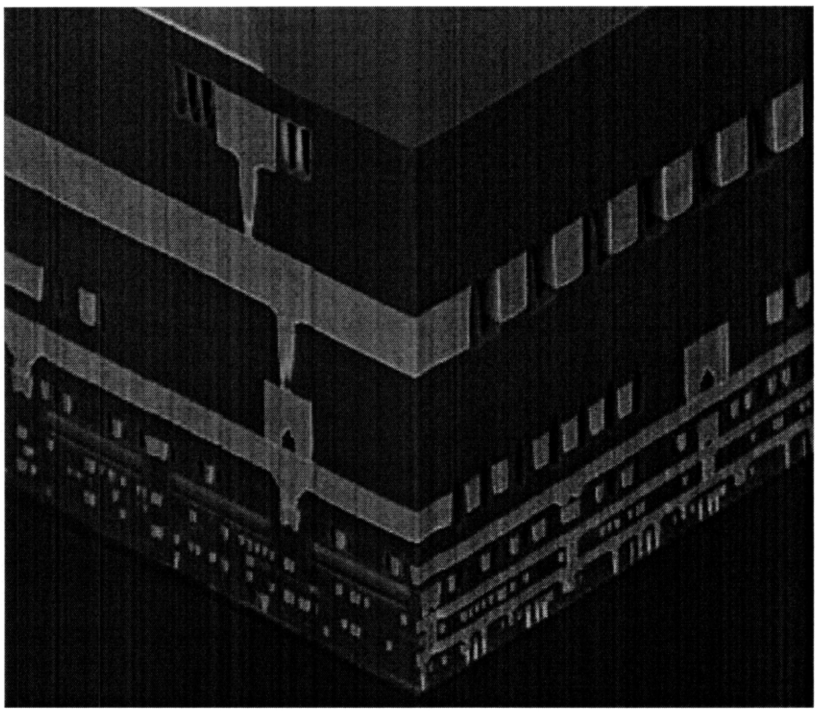

FIGURE 3, DEVICE CROSS SECTION[4]

The method of constructing this complicated web of circuitry is very different from that of constructing a building. Working from the bottom up, a silicon wafer will go through hundreds of steps including layering, patterning, doping and treating before leaving the fab's door. Even after a wafer has completed the manufacturing process, it must be tested, packaged, tested again, and then shipped. The entire manufacturing process is very complex and can take between two and six months to complete.

As device dimensions have become smaller, cleanliness standards have become immensely important. The smallest particles of dust can render an entire device useless. Maintaining the highest

[4] (Scott M. Fulton, 2007)

clean room standards and using the purest form of silicon and other chemicals is critical to maintaining high yields.

### 2.2.2 Silicon Growth and Wafer Preparation

Silicon is the second most abundant element on the earth, and commonly found in sand. It is typically mined and extracted as a ⍰⍰⍰*2* compound, but after several refinement processes the silicon dioxide is transformed into polysilicon with contamination levels of .001 ppb (99.999999999 percent pure Si).[5]

Following the production of pure polysilicon is the growth stage of the wafer production process. The growth stage will transform chunks of polysilicon into ingots of single crystal orientation silicon. This process is done by first placing the chunks of polysilicon into a large crucible and heating the silicon to its melting point. A monocrystalline silicon seed is lowered into the crucible of molten silicon. The seed crystal is rotated in one direction while the crucible rotates in the opposite direction. The seed crystal grows out as it continues to rotate within the melted polysilicon. As the diameter of the seed reaches its intended size, the seed is incrementally pulled from the molten silicon. As the seed is gradually extracted, an entire silicon ingot is formed. The final step in the growth stage is to sand down the ingot until it reaches near perfect roundness. Completed ingots of varying sizes are shown in Figure 4.

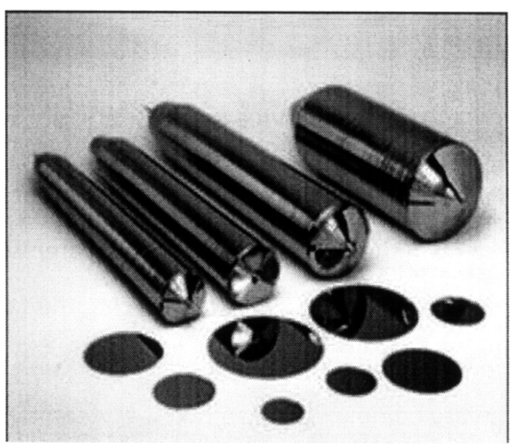

FIGURE 4, SILICON INGOTS OF VARYING SIZES[6]

[5] (Department of Electrical Engineering)
[6] (Active Business Company GmbH)

The ingot is now ready for the next step of the wafer preparation process, slicing. Most high volume producers of silicon wafers use high throughput wire saws to slice an entire ingot at once. The ingot is lowered onto a series of fast moving ultra-thin wires, and as the ingot is lowered, the wires cut thinly sliced wafers. The sawing process is aided by an abrasive slurry that is applied to the wire saw, which helps to ensure a smooth cut. Following the sawing process, the wafers are bathed in another slurry to help remove any residual left behind from the sawing.

Now that the wafers are cut, they go through the final steps, consisting of polishing, cleaning and treating. The sawing process often leaves some waviness or patterns on the surface of the wafer. The wafers are polished to ensure uniformity and smoothness across the surface of the wafer. After polishing, the wafer's outer edges get rounded and profiled. Sometimes, the wafers go through one final step to deposit an additional layer of high purity silicon on the top of the wafer surface.

Producing 450mm wafers brings about a new set of complications that add a significant cost to the raw wafer production process. First of all, the 450mm ingots are very heavy, ranging from 700-1000 kg, or 1 metric ton. Handling them is a significant challenge.[7] The tools to handle the ingot, cut the wafers, polish the wafers, and further treat the wafers all need to be modified to handle the added size and weight. Also, larger wafers sag more in the center of the wafer. Sag adds manufacturing and handling complexities to the production process. Wafer manufacturers reduce the sag by slicing the wafers thicker. Thicker wafers results in fewer wafers produced per ingot, thus increasing the cost of each wafer. Cost increases also stem from the extra time required to produce 450mm ingots. Nearly every step in the production of raw wafers will take longer. Because tools are pumping out wafers more slowly, the cost of the equipment will be spread across fewer ingots, making per wafer cost higher.

At least initially, 450mm wafers will be much more expensive than 300mm wafers. Dean Freeman, a Gartner semiconductor equipment analyst, projected initial 450mm wafer cost to lie between $15,000-20,000 USD. This is in comparison to 300mm costs that started at just over $1000 USD and have now settled at roughly $250 per wafer.[8] 450mm wafers will come down in price in time, but it is unclear by how much. ISMI is projecting a 5.5x increase in wafer costs, which would indicate an expectation to have 450mm wafers priced at roughly $1375 in the long run.

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[7] (Lammers, Big Wafers, Big Prices, 2008)
[8] (Lammers, Big Wafers, Big Prices, 2008)

### 2.2.3 Lithography

Lithography is the process by which patterns of photoresist are placed on and removed from the surface of wafers. The patterns created allow areas of the wafer to be blocked or exposed to subsequent processes. Again using the analogy of building a skyscraper, before the rooms can be decorated and furnished, the level's floor plan must be laid out. The lithography step basically lays out a floor plan for the other functional areas to work with. With the floor plan in place, the etch, implant, deposition and diffusion processes can process the wafer in a highly specific manner. In these other steps, the wafer gets chemically altered, added to, or etched away from, but only where the patterns of the floor plan specify. When one layer is complete, all of the photoresist is removed and the wafer returns to the lithography machines to lay out the next layer.

There are several steps involved in the lithography process, and the tools most essential for this process are the scanners (also known as steppers) and the coat/develop track. The track runs the wafer through a series of steps to prepare the wafer for exposure in the scanner. After the exposure, the track runs the wafer through another series of post-exposure steps. The process is outlined below.

The wafer begins on the track and first undergoes a quick dehydrate/bake step to ensure all moisture has been evaporated from the surface of the wafer. Next an adhesion promoter is applied to the wafer to enhance the bonding with the photoresist. After the adhesion promoter is added, the photoresist is applied to the entire wafer. The wafer gets baked again to allow the photoresist to harden, after which it is sent to the scanner to be exposed to a pattern.

The scanner uses UV light to chemically alter the photoresist. The UV light passes through a series of lenses and ultimately passes through a reticle – a thin glass/chrome plate with the intended pattern/floorplan of the die – and onto the surface of the wafer. When the UV light passes through the reticle and onto a die, a chemical reaction occurs that causes the exposed areas to become more acidic. A reticle typically contains the identical patterns for multiple die. The number of die on a single reticle is a function of the size and shape of each die and the size of the reticle. However, because the the area that can be exposed is much smaller than the size of the wafer, the scanner must move around the wafer exposing different portions of the wafer until every die has been exposed.

Following exposure, the track moves the wafer to a chemical bath with an alkaline solution that removes the acidic regions of the wafer. At this point, only the areas of the wafer that were covered by the reticle have a layer of photoresist. There are other types of resist where the reverse is true;

photoresist remains in areas of the wafer not covered by the reticle. With the desired photoresist pattern now in place, the wafer goes through one final baking process to harden and prepare the photoresist to act as a barrier for the other processes the wafer will soon pass through.

### 2.2.4 Etch

Etching is the process of chemically removing layers of material away from the surface of the wafer. The patterned photoresist that is applied during the lithography step determines where a wafer will and will not be etched. Each wafer will undergo etching a number of times throughout the manufacturing process.

Etching can take two forms, wet etch and dry etch. Wet etch typically involves wafers being immersed in a bath of etchant which must be agitated to stimulate the etching process. The wet etch process is isotropic and relatively imprecise. Wet etching has been largely replaced with dry etchers, also known as plasma etchers. Dry etch tools create neutral free radicals that bombard the surface of the wafer from all sides, etching away at the material in a more anisotropic manner. Variant etchers exist that use ion milling or sputtering to bombard the wafer from a single direction to produce a very anisotropic etch.

### 2.2.5 Diffusion

There are many points in the manufacturing process where a layer of silicon dioxide is formed over the surface of the wafer. Several types of vertical diffusion furnaces (VDF) have been developed to create this oxidation layer. Diffusion furnaces accept a batch of wafers that sit in its chamber under a specific temperature (600-800 Celsius) and pressure for a length of time. The temperature, pressure, and time speed up the growth process. Wafers can sit in the diffusion furnaces for hours or days.

Rapid thermal processing (RTP) is also included in the diffusion functional area but has a slightly different purpose. RTP tools are used primarily to activate dopants from the implant process, but they can also be used for thermal oxidation, metal reflow and chemical vapor deposition. They process wafers in a very short amount of time – from a few seconds to several minutes – with a high amount of heat (up to 1200 C or greater). RTP tools use a lamp, hot chuck, or hot plate to heat wafers up one at a time.

### 2.2.6 Planarization

Many of the manufacturing processes leave the wafer rough and non-uniform. Occasionally layers of material need to be removed and reworked. The planarization step uses chemical mechanical planarization (CMP) tools to grind down and smooth the wafer with high precision. The CMP tools use abrasive slurry in conjunction with polishing pads to basically sand the wafer down to a precise thickness. Most modern CMP tools combine the act of polishing/sanding the wafer with a follow on step of cleaning/washing the wafer to remove any residual material.

### 2.2.7 Thin Films

Thin film deposition is a functional step where layers of new material, such as insulators or metals, are deposited on the surface of the wafer. A number of tools are used in the thin film functional area to allow films of varying thicknesses and films of different chemicals and compounds to be deposited. Films can be applied at the atomic level through the use of Atomic Layer Deposition (ALD), or they can be thicker films using chemical vapor deposition (CVD) or physical vapor deposition (PVD) equipment.

### 2.2.8 Implant

Most steps of the wafer manufacturing process either add material or remove material from the wafer. The implant step will actually change material properties by implanting ions of another material into the wafer. The ions can be charged with varying degrees of energy to control the depth and concentration of the implant. Of course, the implant step will only take effect in the areas where photoresist is not present. Implanting allows the chemical makeup of different materials in the wafer to be altered such that the material becomes more or less conductive. This is a critical step that gives the die the electrical characteristics that make it a functional circuit.

### 2.2.9 Sort, Assemble, Test, Ship

Once the chips on the wafer are manufactured they must be tested packaged and shipped. Given how small the device dimensions are and the vulnerability to any contamination, there is a substantial proportion of defective die on each wafer. Prior to being cut apart and packaged into individual parts, the wafers go through a sort process. Wafers are placed in probe machines, where each die gets connected to a tester that runs electrical test programs through the die to understand the die functionality and electrical characteristics. Each die is classified, or binned, based on its performance during these tests. Money is saved by discarding defective die prior to packaging.

After the sort step, the wafers are sent to Assembly to be sawed apart and packaged. After being sawed into individual die, the good die are selected and packaged.

As a final step, the packaged die go through another series of more rigorous tests to measure device functionality, speed, electrical specifications, and other part characteristics. The die that make the final cut are shipped out to customers.

For the most part, the Sort, Assembly, Test and Ship portions of the manufacturing process are unaffected by the introduction of 450mm wafers. Almost every piece of equipment and tooling used in these steps operates at the die level. The exception to this would be the probers used in Sort and the wafer handling tools in Assembly. The probers and wafer handling tools, however, are significantly less expensive than most of the tools used in the fab. The extra costs incurred in these processes are relatively insignificant and will not be analyzed any further in this thesis.

### 2.2.10 Scaling Equipment to 450mm

There are a many types of tools in the fab, each performing its own task, therefore, the complexities of scaling semiconductor equipment up to handle larger wafers vary significantly from tool to tool. Furthermore, the benefits of scaling up the equipment differ dramatically by equipment function. The industry has loosely categorized tools into one of two categories, beam and non-beam. Beam tools typically process portions of a wafer at a time while non-beam tools operate on the entire wafer at once. These categories will be discussed below along.

**Beam Tools:**

As mentioned previously, beam tools are unique because they only process portions of a wafer at a time. Because of this, larger wafers directly increase processing time for these tools. Lithography scanners are an example of a beam tool. Some metrology tools and implant tools may also be grouped as beam tools as well. Lithography scanners must step around the wafer exposing small sections of the wafer at a time, thus increasing the wafer size will dramatically increase the time required to process each wafer. With more than double the wafer area, the cycle time per wafer for scanners should theoretically double, but as lithography tool manufacturers redesign the tool to create a 450mm platform they will likely find opportunities to make improvements to the current platform. New innovation could reduce exposure time, increase exposure area, or both.

It is not entirely clear how much of an impact 450mm wafers will have on implant tool development costs and throughput. In the past, implant tools have processed sections of a wafer at a time. Varian Semiconductor, the leading implant tool manufacturer by market share, has made significant strides in increasing wafer throughput, despite increasingly larger wafers. Many of these advances appear to be transferrable to 450mm processes, and we should thus expect to see only minimal increases in throughput times as a result of 450mm.

**Non-Beam Tools**

Non-beam tools typically process an entire wafer at once, or even process batches of wafers simultaneously. Most tools, outside of the lithography function, can be considered non-beam tools. Increasing the wafer size to 450mm should not have a significant impact on wafer throughput for non-beam tools. In other words, the same number of wafers will likely be processed in the roughly the same amount of time, but because wafer area has doubled, significant wafer area throughput improvements will be seen. Because most tools in the fab are classified as non-beam tools, there are many significant productivity improvement opportunities from working with larger wafers. Not only will there be wafer area throughput advantages, but reagents and dopant usage improvements, and energy consumption improvements will certainly result as well.

Exact throughput and tool costs for beam and non-beam tools are not presently known, but this uncertainty will be addressed and modeled in section 4.3.4 of this thesis.

## 2.3 Economic Trends

### 2.3.1 Industry Growth

From its infancy, the semiconductor industry has seen astronomical growth in revenue. From 1960 to 2000 worldwide semiconductor sales averaged 14.9 percent growth year over year (see Figure 5). This growth propelled small or nonexistent companies like Intel, Microsoft, IBM, and a slew of other high tech companies to become household names that seem to have penetrated almost every aspect of our daily lives. These were prosperous times, but around the year 2000, the dot-com bubble burst, putting an end to the astronomical growth that high tech companies were accustomed to. Many experts expected semiconductor growth to pick up where it had left off once it had weathered the recession. However, the semiconductor industry didn't rebound as many had expected, and it wasn't until 2004 that IC makers began to recognize that the industry was beginning to mature and growth would follow a new pace. Since 2000, the industry has followed a moderate growth rate of 6.1 percent. This average growth rate is expected to decline over 2009 and 2010 as the semiconductor industry braces for what will most likely be negative growth. Bill McClean, an industry respected market research analyst, predicted at the 2009 ISS conference that growth would decline by a staggering 23 percent in 2009, well beyond anything the industry has ever seen (see Figure 6).

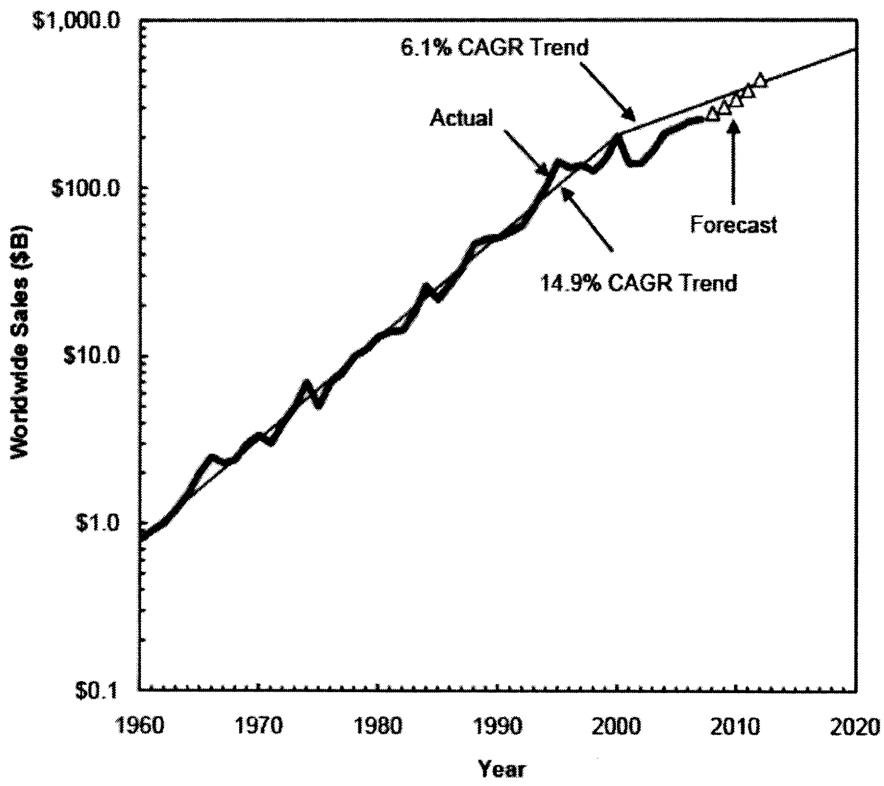



FIGURE 5, WORLDWIDE SEMICONDUCTOR REVENUE[9]

[9] (ICKnowledge, 2008)

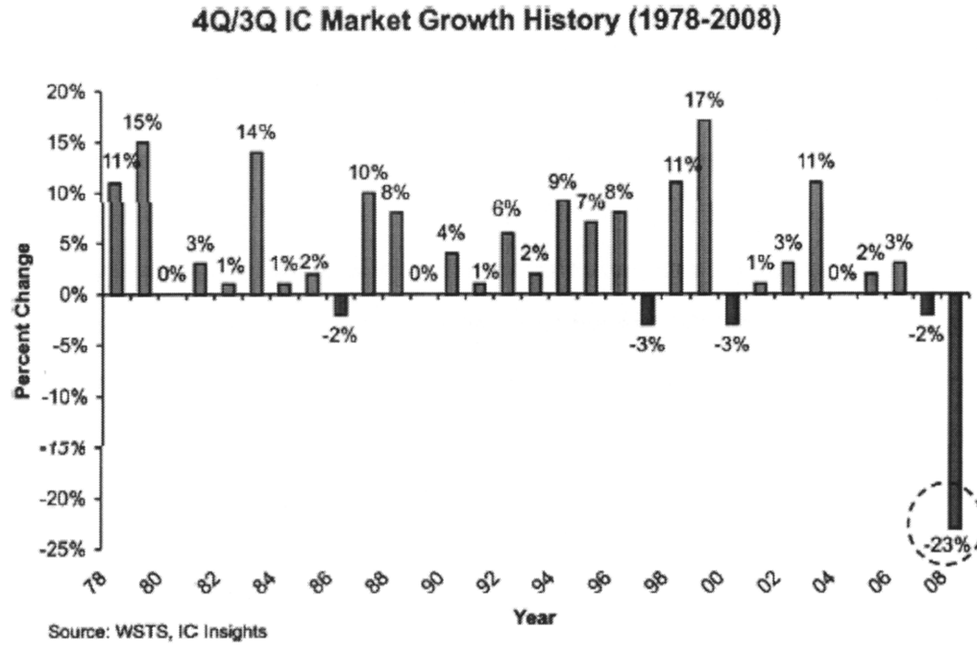



FIGURE 6, IC MARKET GROWTH HISTORY (1978-2008)[10]

While 6.1 percent may seem like a severe blow considering the semiconductor industry's historic 40 year run at 14.9 percent, the growth rate is actually still quite remarkable. The semiconductor industry recently posted 2007 revenues of $268 billion. With revenues in the hundreds of billions and the already ubiquitous existences of cell phones, mp3 players, laptops and other electronic devices throughout the world, maintaining high growth rates has become increasingly more difficult. Both the electronics industry and the semiconductor industry are a relatively small percentage of global GDP and there are many markets, especially emerging economies, that will continue to see large growth in the future. Figure 7 shows the historic growth of the electronics and semiconductor industries.

[10] (McClean, Major Forces Shaping the Global Semiconductor Industry, 2009)

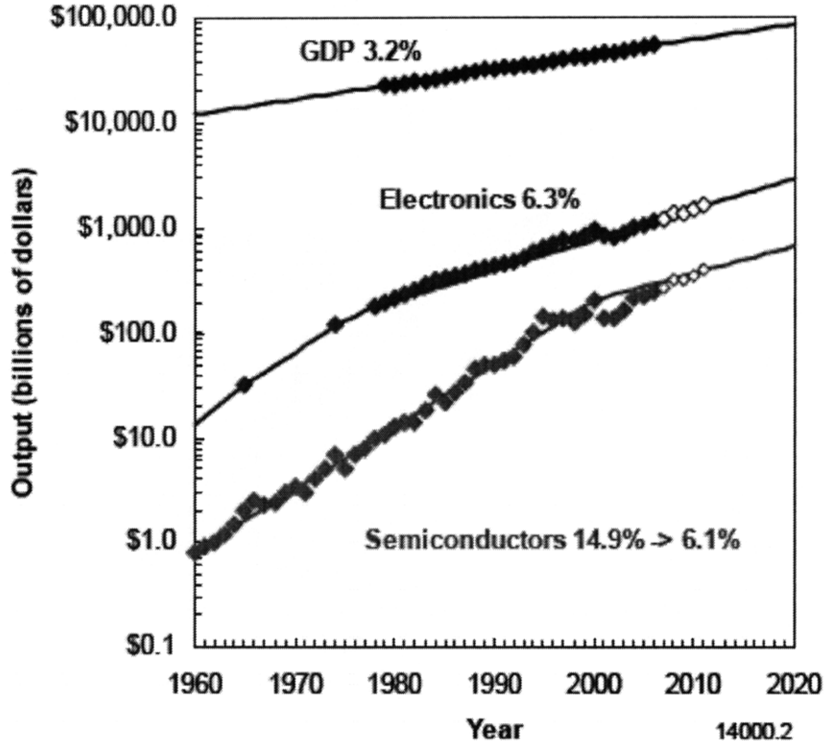



FIGURE 7, WORLDWIDE MARKET TRENDS[11]

### 2.3.2 Growth and Cost Relationship

Perhaps even more impressive than the technology that has come about as a result of the integrated circuit, is the semiconductor industry's remarkable ability to reduce manufacturing costs despite increasingly more complex designs and more complicated manufacturing processes. Consumers continue to foster an insatiable desire for cutting edge electronics, but their ability to consume the products can only happen if the product falls within an affordable range. Over the last 50 years, the price of semiconductors per unit output has followed a 35 percent per year declination rate (see Figure 8). In order to make this possible, the industry is constantly building bigger, more efficient fabrication facilities, and updating their toolsets with the latest technology in order to shrink circuit dimensions as small as possible. Somewhat surprising is the fact that the cost of updating the plants is increasingly more costly, but the return on the investment continues to be impressive as cost per unit out continues to decline at the 35 percent rate (Figure 9).

[11] (Jones, 2007)

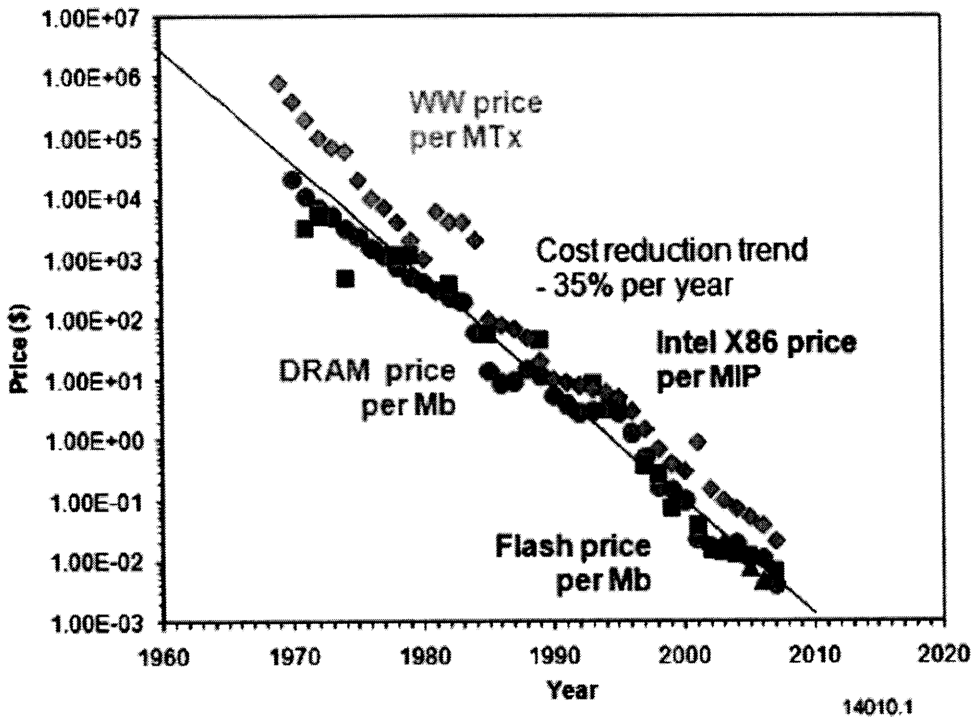



FIGURE 8, PRICE TRENDS[12]

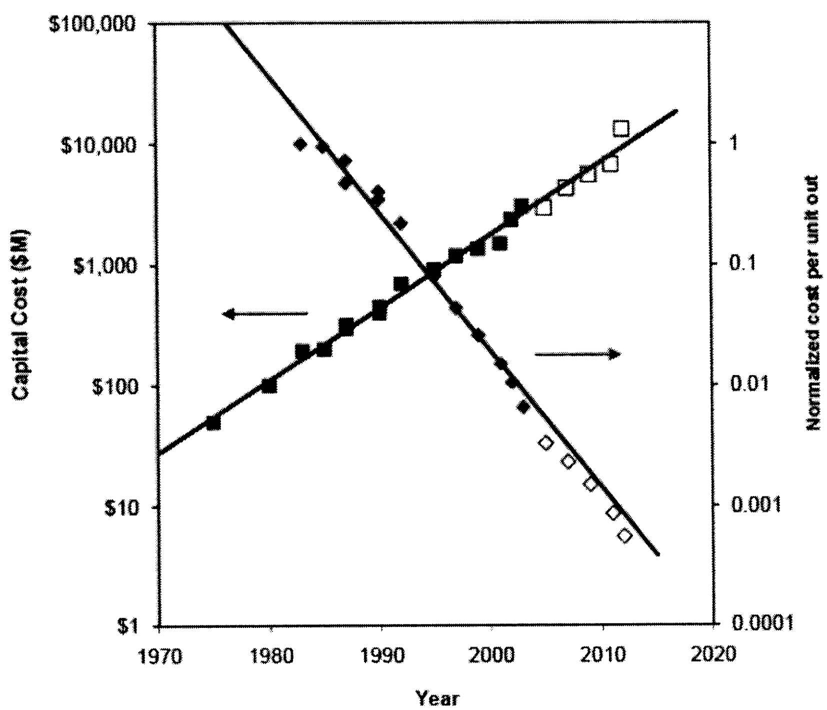



FIGURE 9, CAPITAL COST VS COST PER UNIT OUT[13]

[12] (ICKnowledge, 2008)

## 2.4 Semiconductor Industry Structure

The semiconductor chip is the heart and lifeblood of radios, televisions, cell phones, mp3 players, and many other powerful devices. This section will discuss the supply chain that the capital equipment industry participates in, then dive deep into the specific challenges that the capital equipment industry faces.

The supply chain that produces the electronics of today involves four stages, shown in Figure 10. In order for the industry to continue to grow and thrive, the semiconductor supply chain needs to remain strong and healthy. The following sections will discuss each of these stages in greater detail and describe their essential role in the process.

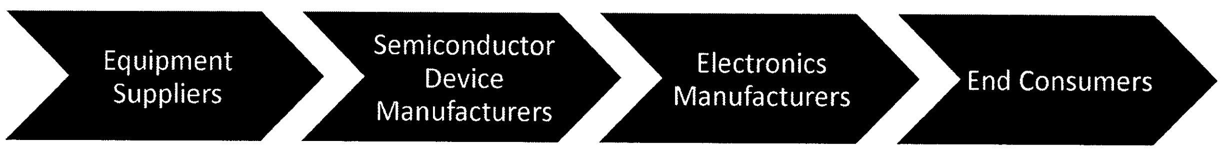



FIGURE 10, SEMICONDUCTOR SUPPLY CHAIN

**End Consumer**

The most important piece of supply chain is the end consumer. Ultimately it is the consumer of the products that drives growth. As long as the end consumer is kept happy and is satisfied, the entire supply chain will prosper. However, keeping the end consumer happy all of the time is virtually impossible. The end consumer demands a constant flow of high quality, new designs, with great functionality, at rock bottom prices. Consumer preferences change faster than electronics manufacturers can design products, much faster than semiconductor device makers can make components, and much, much faster than the capital equipment makers can supply the IC makers with the capital equipment they need. Consequently, big bets are placed on where the markets are heading and how consumers will behave and react.

[13] (ICKnowledge, 2008)

## Electronics Manufacturers

Everyone knows Dell, Sony, Nokia, and Apple. These and other electronics manufacturers have the difficult job of taking all the components that make up an electronic device and combining them together into an affordable, stylish, functional package that people want. The electronics industry is characteristically a fast clock speed industry. Adapting quickly to frequently changing trends and interests of customers is paramount. Many electronics companies launch new products on almost a monthly basis, and consumer preferences can change in the blink of an eye. If the electronics manufacturer is not ready to adapt and evolve, they won't last long.

Motorola learned firsthand the consequences of being slow to adapt. At the end of 2006, Motorola had 23 percent of the worldwide market share for cell phones. By the end of 2007 its share dropped to 13 percent. In response to this, CEO Greg Brown said, *"Demand for some of our products has slowed in an intensified competitive landscape... Our consistency of new product introduction is still not where it needs to be. And we still have gaps in the portfolio in areas that are experiencing high rates of growth, including 3G (third-generation), China and other emerging markets."* [14] Motorola was unable to keep up with the rapidly changing interests of its customers, and their business got suffered greatly as a result. Motorola's stock was trading for roughly $25 a share at the end of 2006, but this soon collapsed to $15 by the end of 2007, and less than $4 in 2009.

Electronics manufacturers must constantly be on top of consumer demands, new product development, and supply chain management. To keep pace, the electronics manufacturers demand a lot from the semiconductor device manufacturers to get the parts to them when they are needed.

## Semiconductor Device Manufacturers

Semiconductor device manufacturers, also known as IC makers or simply device makers, are the companies processing wafers and producing chips. The chips can range in function from microprocessors and memory products to analog devices and discrete circuits. There are a wide range of semiconductor products being produced, but the majority of the worldwide capacity is used to produce memory and microprocessor products. Economies of scale are especially important to memory and microprocessor makers, and not surprisingly, these companies are the most interested in

[14] (Kullman, 2008)

economies of scale savings achieved through 450mm wafers. Many foundries are also very interested in developing 450mm as they seek to provide low cost manufacturing solutions for their customers by pooling customer demand together to fill 450mm capacity. 450mm will be even more important to foundries going forward as fab costs continue to rise and more IC makers seek more economical manufacturing options.

IC makers do a lot of advanced capacity planning and inventory management to ensure that they are always meeting their customer's needs. Because semiconductor products usually require two to six months for fabrication, semiconductor companies cannot easily adjust to changes in demand for their products. They attempt to survey their customers to get an estimate for the demand they will likely experience, but committing to an estimate one month could doom them the next month as changes in the end consumer's preferences filter through the supply chain. Risk mitigation and inventory buildup is a common practice with IC makers to ensure they meet their customer's needs as much as possible.

Memory makers find capacity planning to be especially difficult. Most of the memory products produced must conform to a set of standards created by an industry standards committee known as JEDEC. Memory manufacturers make a wide range of products conforming to these standards. When planning capacity, memory makers need to both consider the likely demand for memory products in general while also selecting the appropriate mix of products to produce. Meanwhile, the other memory makers are faced with the same situation. Assuming the absence of collaboration, memory makers must predict which memory products will be most in demand, while also considering what types of memory products their competitors are producing.

Another challenge that IC makers must deal with is properly planning fab capacity. We discussed the importance of choosing the right product mix, but well before this decision, IC makers must decide on the right amount of manufacturing capacity. This means setting up orders and contracts with equipment manufacturers. These contracts are often made one to two years in advance of when the equipment is delivered and installed. Two years can mean the difference between economic booms and busts, so there is a great deal of risk that semiconductor manufacturers take on when they order capital equipment. The risks of capacity planning are high for IC makers, but these challenges are even greater for equipment manufacturers.

There are a dozen or more dominant IC makers in the world, but that number is shrinking as the industry continues to undergo consolidation. Most dominant among the IC makers are Intel, the world's largest microprocessor producer, and Samsung, the world's largest memory maker. These two firms, together with TSMC, the world's largest foundry, are the most proactive about moving the industry to 450mm.[15] They are eager to see costs reduced in order to stimulate more demand for semiconductor products in the future. Many of the smaller IC makers, struggling to survive in an intensely competitive market, are less enthusiastic about 450mm. With the crash in DRAM and Flash prices throughout 2008 and 2009, many of the memory makers have undergone severe losses to their cash positions. With smaller cash reserves, smaller IC makers will either have to exit the market or partner with other IC makers in order to build 450mm fabs. As the world weathers the current financial crisis, there will be more consolidation within the semiconductor industry, as companies make adjustments and ready themselves to be more competitive in the future.

**Equipment Manufacturers**

Equipment manufacturers are at the tail end of the electronics supply chain. Like the device makers, equipment manufacturers also operate in an intensely competitive environment. The challenges of this competitive environment are discussed in detail in section 2.5.

Being at the tail end of the supply chain, the equipment industry is susceptible to the perils of the bullwhip effect. The bullwhip effect occurs in supply chains with multiple levels where each stage does their own inventory management and variability risk planning. As you move further upstream in the supply chain, variability in orders and demand increases. Distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies: excessive inventory investment, poor customer service, lost revenue, misguided capacity plans, ineffective transportation, and missed production schedules.[16] Many of these effects are prevalent in the equipment industry and they are exacerbated by an already cyclical industry.

Because equipment manufacturers operate in a highly competitive environment, they attempt to stuff their manufacturing pipeline with a steady stream of equipment orders. In order to do this, they typically provide favorable cancellation policies to the device makers in order to encourage more orders to be placed. IC makers end up placing optimistic order quantities with suppliers and when the economy doesn't perform as hoped, IC makers are forced to cancel. This type of behavior allows

[15] (LaPedus, 2008)
[16] (Lee, 1997)

equipment suppliers to profit handsomely during economic booms, but they also suffer deeply during economic downturns.

Equipment manufacturers are already feeling the pain of the current financial crisis. Orders for new equipment have almost completely evaporated. The industry has already seen a lot of consolidation over the last several economic downturns. Consolidation will likely be even more severe during the current recession, given the abysmal growth forecasts for semiconductor equipment. Even if firms manage to stay afloat, cash will be scarce and ambitious projects, like developing 450mm tools, may take a back seat as most equipment suppliers have switched to survival mode.

## 2.5 Capital Equipment Industry Competitive Landscape Analysis

This section is intended to provide a deeper analysis of the daily challenges that face the capital equipment industry. The analysis of the competitive landscape will be done using Porter's Five Forces.

Michael Porter is a renowned professor from the Harvard Business School and is best known for his research and experience in the field of corporate strategy. He has authored many books, with his most famous titled *Competitive Advantage*. In his text he outlines what has come to be known as Porter's Five Forces, a framework for understanding industry structure and the factors that determine the competitive landscape. His framework is depicted in Figure 11. The five forces include potential entrants, supplier power, buyer power, threat of substitutes, and rivalry among existing firms. The goal of any company is to find a position within their respective industry such that they are well situated to guard against these five forces.

The following subsections will discuss the state of these five forces in the capital equipment industry.

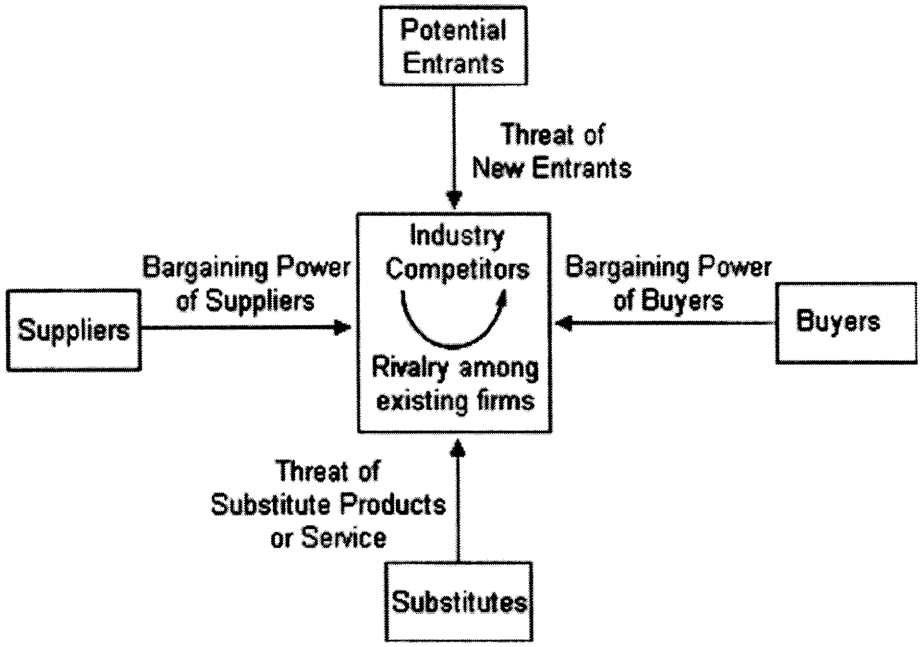



FIGURE 11, PORTER'S FIVE FORCES[17]

### 2.5.1 Competition and Rivalry

From 1980 to 2000, semiconductor companies spent enormous amounts of capital to increase fab capacity and make equipment upgrades. During this time, the equipment industry experienced nearly 20 percent annual growth. The rapid growth allowed equipment makers to grow without having to worry extensively about increasing their market share. Companies like Applied Materials, Tokyo Electron, and several other formerly obscure companies went from menial cash flows, poor financial health, and weak technology to billion dollar revenue streams, greater market power, and cutting edge performance and technology.

Since 2000, the growth of the equipment industry has changed dramatically. For the last eight years the capital equipment industry has had a cumulative annual growth rate of 4.5 percent. It appears that the industry is finally moving from a period of strong growth to a period of maturation. The pattern of an industry moving from growth to maturity is a crucial transition in an industry life cycle (see Figure 12). An entire text could be dedicated to discussing each of the phases of the life cycle. What is important to note is that this curve will look different for every industry. Some industries skip the maturation phase

[17] (Porter, 1998)

all together. Others never decline and continue growth with global GDP. Some start to mature but hit another period of growth as innovation spurs new applications. Despite the innate differences of each industry, a general pattern has surfaced. Most industries see a period of slow growth during introduction, massive growth during wide scale adoption, maturation as the market becomes saturated, and finally decline as substitutes become more prevalent.

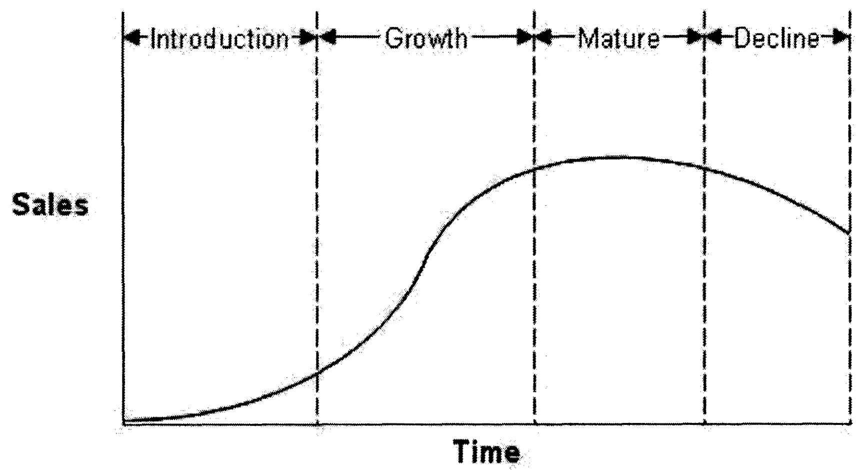



FIGURE 12, INDUSTRY LIFE CYCLE

Typically, when an industry matures, companies can no longer rely on industry growth to obtain a sufficient return on investment. Instead, companies must search for new ways to sustain growth. This often leads to market share battles. To gain market share, firms either attempt to strengthen their position in existing product lines or they try to expand into complementary product lines. When firms intrude on each other's territory, intense rivalry, price wars, and reduced industry revenues are the result. This type of competition is not healthy in the short run, but it typically ends up forcing consolidation that allows fewer companies to be more profitable in the long term. The capital equipment industry is in the thick of this shake-out, but it has been a long process, and the industry will likely experience much more consolidation for many years to come. Once the dust settles, a handful of dominant players will emerge with much more stable competitive positioning due to their economies of scale and scope and technological superiority. For now, more players exist in the capital equipment industry than the industry can healthily support, but this will change over time.

Beyond the increased competition resulting from lackluster industry growth, the equipment industry faces intense competition due to a lack of differentiation in their products. The tools that the equipment makers produce are basically commodities. It's hard to imagine that a tool that costs between $1M and $40M could actually be considered a commodity, but despite the high price tag, each tool has a very specific function to perform, and it is either capable or incapable of performing its function. The purchase decision for these tools boils down to how fast the tool can perform its specific task and at what cost. It's really a game of price and productivity. Occasionally a new innovation is developed that gives a tool maker a big advantage over their competitors, which is something Varian had success doing with their implant tool several years ago and Applied Materials has done with their chemical mechanical planarization tools, but these companies are the exceptions to the rule, and they are already seeing an end to their short run in technological superiority. For the most part, companies are producing technologically similar tools. Buyers will make their selections based on speed and cost. Because speed is tied to the design of the tool and is relatively unalterable, price becomes a tool maker's only bargaining chip. With price as the true differentiator, IC makers are able to pit tool makers against each other to achieve the best possible price.

### 2.5.2 New Entrants and Mobility Barriers

With so many factors contributing to intense rivalry in the equipment industry, another firm would have to be crazy to enter, right? While the equipment makers may not be enjoying greater than fifty percent profit margins like Harley Davidson or Microsoft, they are still in a growing industry, and they usually turn a profit.

Regardless of whether an industry has negative profit margins or 95 percent profit margins, profitability is only one industry trait that a potential entrant might look at to decide whether to enter or not. There are many other barriers to entry that can be equally as important in deciding whether an industry is attractive or not. This section will analyze the most relevant barriers that limit the competition in the equipment industry.

## Economies of scale

Economies of scale is probably the most critical barrier limiting the number of competitors in the market space. There is a tremendous amount of upfront costs required to develop the technology that enables the tools to perform their function. Additionally, the equipment is extremely sensitive and precise. Manufacturing these precision tools can be very expensive and many of the tools are built inside of clean-rooms to ensure the highest quality standards. A firm needs to have enough capacity to sell enough tools to make up the development and fixed costs. Economies of scale are essential for any firm to remain profitable in the capital equipment industry.

## Economies of scope

Economies of scope can also provide a significant competitive advantage. Firms that develop tools for multiple functional areas find greater opportunity to take advantage of synergies between their product lines. Having multiple product lines allows firms to save money on administrative costs, sales costs, procurement costs through bulk purchases, and manufacturing costs through shared resources. Additionally, companies that offer larger portfolios give their customers the option to consolidate their supply base through buying multiple tool types through a single source.

In addition to saving on costs, there are also technological similarities from one tool type to the next. Technological innovations often get passed from one tool to the other. Companies that have many types of tools benefit significantly when applying a breakthrough on one tool to all of their tool platforms. Technological similarities among tool platforms also allow many resources to be shared for tool production. This results in lower per tool development costs.

## Experience and Technological Capabilities

Experience and product technology present another significant barrier to entry. The industry has been evolving and improving rapidly since its beginnings. The rate at which suppliers are learning and improving is extremely fast. Approximately every two years, new state of the art equipment is created. Even if a potential entrant had the technological know-how to enter the market, by the time their manufacturing facilities and their relationships with customers had been established, the technology would have advanced well beyond them. It takes many tool generations for a new entrant to become remotely competitive, technologically.

The learning curve is impossibly steep for a new entrant. The only candidates that could overcome this barrier would be existing suppliers branching off into new functional areas, or chip manufacturers with the time and resources to expand into this complementary business.

**Capital Requirements**

The last major barrier to entry is the enormous and risky up-front capital investment that is required. Few firms have the financial strength to enter the capital equipment market. Not only is the capital requirement very high, but the risks are equally as high. The semiconductor industry is cyclical by nature, and there is no guarantee of getting a return on investment.

### 2.5.3 Buyer Power

The buyer has always had a lot of power in the purchase of capital equipment. Furthermore, this power has become stronger over the years, which has pushed suppliers into an even more competitive environment. The main factors for the significant buyer power in the capital equipment industry are listed below.

- *Concentration of Purchases* – Because Intel, Samsung, TSMC and a handful of other IC makers purchase most of the capital equipment, suppliers must work hard to secure a contract with these companies. Losing a bid with Intel or Samsung will put a significant dent in a supplier's future revenue.
- *Lack of Product Differentiation* – The products are largely undifferentiated, which allows IC makers to easily pick and choose which supplier to select based on price and performance.
- *Low Buyer Switching Costs* – There are definitely some switching costs for the buyers, namely testing and qualifying tools from a new supplier. However, the cost of switching to another supplier is typically small in comparison to the tool costs. Buyers may order between five and fifty tools, each with multimillion dollar price tags. Buyers will be happy to pay the upfront switching costs to save millions in tool costs.

- *Threat of Backward Integration* – Backward integration is a form of vertical integration where a firm, either by acquiring suppliers or developing their own expertise, performs the operations of their suppliers. Backward integration is commonly used as a growth strategy or as a way to reduce the firm's dependency within a supply chain.

  In the semiconductor industry, an IC maker would need both financial stability and superb technological capability in order to backward integrate. Intel and Samsung are probably the only companies capable of such a move. Samsung has actually already attempted to do some equipment development themselves. Due to a saturated and overly competitive market, buyers do not pose a serious risk of backward integrating.

### 2.5.4 Supplier Power

Most tools require raw inputs like sheet metal, electrical circuit boards, tubing, fasteners, etc. These and other components can be purchased from a wide list of commodity suppliers. Because these parts are commodities and there is a long list of providers, equipment makers have a good deal of power with their suppliers. They can negotiate based on price and switch suppliers easily if an acceptable price agreement cannot be reached.

On the other hand, because semiconductor equipment operates at the atomic level, custom parts with immense precision are often required. The suppliers of these parts hold a great deal of power, given that quality of the part is valued more than cost. For example, highly calibrated lenses are required to build lithography tools, and ASML relies solely on Zeiss to deliver the lenses for the equipment. ASML revealed in their 2007 annual report that approximately 40 percent of their cost of sales were purchased from Zeiss. Zeiss has a significant amount of supplier power with ASML, and most other equipment makers have at least a handful of suppliers that provide custom precision parts.

### 2.5.5 Substitutes

There are no direct substitutes for semiconductor equipment. The capital equipment in existence today provides the only economical way of producing high density, high performance semiconductor products. At the present time there are also no cost effective, high performance substitutes for silicon based integrated circuits.

# 3. Theory and Economics of Wafer Size Transitions

This chapter will open by briefly discussing the history and basic benefits of wafer size increases. Next, the economics of wafer size increases will be looked at in greater detail to understand what kind of cost savings should be expected from a transition to 450mm wafers. Finally, this chapter will conclude with an in depth analysis of the 300mm wafer size transition. The 300mm transition faced a number of challenges, and there is a great deal that can be learned from this transition and applied to the 450mm transition.

## 3.1 History and Basic Theory behind Wafer Size Increases

The basic theory behind a wafer size increase is that through doubling the area of the wafer, you can double the output at less than double the price. The tools that process silicon wafers represent the majority of the cost for IC makers to produce chips. Many of these tools process entire wafers, or multiple wafers, at a time. For a small increase in cost, the tools can be upgraded and scaled up to handle and process larger wafers. This allows IC makers to purchase fewer tools while maintaining the same output.

Since the birth of the transistor 60 years ago the semiconductor industry has undergone eight major wafer size transitions. Figure 13 shows the relative size increase of each wafer. Two prominent wafer sizing trends have occurred throughout this time period. First, most recent transitions have represented a 50 percent increase in wafer diameter, or a 225 percent increase in wafer surface area. Second, the wafer size transitions have historically occurred once every five to ten years, though the frequency of wafer size increases has slowed over the last several wafer size transitions (see Figure 14). The reasoning behind each of these trends will be discussed separately in this section.

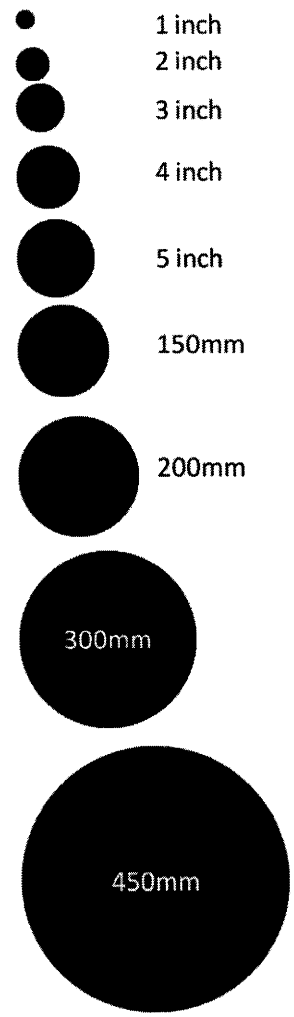



FIGURE 13, WAFER SIZE COMPARISON

### Why a fifty percent increase in diameter?

A fifty percent increase in diameter results in a 225 percent increase in total wafer surface area. This means that for every wafer that is fabricated, more than twice the number of microprocessors, or memory devices are produced. This increase in output is necessary to recoup the cost of upgrading all of the tools to handle 450mm wafers. This increase in output has historically been more than sufficient to offset the costs of developing an entirely new fleet of fab tools. A detailed analysis of costs and productivity improvements will be discussed later in this chapter.

One may be prompted to ask, "if bigger is better, why not increase the area by 100x and avoid all the timely and expensive intermediate wafer size transitions?" The simple explanation would be that the technology is not advanced enough to cost effectively produce wafers of that magnitude. First of all, a raw silicon wafer of that size would be extremely difficult, if not impossible, to manufacture. The technology is not advanced enough to make wafers of that size while maintaining the necessary high purity standards. Secondly, a 100x increase in output due to extremely large wafers would spark an enormous, non-linear jump in semiconductor product supply. Chip demand cannot justify such an increase, making the added cost of developing extremely large wafers a task of diminishing returns. A fifty percent increase in diameter represents a happy medium where wafer manufacturing cost efficiencies can be realized without increasing output beyond what the market demands.

### The Timing of a Wafer Size Increase

The timing of implementing the size increase is also important. Two main factors drive the timing of the wafer size transition: the cost of transitioning and the market demand for new products. In the industry's early years, transitions happened rapidly, in part due to a huge growth in appetite for semiconductor products. The transitions were also happening rapidly because the cost of making the transitions was relatively small. A tool processing a wafer the size of a quarter didn't need to be significantly altered in order to handle a wafer the size of a silver dollar. When wafers reached diameters of 150mm and 200mm, however, new technological problems emerged and scale ups became more costly and complicated. Even though strong demand for semiconductor products continued all the way through the 90s, wafer size transitions happened less frequently due to these increasing transition costs (refer to Figure 14).

After the dot-com bubble, demand for semiconductor products finally showed signs of slowing. This combined with the heavy costs experienced as the industry went through the 300mm transition has allowed the industry to delay the 450mm transition beyond when the next size increase would have been expected. At least twelve years will have passed since the 300mm launch before 450mm becomes a reality, and this could be pushed out even further if demand slows. If recent trends continue as they have, wafer size increases may occur much less frequently in the future or they may even reach a cap where it is more economically feasible to build extra manufacturing facilities than to attempt another wafer size scale up. In any case, increasing the size of the wafer has historically been a necessary and profitable investment for the industry.

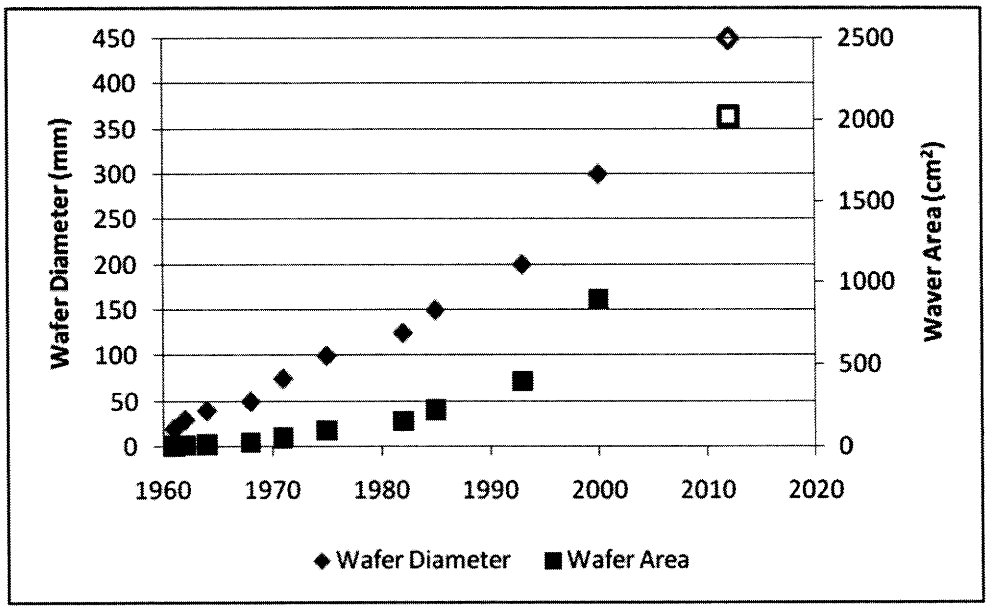



FIGURE 14, WAFER SIZE TRANSITION BY YEAR

## 3.2 Wafer Size Economics

As mentioned previously, wafer size increases can bring great economies of scale cost savings to semiconductor manufacturing. ISMI estimates that over 30 percent savings can be achieved by manufacturing on 450mm wafers. This section will break down the major costs of manufacturing semiconductor products, and it will discuss the impact of a wafer size increases on each of these costs. ISMI's cost breakdown is shown in Table 1.

| Cost Components | Share of Fab Costs | Cost Multiple | Output Multiple | Spend Impact |
|---|---|---|---|---|
| **Fab Capital Spend** | 50% | 1.3 | 2.3 | -45% |
| **Utilities & Maintenance** | 19% | 1.3 | 2.3 | -45% |
| **Substrate** | 7% | 5.5 | 2.3 | 135% |
| **Other (Labor, Materials)** | 24% | 1.3 | 2.3 | -45% |
| **Total (Wafer Costs)** | 100% | 1.6 | 2.3 | -32% |

Source: Analysis of ISMI economic projections

TABLE 1, 450MM WAFER MANUFACTURING COST BREAKDOWN

**Fab Capital Spend:** Fab capital spend refers to the cost of the equipment required to manufacture silicon chips. The semiconductor industry is an extremely capital intensive industry, so it should come as no surprise that the cost of the manufacturing equipment is the largest cost and makes up roughly fifty percent of wafer manufacturing cost. In order to process 450mm wafers, nearly all equipment within a plant must be redesigned and re-manufactured. For some tools, this means a simple scale up in size, but for others it could be a major undertaking as a larger wafer could present many new development challenges. In any case, there are costs involved with developing a whole new fleet of tools that can handle larger wafers. This development cost increases the price tag on every tool.

While the new tools will be more expensive, they will also be more productive. For every wafer processed, more than twice the number of chips is produced. Unless the cost of the tools increases by more than the throughput of the tool, the overall tool capital spending per device produced will decrease. ISMI projects that for the 450mm scale up, the costs should increase by 1.3x while the die throughput of the tools will increase by 2.3x. If this is true, then the number of tools needed to get the same output will only be 55 percent of what they were before. Even though the cost of the tools will increase, semiconductor companies can save roughly 45 percent on capital equipment because the number of tools required will be significantly reduced.

ISMI's projection of cost savings due to fab capital spend is somewhat optimistic. Equipment suppliers would argue that the costs will be much higher, especially given that for the 300mm transition the costs were exorbitant. However, equipment makers are likely inflating their numbers, hoping to convince IC makers that a transition is either unprofitable or costly enough that IC makers need to assist equipment makers with the development costs . The fact of the matter is that nobody knows how much each tool will cost to develop. The equipment makers are best suited to make accurate projections, but they are unwilling to share accurate information for fear of losing bargaining power and competitive advantage. Because there seems to be a dearth of good information with regard to tool productivity and cost, Section 4.3.4 will model the impact of various cost-productivity scenarios to get a better feel for how fab capital spend and tool productivity affect the attractiveness of the 450mm investment.

**Utilities & Maintenance:** Utilities and maintenance make up roughly 19 percent of the wafer manufacturing cost. A reduction in the number of tools will correspond directly to a reduction in the costs incurred by a plant to maintain and operate the tools. On the other hand, larger tools are generally more complicated and more expensive to maintain and repair. Regardless, the extra cost of maintaining a larger tool will not come close to the savings from maintaining fewer tools. Maintenance cost savings from transitioning to 450mm wafers will follow similarly to the fab capital cost savings of 45 percent.

**Substrate:** The substrate currently makes up roughly 7 percent of the wafer manufacturing cost. Wafer costs have increased exponentially as wafers have increased in size. This is due to the difficulty of producing larger, defect free, pure silicon wafers. ISMI estimates that 450mm wafers will cost 5.5x more than 300mm wafers. If there is only a 2.3x increase in throughput, then the overall substrate cost per die will be 135 percent greater.

**Other (Labor & Materials):** Labor and other material makes up the remaining 24 percent of the cost of the wafer manufacturing process. Because output per tool is much higher for 450mm tools, it is logical to assume that the number of technicians, operators and engineers to achieve the same output will decrease. In other words, the number of people per tool will remain unchanged while the output per tool will go up. There should also be other material savings as there will be more efficient use of consuming reagents, dopants, and other chemicals. ISMI predicts the labor and material cost savings to be equal to the savings seen on capital equipment and utilities and maintenance, or 45 percent.

## 3.3 Case Study: Transitioning to 300mm

The high cost of investing in 300mm has led to reluctance by the industry to move ahead with future wafer size increases. Many people fear the worst if the industry goes ahead with 450mm, but if the industry can learn from the mistakes made on 300mm development, the cost of developing 450mm could actually be very reasonable and perhaps offer a good return on investment to equipment makers.

This section will take a more detailed look into the 300mm transition and analyze the overall development process and key factors that have led to high development costs.

### 3.3.1 300mm Overview

While 200mm wafers began their manufacturing debut in 1993, device companies were already looking ahead to decide when the next wafer transition should be. Demand for their products had been growing at more than 14 percent per year for the previous 25 years, and there was no end in sight. In fact, it appeared that before the end of the decade, the largest chip maker, Intel, would have to build two 200mm factories per year to support the growth.[18] So the planning stages began, and in 1995 the industry agreed on 300mm as the next wafer size with a production date targeted for 1998. Suppliers began constructing the first generation equipment throughout the next couple of years in preparation for the aggressive launch date.

Transitioning from 200mm to 300mm wafers is a topic that evokes a good deal of emotion in the semiconductor industry, especially when discussed with equipment suppliers. Prior to 300mm, device makers bore the brunt of the investment required to develop the new tools for a wafer size increase. In the past, equipment companies had been relatively small, and incapable of financing such large development projects. However, due to prolonged growth and increased consolidation in the equipment supply chain, equipment suppliers were larger and healthy enough to fund the 300mm investment. As a compromise, IC makers and equipment suppliers agreed to share the financial burden of transitioning to 300mm wafers, which basically meant that equipment suppliers would pay for all of the tool development costs, and device manufacturers would pay for testing and qualifying the new tools.[19]

For a myriad of reasons, 300mm proved to be more difficult and much more expensive than past wafer transitions. VLSI Research conducted its own independent survey and estimated 300mm development costs at $11.6B compared to the 200mm development costs of $1.3B (see Figure 15, Wafer Transition R&D Spending). This represented a nine-fold increase in cost of development. If a nine-fold increase were to occur again on the 450mm transition, the cost of development would exceed $100B. But simply projecting based off a trend would be presumptuous, especially considering that

[18] (Seligson, Daniel, 1998)
[19] (Seligson, Daniel, 1998)

there is good evidence to show that the high costs of developing 300mm can be attributed to many adverse factors that will likely not be repeated on 450mm. In any case, moving to 300mm wafers was an extremely long and expensive transition for equipment suppliers, and it is because of these memories that so many equipment suppliers oppose 450mm wafers.

The remainder of this section will discuss some of the critical issues that caused the 300mm wafer scale up to be so expensive and difficult. It will also draw parallels between what was seen for the 300mm scale up, and what might be expected for the 450mm scale up.

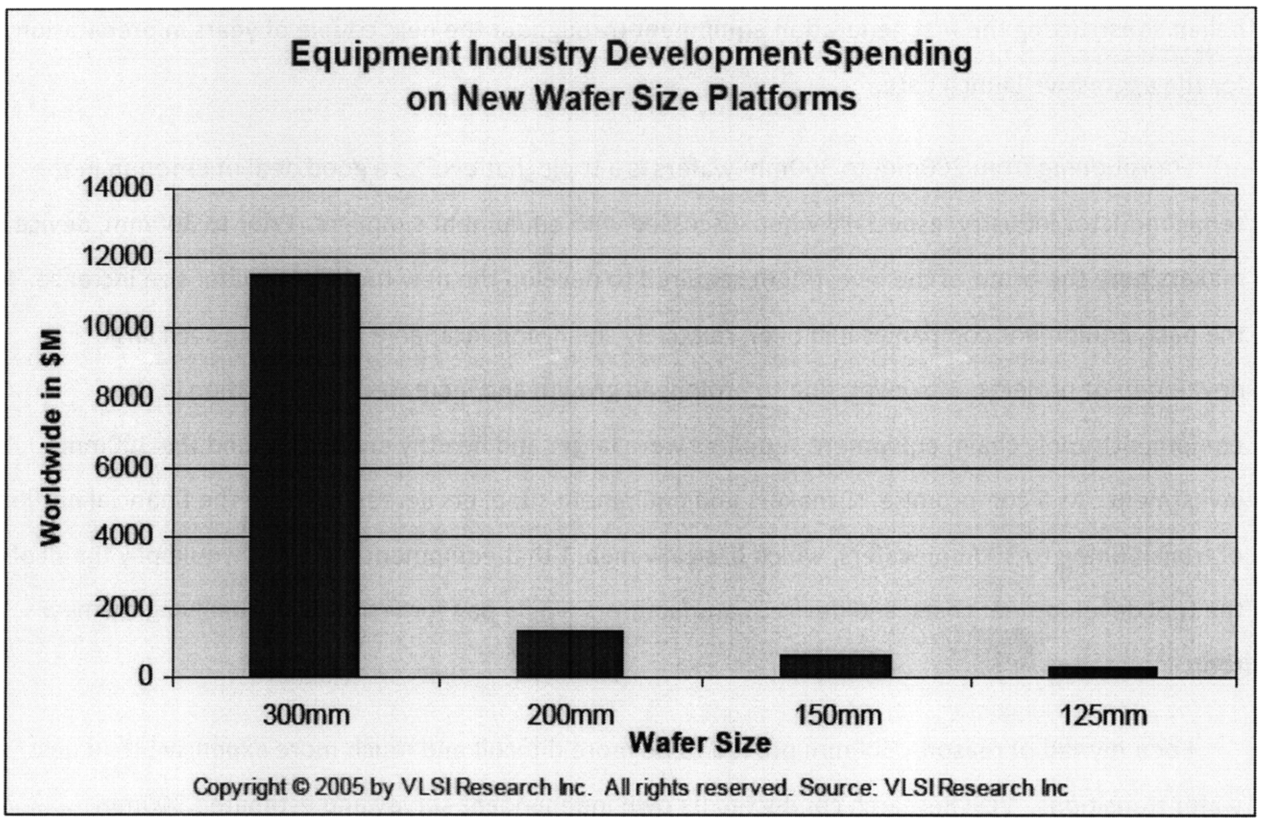



FIGURE 15, WAFER TRANSITION R&D SPENDING[20]

[20] (Hutcheson, 2005)

### 3.3.2 Mismanagement, Lack of Consensus and Aggressive Timelines

Many of the struggles experienced with the 300mm transition can be linked to poor management by the consortia managing the transition. Evidence of this lies in the lack of industry consensus with regards to technical standards and timing of the transition.

The first major blunder was failing to agree on a single lot size. During a SEMI standards meeting in February of 1995, representatives from various semiconductor manufacturing companies, as well as equipment suppliers, assembled to agree on numerous standards, key among them being the wafer lot box size. Numerous options were on the table, but the majority of the representatives in attendance sought to continue with the traditional 25 wafers per lot. Motorola, one of the more aggressive proponents of 300mm wafers, was adamant about shifting to a 13 wafer lot size.[21] Smaller lot sizes allowed them to have better customer responsiveness and more flexibility for running their higher mix of devices. Despite their best efforts, Motorola couldn't gain the needed support for the smaller lot size. Most of the other device makers were involved in the low mix, high volume business of making memory devices. Realizing that their objectives did not align with many of the other IC makers, Motorola gradually distanced themselves from the standards committee and pushed forward with what they believed was in the best interest of their own business. In the end, no single industry standard for lot size emerged. Having to design and manage equipment to support both the 13 and 25 lot standards caused unnecessary confusion and distraction.

A second major blunder was sticking to an overly aggressive launch date. 200mm wafers had just hit production and the industry was already looking forward to the next wafer size. A 1997 launch only left a few years for planning and development, and it was far too optimistic for a transition as complicated as 300mm. Unlike past wafer size transitions, 300mm finally crossed a threshold where the size and weight of the wafer lot boxes exceeded that of what humans could easily handle safely and efficiently. As a result, alongside the development of the new, larger, more complicated equipment, new automated wafer handling systems (AMHS) had to be developed. In addition to this, other issues related to the size of the equipment and the size of the wafers were beginning to make wafer size scale ups more difficult than had previously been experienced. The timeline was far too aggressive, and the

[21] (Seligson, Daniel, 1998)

industry ultimately had to backtrack to develop all the automation requirements that were discovered later on.[22]

Another key mistake was the failure to properly incentivize the suppliers. The consortia managing the 300mm transition insisted that suppliers begin their 300mm development on older process technology. Meanwhile, 200mm equipment was being developed on the cutting edge process technology. The suppliers that spent precious funds developing the first 300mm tools had no market in which to sell the already outdated 300mm equipment. They were forced to spend more money to redevelop their 300mm tools for the newest process technology. In a strange way, suppliers were actually incentivized to be the last to market. Some suppliers had the foresight to realize that delaying their 300mm development would bring great savings to their company. Unfortunately, these misaligned incentives caused suppliers to be disconnected in the development timeline. The result of this was having some very prepared suppliers, some suppliers rush to meet the deadline, and some suppliers completely drop the ball. It was absolutely necessary to have all of the suppliers united in their development of the 300mm tools, because without a complete 300mm toolset, none of the suppliers' tools could be sold. For 300mm, lithography equipment suppliers proved to be particularly unprepared for the transition, creating a hole in the manufacturing process which doomed the first generation of 300mm.[23]

A final sign of the lack of unity throughout this transition was the excessive number of 300mm standards creating bodies. Ideally there would only be one standards committee or consortia setting the tool requirements, but by the late nineties, three groups were involved in this, I300I, SELETE, and SC300. I300I and SELETE were the two main bodies overseeing and managing the 300mm transition. SC300 was a joint venture, and the first 300mm fab, between Motorola and Infineon. SC300 developed many of their own standards and placed orders for tools with special requirements. Meanwhile, I300I and SELETE were creating their own standards, and even they did not always align. Because there were three separate working separately to develop 300mm standards, work was duplicated, requirements were contradicted, and multiple standards came into existence. This proved to be distracting and inefficient.

[22] (Hutcheson, 2005)
[23] (Hutcheson, 2005)

### 3.3.3 1998 Downturn and 2000 Dot-Com Bubble

Not only was the transition to 300mm poorly managed, but it had to weather the perfect storm as the Asian financial crisis beginning in 1997, and later the dot-com bubble in 2000, made the transition nearly impossible. These major economic catastrophes could not have been foreseen, and they have caused the industry to grow at a dramatically different pace ever since.

The Asian financial crisis started in Thailand in 1997. The Thai government had acquired a burden of foreign debt that effectively bankrupted the country even before they were forced to float their currency in July of 1997. The crisis in Thailand quickly spread throughout Asia, as investor confidence deteriorated throughout the region. The consequences of the Asian financial crisis were widespread and resulted in reductions in Asian currencies, stock markets, and asset prices of many Asian countries.[24] Among the hardest hit were Thailand, South Korea, and Indonesia, but all countries in the surrounding region were effected as they suffered from a loss of demand and confidence.

The onset of the Asian Financial Crisis created new fears throughout the semiconductor industry. It was unclear what impact a crisis of this magnitude would have on the semiconductor industry. Not only did IC makers worry about how demand for their products would be affected, but they worried about what might happen to their existing manufacturing capacity which had been built up in Asia, predominantly in South Korea and Taiwan. In addition, the majority of equipment suppliers were based in Japan. The entire semiconductor industry was reeling from the effects of this unforeseen economic catastrophe. The confluence of an unproven 300mm technology mixed with volatile market conditions caused IC makers to cut new investment. 300mm was placed indefinitely on hold as IC makers retrenched and waited for the dust to settle. Meanwhile, equipment suppliers were sitting on their multi-billion dollar investment wondering when their customers would finally decide to buy their new products.

Figure 16 shows the distribution of 300mm development spending throughout time. There is a clear bimodal distribution caused by the postponement of the development during the Asian Financial Crisis. In late 1998, IC makers began to see a light at the end of the tunnel. Believing that the worst was behind them, many IC makers decided that it was finally time to invest in 300mm capacity. Unfortunately, the delay in purchasing 300mm capacity allowed the 300mm tools to become outdated.

[24] (Tiwari, 2003)

Suppliers had to once again redevelop and upgrade their tools for the latest process technology. This second major push in spending on 300mm accounts for the second hump seen in Figure 15.

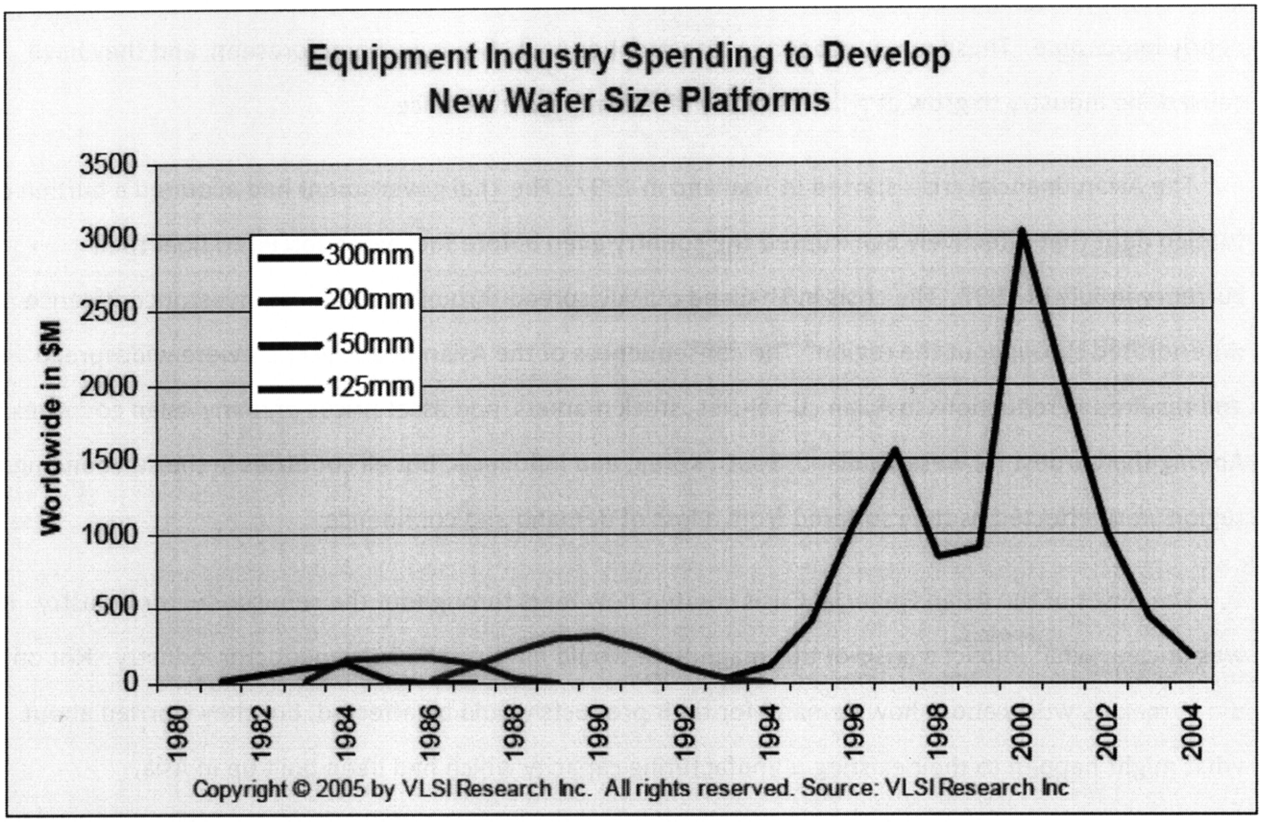



FIGURE 16, WAFER TRANSITION SPENDING THROUGH TIME[25]

As difficult as the economy and development difficulties had been, equipment makers finally had something to look forward to. With a once again booming economy, IC makers were eager to add capacity and prepare for another period of growth and prosperity. IC makers spent more on equipment in 2000 than they had ever spent before. Capital equipment industry revenues exceeded $60B.

The boom of 2000 was short lived, however, as the US began its biggest recession in almost two decades. Unlike other downturns driven by supply and demand, this one was very much macro-economic and severe. During the dot-com recession, demand for PCs fell for the first time in the 20 year history, cell phone sales flattened, and IT/communications were hit especially hard. 2001 IC maker revenues were below $140B, marking a 30 percent decrease from the previous year. 2002 represented little improvement with consumer spending in semiconductors rising only 3 percent higher than the previous year.

[25] (Hutcheson, 2005)

Fresh concerns about future demand for semiconductor products sprouted, and IC makers cut their spending. Equipment suppliers were once again disappointed by the difficult economic circumstances and would have to continue to be patient while they waited for a return on their 300mm investment. Figure 17 shows the capital spending trends throughout the dot-com bubble and the recovery thereafter. Semiconductor equipment sales plunged immediately following the bursting bubble due to IC makers' reluctance to add new capacity during a downturn. The capital equipment industry slowly emerged from the recession, but the recovery was slow. Even as of 2009, the yearly revenues for the capital equipment industry have not surpassed the 2000 levels.

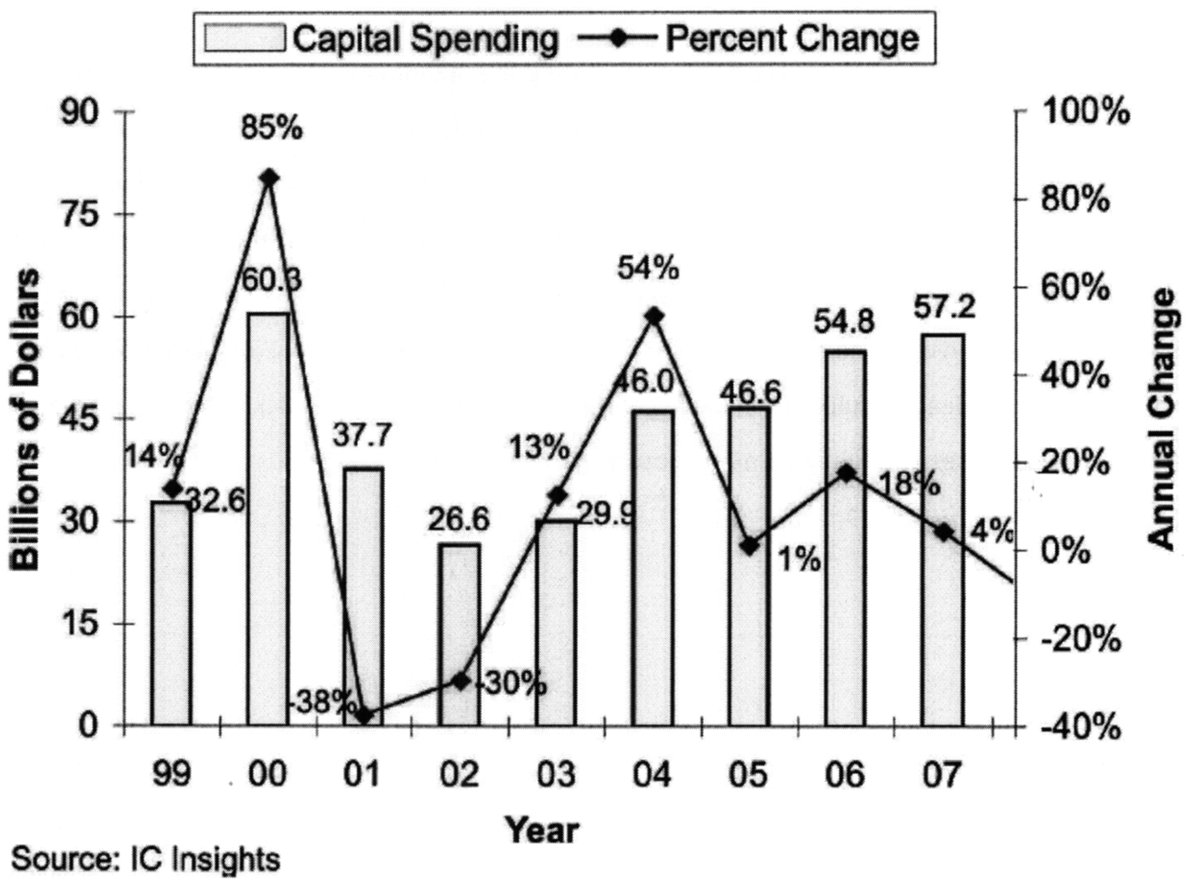



FIGURE 17, WORLDWIDE SEMICONDUCTOR EQUIPMENT CAPITAL SPENDING TRENDS (1999-2007)[26]

[26] (McClean Report, 2008)

### 3.3.4 Conclusions and Takeaways

The transition to 300mm wafers was a long and painful one, especially for the equipment makers. Investment started as early as 1993, and equipment makers are just now seeing a return on their investment. It is no wonder, with a payback period going well beyond a decade, that equipment suppliers are reluctant to go through the same type of investment all over again.

The 300mm transition went poorly, but many of the problems with the transition can be linked to poor management and bad luck. Looking back at Figure 16, it is clear that spending for 300mm went incredibly inefficiently. Had the development followed a unimodal curve, similar to the previous wafer size transitions, the industry would not have experienced a nine-fold increase in costs.

It is well known that inefficiencies took place during the 300mm development. So long as the consortia managing the 450mm transition can learn from mistakes past, 450mm may be a beneficial investment for IC makers and equipment suppliers alike. In order for 450mm to be a smooth and efficient transition, the following should take place. First, suppliers must be incentivized properly to keep the development timeline of all suppliers synchronized. Second, IC makers must share some of the development burden or agree on a risk sharing method such that external factors, like worldwide recessions, will not leave equipment makers carrying the short end of the stick. Third, equipment standards must be set and followed more closely than on 300mm.

# 4. Impact of 450mm Wafers on Equipment Manufacturers

This chapter will begin by discussing the dynamics surrounding the 450mm transition debate. There are many opinions about how equipment suppliers should deal with 450mm, and these will be discussed in greater detail. Next, the supplier cost model – a model developed by the author of this thesis to evaluate the pros and cons of 450mm for equipment suppliers – will be introduced. The basic inputs and outputs to the model will be discussed and analyzed. Last, this chapter will conclude with a series of scenarios that are run through the model. Each scenario will be analyzed to understand better the impacts of 450mm on individual suppliers as well as the equipment industry as a whole.

## 4.1 450mm and the "Prisoner's Dilemma"

The decision to go to 450mm is a classic expansion of what game theory has coined "The Prisoner's Dilemma." The prisoner's dilemma goes as shown in Figure 18.

*Two suspects are arrested by the police. The police have insufficient evidence for a conviction, and having separated both prisoners, visit each of them to offer the same deal. If one testifies ("defects") for the prosecution against the other and the other remains silent, the betrayer goes free and the silent accomplice receives the full 10-year sentence. If both remain silent, both prisoners are sentenced to only six months in jail for a minor charge. If each betrays the other, each receives a five year sentence. Each prisoner must choose to betray the other or to remain silent. Each one is assured that the other would not know about the betrayal before the end of the investigation. How should the prisoners act?*

| | Prisoner A - Defect | Prisoner A - Silent |
|---|---|---|
| Prisoner B - Defect | A: 5 Years<br>B: 5 Years | A: 10 Years<br>B: FREE! |
| Prisoner B - Silent | A: FREE!<br>B: 10 Years | A: 6 Months<br>B: 6 Months |

FIGURE 18, PRISONER'S DILEMMA

The best mutual outcome is for each prisoner to remain silent. However, there are severe consequences if a prisoner remains silent while the other defects. If each prisoner is seeking the best possible outcome for himself, then the overall outcome will be both prisoners defecting. This results in the Nash Equilibrium. A *Nash Equilibrium* is a stable state of a system that involves several interacting participants in which no participant can gain by a change of strategy as long as all the other participants remain unchanged.

**How is 450mm similar to the prisoner's dilemma?**

There are two options available to each supplier. A supplier can either develop 450mm tools or not develop 450mm tools. The decision that a supplier chooses to make has a large effect on the outcome of the other suppliers. Like the classic case of the prisoner's dilemma, there are three possible outcomes, each shown in Figure 19 as well as described in greater detail in the sections below.

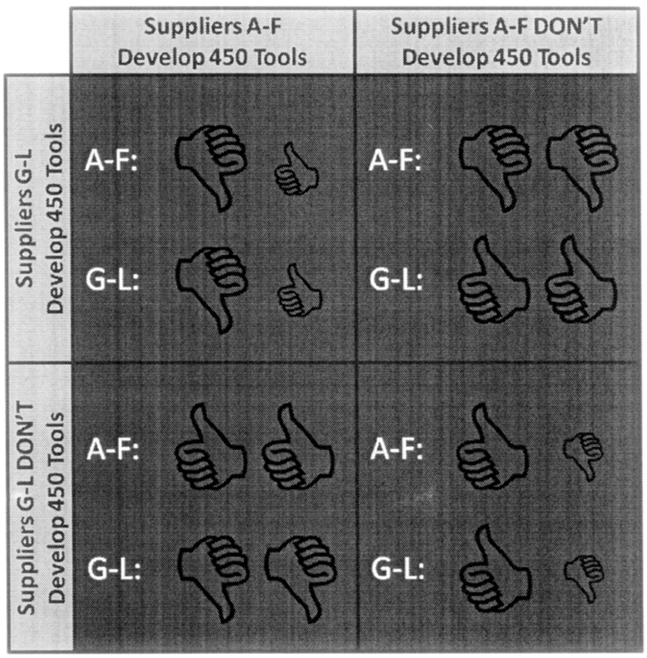



FIGURE 19, 450MM PRISONER'S DILEMMA

**Unite and Fight (bottom right)**

Suppliers are concerned that moving to 450mm will be a very costly investment that provides little to no benefit for suppliers. If they develop larger, more efficient tools then IC makers will buy less equipment to save on manufacturing costs. Fewer tool sales means the overall equipment industry revenues shrink, and unless the number of companies sharing that revenue is reduced, all suppliers will suffer. If all of the suppliers remain united and refuse to develop the more efficient tools, then the overall result will be positive.

Suppliers have been outspoken about the dangers of going to 450mm. To express these concerns, many of the manufacturers have banded together and used the voice of a trade group known as

Semiconductor Equipment and Materials International (SEMI), and they have produced anti-450mm analyses in order to steer the industry away from another wafer size increase. With the largest suppliers among the SEMI ranks, it is questionable whether there will be sufficient support for 450mm to be possible. After all, there must be enough suppliers to support all of the required tool platforms for 450mm to be possible. If a sufficient number of defecting suppliers cannot be formed and the industry does not make the transition to 450mm wafers, then the overall net effect on the equipment industry will be largely positive. After all, if the industry remains on 300mm wafers, then equipment manufacturers can continue to sell more of the less efficient 300mm equipment and will not have to invest in the expensive development of 450mm tools. This is depicted in the bottom right square of Figure 19.

As a cautionary note, there is potential for this strategy to backfire. The semiconductor industry has thrived on its ability to continually provide complex products at low costs. If the industry does not continue to invest in cost cutting strategies then the cost of creating more technically complex designs will increase. If manufacturing costs are not reduced enough to offset the rising development costs, then semiconductor chip prices will increase. This increase in prices will curb worldwide demand for semiconductor products and could potentially reduce long term earnings for both IC makers and equipment suppliers.

**Disband and Develop (top left)**

Either overtly or secretly the suppliers could all agree to satisfy their customer's requests and produce 450mm tools. As previously discussed, producing the more efficient equipment will reduce industry revenues. If the size of the pie shrinks then the industry structure will need to change. This means mergers, acquisitions, alliances, and most likely business failures. Because this scenario results in reduced revenues for the industry as a whole, it can be seen as a negative outcome. However, the equipment makers that emerge from the shakeup will end up with a much better market position than they had previously enjoyed. They will be larger, more powerful, and hopefully more profitable.

**Befriend and Betray (top right/bottom left)**

The opportunity for the greatest reward can be achieved by going to 450mm wafers and stealing market share while the competition does nothing. Most equipment makers have not publicly admitted to having done any development on 450mm tools. In fact, most of the equipment makers have aligned with the SEMI organization to fight against the 450mm transition. The billion dollar question is, are they joining into SEMI because they truly intend to defeat the 450mm transition, or do they want to send one signal to their competitors, then do the opposite.

It is possible that many, if not all of the equipment makers, are working to develop 450mm tools behind closed doors. Now that IC makers have announced their intentions to make 450mm wafers a reality, the suppliers that have been developing and preparing the next generation 450mm tools will have a leg up on their competition. This is immensely important, given the fact that the market is already in a relatively unhealthy state, and 450mm will only increase the turbulence and flush out the competition that can't keep up.

This strategy has a hitch. If the industry does not gain the momentum required to shift to 450mm wafers, then all of the development done by the overly eager suppliers will be for naught. But even the equipment suppliers opposing the transition, such as AMAT, recognize that 450 is possible in the not too distant future.[27]

**Finding Equilibrium in the Prisoner's dilemma**

On one hand, a sufficient number of equipment makers must develop the 450mm tools in order to have a complete set of 450mm tools. No supplier has the capability to develop all of the tools required for a complete factory, and without a complete set of tools, a transition to 450mm is not possible. If too few suppliers develop 450mm tools, then the transition cannot be completed, and the scenario represented in the "insufficient support" section of Figure 20 results. The overall impact to the industry is negative. However, the only suppliers damaged in this scenario are the ones that made failed attempts to go to 450mm.

On the other hand, if a transition to 450mm is successful, some consolidation will be necessary to ensure an ongoing healthy capital equipment industry. The unhealthy situation involving too many 450mm players is shown in the "Saturated Market" region of Figure 20. Two factors cause this region to

[27] (LaPedus, 450-mm Fab Debate Surfaces, 2009)

yield a negative result. First, a larger number of suppliers developing duplicate versions of tools will result in a higher overall development cost. Second, all of the suppliers making the 450mm leap will have to share the 450mm revenue. As the number of suppliers in competition increases, each supplier's share of the 450mm revenue decreases. In addition to this, the revenues will be even more meager than before, given that they have been selling more productive tools to the IC makers.

To remain healthy, the equipment industry must find a "450mm adoption sweet spot," represented in the center of Figure 20. It is difficult to say exactly how wide this sweet spot is, and it is also difficult to assess which suppliers deserve to be included in this sweet spot. The industry is limited in its ability to regulate who develops 450mm equipment. The utility of this pictorial is its demonstration of the risks involved with moving to 450mm wafers, and hopefully by increasing awareness of the risks, equipment suppliers will use caution when deciding to jump into the 450mm dogfight.

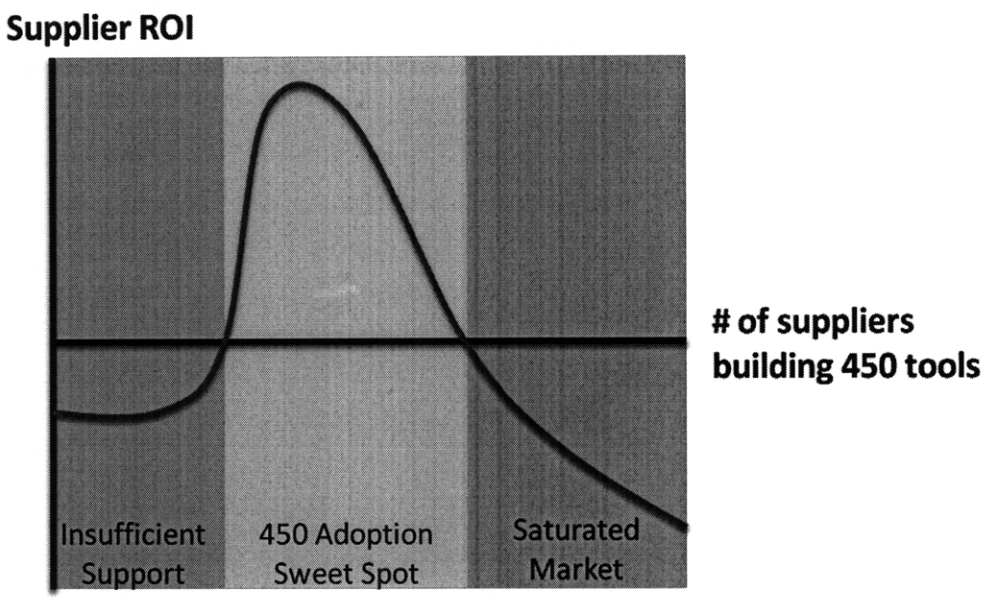



FIGURE 20, 450MM DEVELOPMENT SWEET SPOT DIAGRAM

## 4.2 Supplier Cost Model

Beyond the number of suppliers that decide to develop 450mm tools, there is a myriad of other factors that will have a substantial impact on whether 450mm is successful. Growth is obviously a critical factor, as is the efficiency of the tools. The overall cost of developing tools will be a factor as well. The list goes on and on. Early on in this analysis it became clear that a decision to go to 450mm would not be cut and dry and the outcome would be based on many forward looking projections. To deal with the uncertainty, it was clear that the various possibilities would need to be modeled to truly understand how each factor affected the outcome.

The supplier cost model is an Excel based model that allows the user to determine what financial impact the transition to 450mm wafers will have on equipment manufacturers over a range of economic scenarios. The model is intended to be run iteratively with many input scenarios to determine which inputs have the greatest impact on the 450mm net present value (NPV). Furthermore, it is intended to help the user understand the conditions under which most suppliers benefit from 450mm.

The model does not provide a deep analysis for forecasting demand. Demand is an input to the model. The model does not provide a "yes" or "no" answer to 450mm. It is intended to allow for various scenarios to be analyzed in order to understand the impact of 450mm under a range of inputs and circumstances. Finally, the model does not cover every factor that may impact the feasibility of 450mm. It focuses on the most important factors – the factors that drive the investment decision.

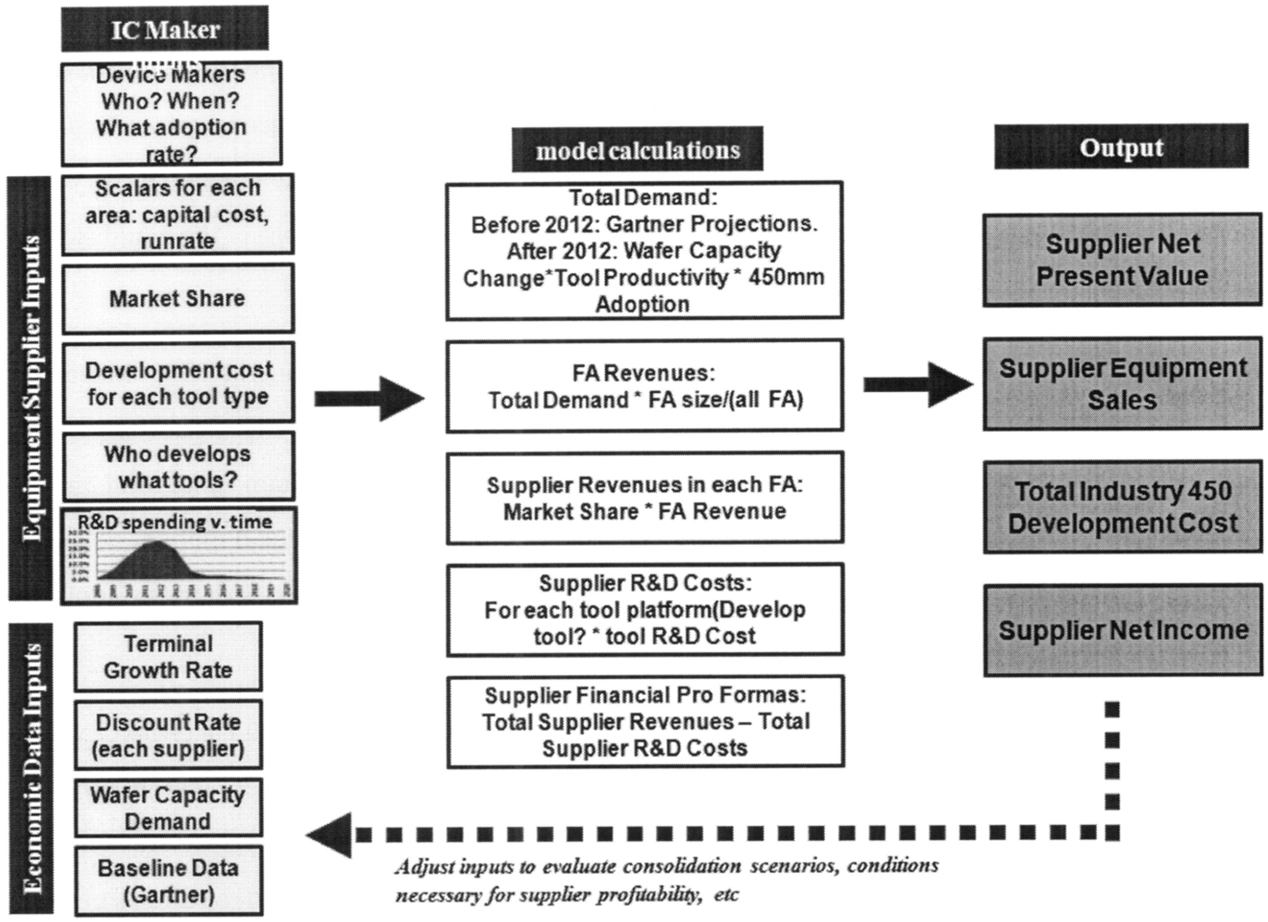



FIGURE 21, SUPPLIER COST MODEL FLOW CHART

Figure 21 shows a high level flow chart for the supplier cost model. The model is much more complex and involved than what is displayed here, but this chart shows the main pieces of the model. First, inputs include economic data projections, equipment development projections and IC maker adoption projections. Historical data collected by Gartner is heavily used in conjunction with the user defined inputs to make calculations and future projections. Finally, the model outputs the results that are most relevant for determining the impact of the 450mm investment.

As an introduction to the model, this section will discuss the outputs and inputs to the model.

### 4.2.1 Model Outputs

**Net Present Value (NPV)** – This is the most relevant and useful metric to determine the impact of the 450mm investment on capital equipment suppliers. 450mm is intended to produce long term benefits by stimulating demand for semiconductor products through the reduction of chip manufacturing costs. Many of the benefits will not be realized until 450mm makes up a significant share of the worldwide capacity, which won't occur for many years after the initial investment.

To quantify the benefit, the model takes the following approach to calculating the NPV. For each supplier, the model calculates the expected revenue each year from fab equipment sales. This calculation is done twice, once assuming the industry does not transition to 450mm wafers and once assuming the industry has shifted to 450mm wafers. The difference in each calculation for each year is the cash flow used for the NPV calculation. Each year's cash flow is discounted back to today's dollars and summed together to show how much the investment is worth today.

The revenue based NPV is calculated for each year out to 2025. At the year 2025, a terminal value is determined based on a specified industry discount rate and an expected industry terminal growth rate. The terminal value is also discounted back to today's dollars and added to the NPVs calculated for the other years. Calculating a terminal value for the 450mm investment is necessary to capture all of the value of 450mm. Much of the benefit of 450mm is derived from the long term growth stimulated through low cost manufacturing. Most of this growth stimulation will not occur until 450mm capacity constitutes a significant percentage of the worldwide manufacturing capacity.

It is necessary to emphasize the fact that this NPV is generated by calculating the expected 300mm and 450mm future revenue differences. It does not include potential profit and loss impacts below the revenue line, except for the required 450mm development spending. Examples of items not included are R&D tax credits, manufacturing cost efficiency changes, and potential government subsidies. Inclusion of these factors would have been completely speculative and would have clouded the data. Nevertheless, they are important considerations to address upon reviewing the model outputs.

Because each supplier varies in size and volume, an absolute NPV alone will not tell the entire story. To understand the relative impact of 450mm, the model computes three separate NPV calculations.

- **NPV ($M) – All Firms (see Figure 22) –** This is the absolute NPV for each firm. It accounts for all firms regardless of whether they actually develop any 450mm equipment. Firms that do not invest in 450mm will typically show a negative NPV in this calculation due to losing significant market share when the rest of the industry transitions to 450mm and they are left behind.

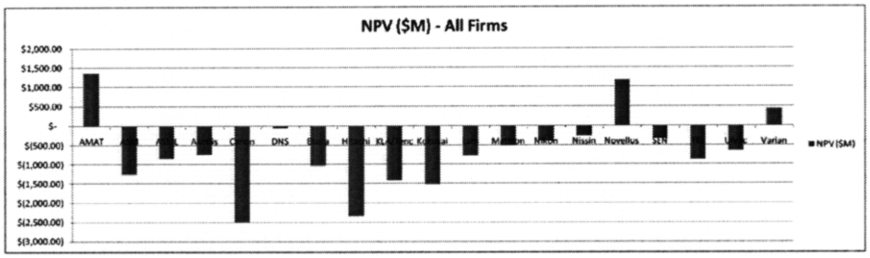



FIGURE 22, SUPPLIER COST MODEL NPV OUTPUT – ALL FIRMS

- **NPV – 450mm Firms Only (see Figure 23) –** This calculation is a repeat of the NPV calculation for all firms, except any firms that do not develop 450mm equipment, or firms that are acquired, and their market share goes to a competitor, have their NPV set to zero. Hence, the chart below has fewer bars than the chart for all firms.

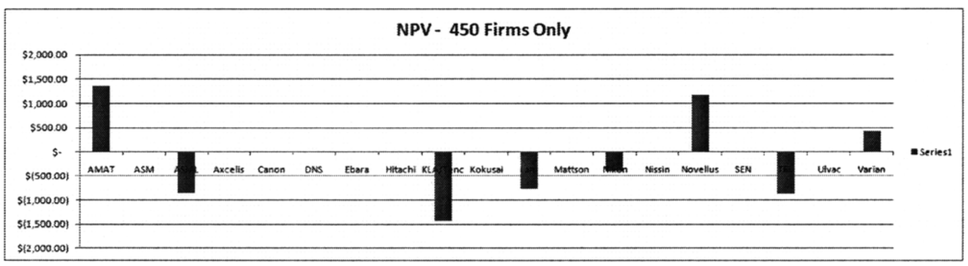



FIGURE 23, SUPPLIER COST MODEL NPV OUTPUT – 450MM FIRMS ONLY

- **NPV/2007 Equipment Sales (see Figure 24) –** Because all of the equipment suppliers differ in size, scope and influence, an absolute NPV will not show the relative impact to each supplier. To put the impact of the 450mm investment into relative terms, this NPV calculation normalizes each supplier's NPV by their 2007 equipment sales.

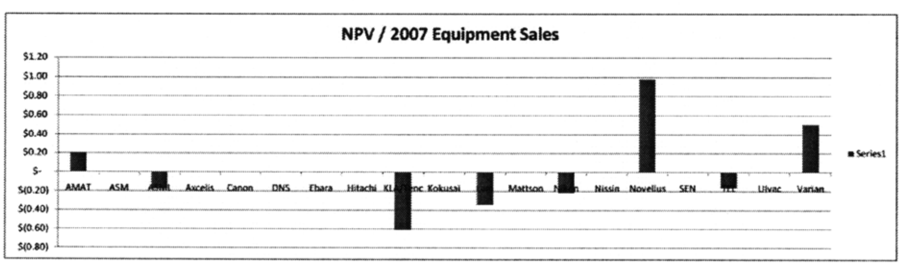



FIGURE 24, SUPPLIER COST MODEL NPV OUTPUT - NORMALIZED

**Supplier Fab Tool Sales (see Figure 25) –** The model shows how each supplier's equipment sales will evolve through 2025. On the left side of Figure 25, supplier S will have a significant increase in sales. This could be due to market share gain resulting from other suppliers failing to make the 450mm leap, or it could be due to advancing into adjacent markets that they previously held less share of. On the right side of Figure 25, supplier E's equipment sales are displayed. Supplier E does not make the 450mm transition, and because most of their customers transition to 450mm fabs, they take a catastrophic hit to their overall sales.

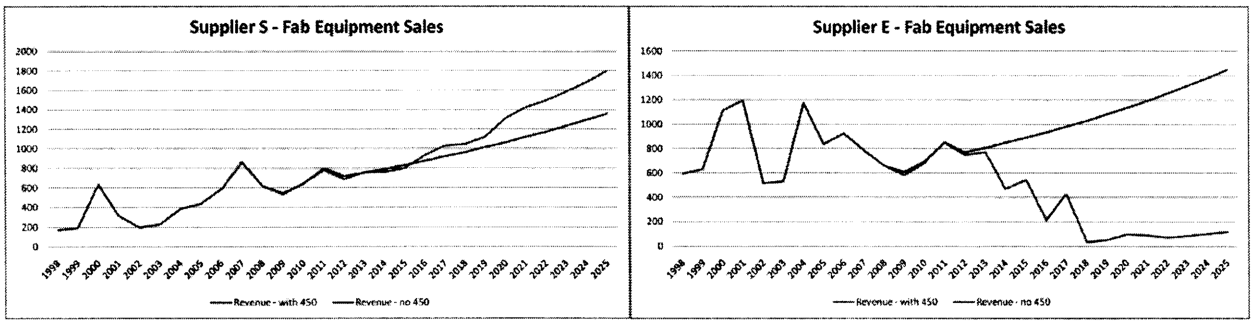



FIGURE 25, SUPPLIER COST MODEL REVENUE OUTPUT

**Supplier Net Income (see Figure 26) –** Supplier Net Income is largely affected by tool sales, but for diversified companies, like company E, the impact of losing almost all of their company's equipment sales has almost no effect on the overall company's profitability. Supplier S, on the other hand, is a pure play supplier that sees a direct impact on the overall firm's profitability as a result of the increased sales brought on by 450mm tool sales. Supplier net income is a difficult thing to forecast past a few years, and as a result, this output should be given little consideration when evaluating the impact 450mm.

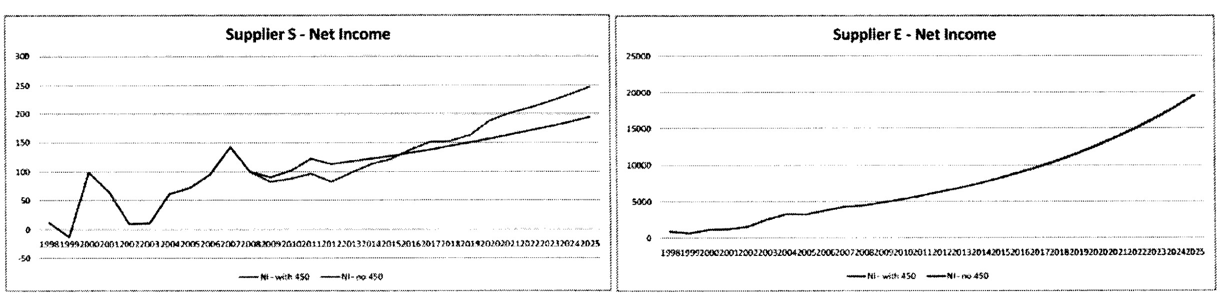
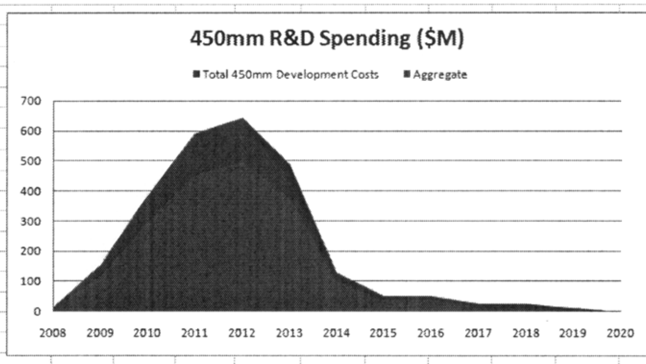



FIGURE 26, SUPPLIER COST MODEL NET INCOME OUTPUT

**Supplier 450mm R&D Spending (see Figure 27) –** This chart shows the overall spending as well as the distribution of spending for 450mm tool development (all numbers in millions). The blue area represents the amount of spending the equipment suppliers will incur for developing the major tool platforms. The red area is a simple adder to account for the additional spending that this model does not capture. Such spending might include costs of developing automation for the equipment, consortia and standards development costs, costs of non-major tool platform development by all suppliers, and raw wafer R&D costs.




| Total 450mm Cost to Top Suppliers ($M) | |
|---|---|
| $ | 1,985.00 |

| Total 450mm Development Cost | |
|---|---|
| $ | 2,580.50 |

30% Spending outside of tool R&D costs

**450 Development Costs**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aggregate | 9.925 | 119.1 | 297.75 | 456.55 | 496.25 | 377.15 | 99.25 | 39.7 | 39.7 | 19.85 | 19.85 | 9.925 | 0 |
| Other Supp | 2.9775 | 35.73 | 89.325 | 136.965 | 148.875 | 113.145 | 29.775 | 11.91 | 11.91 | 5.955 | 5.955 | 2.9775 | 0 |
| Total | 12.9025 | 154.83 | 387.075 | 593.515 | 645.125 | 490.295 | 129.025 | 51.61 | 51.61 | 25.805 | 25.805 | 12.9025 | 0 |

FIGURE 27, SUPPLIER COST MODEL R&D SPENDING OUTPUT

### 4.2.2 Model Inputs

There are many inputs to the model. Each has been classified into one of three categories, general inputs, R&D and investment inputs, and demand and growth inputs. These three categories will each be covered separately in the following subsections.

#### *4.2.2.1 General Inputs*

- **Wafer Area Gain** – By increasing the diameter of the wafer, the surface area increases by $A=\pi r^2$. Thus, increasing the size of the wafer to 450mm from 300mm will yield an area improvement of 2.25 times that of a 300mm wafer. However, what is more important is how much die per wafer (DPW) can be increased as a result of the larger wafer. Because die are rectangular, there will always be wasted area at the perimeter of the wafer where a rectangular die cannot fit. Thus die per wafer depends on the diameter of the wafer [d, mm] and the size of the integrated circuit [S, $mm^2$], as outlined in the equation below. DPW can be calculated by the following formula:

$$DPW = d*\pi*((d/(4*S)) - (1/sqrt(2*S)))$$

For the wafer area gain input, the DPW increase should be entered, not the 2.25x actual area gain.

- **450mm Tool Price** – The price of tools are expected to increase due to the added investment of developing these larger toolsets. Scaling up to 450mm tools is, for the most part, not a technically complicated undertaking. The price of the tools should not rise by the same ratio that the wafer increases in size. Expected costs can be estimated by looking back at how previous wafer size transitions affected prices.
- **450mm Tool Run Rates –** Run rate simply refers to the number of wafers a single tool can process in an hour. Because the wafers have increased in size, many of the tools will require more time to process each wafer. This will likely be the case for lithography tools that typically processes the wafer via a reticle that can only handle sections of a wafer at a time. With a larger wafer, the lithography tool will have to process more sections, and will therefore take longer to process. In other words, lithography run rates will likely decrease. In contrast, there are many tools, such as diffusion furnaces, where the wafers are basically put into an oven and left to bake for a certain amount of time. The rate at which wafers can be passed through the tool is largely independent of the size of the wafer.
- **Cost CAGR / Run Rate CAGR –** Looking back at the prices and costs of past wafer size transitions, costs and run rates can change drastically following the initial year of transition. To account for this, the model allows users to specify the expected cost and run rate CAGRs. Also, cost and run rates won't continue on the initial CAGR forever. The model allows the user to input the number of years these costs and run rate trends will last, followed by a generic cost increase (most likely tracking GDP) after the selected number of years.
- **Discount Rate –** Discount rate refers to the percentage rate used to discount future cash flows into present day dollar values. It is based on the idea that a dollar today is worth more than a dollar tomorrow. A good measure to use for the discount rate is each firms weighted cost of capital (WACC). WACC represents the return that a company should benchmark against when deciding on investments. If an investment's expected return is less than the company's WACC, there are probably more profitable ways to spend the company's capital. WACC is different for

every company, but generally similar for companies operating in the same industry. This is because these companies are exposed to the same risks and are subject to similar returns. This model uses discount rate in order to calculate the net present value of the 450mm investment for each company. Because every firm has a slightly different WACC, discount rate is an input that can be modified. The equipment industry has historically used a discount rate around 12 percent. Given the recent economic turmoil in 2008 and 2009 as well as a weak future economic outlook, a lower discount rate, probably in the high single digits, would be more realistic.

#### *4.2.2.2 R&D and Investment Inputs*

- **Transition Year** – The year in which the industry begins pilot lines. The sooner the transition is made, the sooner everyone will reap the benefits of the investment. However, if the investment is negative overall, then delaying the investment will be most beneficial. The International Technology Roadmap for Semiconductors (ITRS) has the 450mm scheduled for launch in 2012. This is a best case scenario, and given 2009 market conditions, it is likely that the launch date will be pushed out to 2014, or even later.
- **Tool R&D Investment Curve (see Figure 28)** – The development of the 450mm tools will incur costs that are spread out over a number of years. The spread of the investment impacts the amount each supplier will be required to spend in each year as well as the NPV calculation. Below is a sample cost distribution that may be experienced if the transition occurs in 2014.

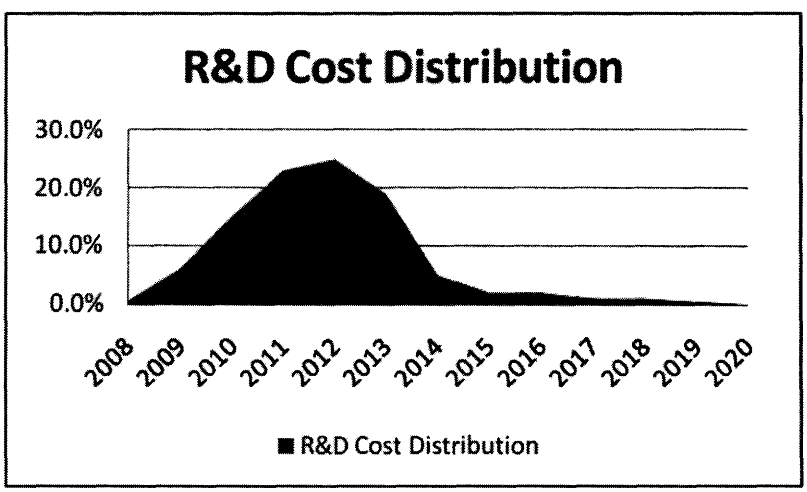



FIGURE 28, SUPPLIER COST MODEL COST DISTRIBUTION INPUT

- **Tool Development Cost (see Figure 29) –** This is an area of great debate. Naturally, nobody knows the actual costs of developing toolsets that have never been created. However, good estimates can be made. There is no significant technological barrier to creating these new, larger tool platforms, but the tools themselves are very sensitive, such that even a simple scale up could consume a lot of resources. For each major tool platform, there is an overall cost that can be modified. This cost will be spread out according to the "Tool R&D Investment Curve."
- **450mm Tool Developers (see Figure 29) –** Not all companies that currently make tool platforms will have the ability to create the next generation. Some may not have the resources to scale all their tool platforms up, while some simply don't believe it will be a profitable investment and will forego the investment altogether. Whatever be the case, this section allows the user to select which suppliers will develop its own tool for each tool platform.

  The supplier cost model is set up to analyze the nineteen largest equipment suppliers. Together they make up the vast majority of the equipment market. Because there are other potential suppliers outside of these nineteen doing 450mm development, there is an entry field to account for the "other" suppliers' impact. The number of "other" firms developing 450mm tool platforms can be input along with their combined 300mm market share on each tool platform. The model will account for their presence in 450mm, adjust the market share of the top nineteen suppliers and redistribute revenues from equipment sales.

  The format to input the top nineteen 450mm Tool Developers varies slightly from the rest of the model's input fields. Boxes are highlighted yellow to indicate that a supplier already has some market share in 300mm for that tool platform. A "1" indicates an assumption that a supplier will develop that tool platform for 450mm. If a supplier is not expected to develop a certain tool platform, then that cell should be left blank. A "1" can be entered into a cell that is not highlighted yellow, signifying that a supplier will advance into a new area, as long as the supplier has a yellow highlighted box for another tool in that same functional area (FA).

| FA | Tool Type | Total($M) | AMAT | ASM | ASML | Axcelis | Canon | DNS | Ebara | Hitachi | KLA/Tencor | Kokusai | Lam | Mattson | Nikon | Nissin | Novellus | SEN | TEL | Ulvac | Varian | Other | Market % | Companies & 2007 Market Share |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LI | Advanced Scanner | 30 | | | 1 | | 1 | | | | | | | | 1 | | | | | | | | | |
| LI | Litho Track | 40 | 0.5 | | | | | 0.5 | | | | | | | | | | | 1 | | | 1 | 4.3% | SEMES(4.3%) |
| ET | Dry - Dielectric Etch | 40 | 1 | | | | | | | 1 | | | 1 | | | | | | 1 | | | 1 | 250.0% | FOI(2.5% |
| ET | Dry - Silicon Etch | 40 | 1 | | | | | | | 1 | | | 1 | | | | | | 1 | | | 1 | 1.5% | Aziva(1.5%) |
| ET | Dry - Metal Etch | 40 | 1 | | | | | | | 1 | | | 1 | | | | | | | | | | | |
| ET | Dry - Compound Etch | 40 | | | | | | | | | | | 1 | | | | | | | 1 | | 3 | 18.4% | Oerlikon(10.5%), Samco(4.1%), Tegal(3. |
| ET | Strip / Ashing | 30 | | | | 1 | | | | 1 | | 1 | | 1 | | | 1 | | | 1 | | 5 | 32.7% | Canon Marketing Japan(2.9%), FOI(1.4 |
| ET | Scrubber | 15 | | | | | | 1 | | | | | | | | | | | 1 | | | 4 | 19.4% | Akrion(1.4%), Kaijo(5.7%), SES(11.2%), |
| ET | Auto Wet Station | 40 | | | | | | 1 | | | | | | | | | | | 1 | | | | | |
| ET | Bevel Clean | 40 | | | | | | | | | | | | | | | | | | | | 3 | 100.0% | Jusung(21%), PSK(7%), Sosul(73%) |
| ET | Spin/Spray (single) P | 30 | 1 | | | | | 1 | | | | | | | | | | | 1 | | | 6 | 57.3% | Akrion(4.2%), FSI(4.5%), SEMES(4.5% |
| DI | VDF | 30 | | 1 | | | | | | | | 1 | | | | | | | 1 | | | 2 | 5.7% | Aviza(3.5%), Koyo Thermo(2.2%) |
| DI | RTP/RTA (anneal) | 40 | 1 | 1 | | 1 | | 1 | | | | | | 1 | | | | | | | | 1 | 4.3% | Ultratech(4.3%) |
| DI | Gate Stack | 40 | 1 | | | | | | | | | 1 | | | | | | | 1 | | | | | |
| PL | CMP | 35 | 1 | | | | | 1 | 1 | | | | | | | | 1 | | | | | | | |
| TF | Vertical Tube LPCVD | 40 | | 1 | | | | | | | | 1 | | | | | | | 1 | | | 1 | 5.0% | Aviza(4%), Koyo Thermo(1%) |
| TF | APCVD/SACVD | 40 | 1 | | | | | | | | | | | | | | | | | | | 1 | 1.3% | Aviza(1.3%) |
| TF | High Density Plasma C | 40 | 1 | | | | | | | | | | | | | | 1 | | | | | | | |
| TF | Non-Tube LPCVD | 40 | 1 | | | | | | | | | 1 | | | | | 1 | | 1 | | | 3 | 11.2% | Aixtron(5.8%), Integrated Process Sys |
| TF | Low Density Plasma C | 40 | 1 | 1 | | | | | | | | | | | | | 1 | | | | | | | |
| TF | Sputtering/PVD | 40 | 1 | | | | | | | | | | | | | | 1 | | | 1 | | 2 | 5.1% | Aviza(1.4%), Canon Anelva(3.7%) |
| TF | ECD | 40 | 1 | | | | | | | | | | | | | | 1 | | | | | 1 | 17.9% | Semitool(17.9%) |
| TF | SOD | 40 | | | | | | | | | | | | | | | | | 1 | | | 1 | 7.8% | Tokyo Ohka Kogyo(7.8%) |
| TF | Epitaxy | 40 | 1 | 1 | | | | | | | | 1 | | | | | | | | | | 2 | 5.9% | LPE(4.2%), NuFlare(1.7%) |
| TF | ALD | 50 | | 1 | | | | | | | | 1 | | | | | | | | | | 4 | 44.2% | Aixtron(1.6%), Aviza(9.5%), Integrated |
| TF | UV Cure | 30 | | | | 1 | | | | | | | | | | | | | | | | | | |
| IM | High energy/low curre | 40 | | | | 1 | | | | | | | | | | | | 1 | | | 1 | | | |
| IM | Med Current Implante | 40 | | | | 1 | | | | | | | | | | 1 | | 1 | | 1 | 1 | | | |
| IM | High Current Implante | 40 | 1 | | | 1 | | | | | | | | | | | | 1 | | | 1 | | | |
| IM | Ultra High Dose | 40 | | | | | | | | | | | | | | | | | | | 1 | | | |
| Metro | pattern defects (optic | 20 | 1 | | | | | | | 1 | 1 | | | | | | | | | | | 3 | 9.9% | Hermes-Epitek(1.9%), Tokyo Seimitsu( |
| Metro | bare wafer particle | 20 | | | | | | | | 1 | 1 | | | | | | | | | | | 2 | 5.2% | Lasertec(2.1%), Topcon(3.1%) |
| Metro | film thickness | 20 | | | | | | 1 | | | 1 | | | | | | | | | | | 5 | 44.9% | Advanced Metrology Systems(2.9%), |
| Metro | CD SEM | 40 | 1 | | | | | | | 1 | | | | | | | | | | | | | | |
| Metro | Registration/Overlay | 40 | | | | | | | | 1 | 1 | | | | | | | | | | | 2 | 17.8% | Nanometrics(14.1%), Tokyo Aircraft Ins |
| Metro | Macro Defect | 30 | | | | | | | | | 1 | | | | 1 | | | | | | | 2 | 54.2% | Rudolph(40.7%), Vistec(13.5%) |
| Metro | Optical Defect Review | 30 | | | | | | | | | | | | | 1 | | | | | | | 4 | 76.5% | Lasertec(1%), Nidek(4.9%), Olympus(19 |
| Metro | CD Optical | 30 | | | | | | | | | 1 | | | | | | | | | | | 2 | 26.8% | Nanometrics(23.3%), Nova(3.5%) |
| Metro | SEM Defect Review | 40 | 1 | | | | | | | 1 | 1 | | | | | | | | | | | 1 | 5.1% | JEOL(5.1%) |

FIGURE 29, SUPPLIER COST MODEL SUPPLIER TOOL DEVELOPMENT PLAN INPUT

### *4.2.2.3 Demand & Growth Inputs*

- **Capacity Growth Beyond 2012 (see Figure 30)–** Capacity (in millions of square inches) should grow according to how the worldwide demand for chips grows. If the demand for chips is growing at 9 percent, then the worldwide capacity in millions of square inches will also need to grow at 9 percent. For each set of years, 2011, 2012-2015, 2016-2019, 2020-2025, an expected capacity growth needs to be forecasted. This input must be entered assuming that 450mm wafers do not become a reality, and the current chip cost structure continues. The actual capacity growth, which takes into account the cost efficiencies of 450mm, will be calculated based off of the expected growth without 450mm, the amount of 450mm capacity worldwide, and the 450mm growth improvement (discussed in the next bullet).

Capacity Growth (millions of square inches)

| | 2011 | 2012-2015 | 2016-2019 | 2020-2025 |
|---|---|---|---|---|
| no 450 | 9.00% | 9.00% | 9.00% | 9.00% |
| with 450 | 9.00% | 9.08% | 9.82% | 11.51% |

FIGURE 30, SUPPLIER COST MODEL GROWTH EXPECTATION INPUT

- **450mm Growth Improvement –** 450mm wafers are an attractive investment because the larger wafers will reduce total manufacturing costs. The reduced production costs can be passed on to the end consumer, reducing consumer electronics prices. Cheaper electronics leads to more consumption, which increases the total demand for semiconductor products. Therefore, as more 450mm capacity comes on line, the overall worldwide demand for semiconductor products should increase. But by how much will 450mm products increase worldwide demand? The 450mm growth improvement input represents the amount of growth improvement the world would see if all of the worldwide capacity was produced on 450mm wafers, and priced based on 450mm production costs.

  So, for example, assume that 450mm would reduce the cost of goods sold (COGS) by 30 percent, and COGS make up 66 percent of the overall costs. A 30 percent reduction in COGS would result in 20 percent savings reflected in the price of semiconductor products. If semiconductors make up 30 percent of the cost of manufacturing consumer electronics, then consumers might expect to see a 6 percent decrease in the prices of the products they buy. If all products can be reduced by 6 percent, then worldwide demand would go up significantly. The increase in demand due to the 6 percent price reduction in all consumer electronics represents the 450mm Growth Improvement.
- **450mm Adopters (see Figure 31)** - 450mm investment success depends heavily on the number of IC makers that buy the tools, as well as the amount of resources each company commits. This input gives the user flexibility to choose which IC makers will go to 450mm wafers, and how much of their resources they will dedicate to 450mm.

  The user can select which IC maker to include in the analysis. Along with the IC maker's name, the combined capital spending in 2005, 2006, and 2007 must be entered in addition to the type of integrated device the IC maker produces – logic, memory, foundry, or other. On the right hand side of the input chart, the user must specify the percent of fab equipment spending each IC maker will dedicate to 450mm tools in each year. No spending can occur before the 450mm transition year specified in a different input field.

  **Accounting for re-use –** Each IC maker will typically re-use equipment from older process technologies to handle the less critical steps on a new technology process. The amount of re-use a firm employs will vary from firm to firm, but typically results in a significant amount of savings when compared to how much the company would have to spend if they bought all new equipment every other year.

Re-use of equipment will not be possible when 450mm wafers are first introduced. There will be no older generation tools in existence that can process 450mm wafers, and so each IC maker will need to fully load their 450mm factories with brand new tools. The model requires specific inputs from the user to handle the increased spending that is likely to result from the initial 450mm ramp. First, for each IC maker, the user must specify the usual percentage of their 450mm capacity that is re-used. Second, the user must specify how much re-use takes place in each year as they begin manufacturing on 450mm equipment. This should be 0 percent for the first 1-4 years as the supplier is ramping up and has no older 450mm tools to re-use.

| 450mm market potential: | | | | | percent of 450 vs other size equipment spending | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chip Maker | 05+06+07 Ca | Equip | %share | reuse - % c | company | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
| Intel | 16484 | 9294 | 3.8% | | logic | | | 15% | 15% | 85% | 90% | 95% | 98% | 98% | 98% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Samsung | 21335 | 12029 | 12.7% | | memory | | | 7% | 15% | 85% | 90% | 95% | 98% | 98% | 98% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| TSMC | 7306 | 4119 | 4.4% | | foundry | | | | 15% | 15% | 70% | 80% | 85% | 85% | 85% | 85% | 85% | 85% | 85% |
| Re-Use | | | | 30% | | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Micron | 7855 | 4429 | 4.7% | | memory | | | | 20% | 20% | 80% | 85% | 98% | 98% | 98% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Hynix | 11410 | 6433 | 6.8% | | memory | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Toshiba | 8482 | 4782 | 5.1% | | memory | | | | | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | 30% | 30% | 30% | 30% | 30% | 30% | 30% |
| Infineon | 5093 | 2872 | 3.0% | | memory | | | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | | | 30% | 30% | 30% | 30% | 30% |
| Elpida | 4279 | 2413 | 2.6% | | memory | | | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | | | 30% | 30% | 30% | 30% | 30% |
| Nanya | 3824 | 2156 | 2.3% | | memory | | | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | | | 30% | 30% | 30% | 30% | 30% |
| Powerchip | 6050 | 3411 | 3.6% | | memory | | | | | | | 20% | 20% | 80% | 85% | 95% | 95% | 95% | 95% |
| Re-Use | | | | 30% | | | | | | | | | | | | 30% | 30% | 30% | 30% |
| ProMOS | 3485 | 1965 | 2.1% | | memory | | | | | | | 20% | 20% | 80% | 85% | 95% | 95% | 95% | 95% |
| Re-Use | | | | 30% | | | | | | | | | | | | 30% | 30% | 30% | 30% |
| SanDisk | 3219 | 1815 | 1.9% | | memory | | | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | | | 30% | 30% | 30% | 30% | 30% |
| UMC | 2688 | 1516 | 1.6% | | foundry | | | | | | | 20% | 20% | 80% | 85% | 95% | 95% | 95% | 95% |
| Re-Use | | | | 30% | | | | | | | | | | | | 30% | 30% | 30% | 30% |
| ST | 3934 | 2218 | 2.3% | | memory | | | | | | 20% | 20% | 80% | 85% | 95% | 98% | 98% | 98% | 98% |
| Re-Use | | | | 30% | | | | | | | | | | | 30% | 30% | 30% | 30% | 30% |

FIGURE 31, SUPPLIER COST MODEL IC MAKER ADOPTION SCHEDULE INPUT

- **Growth of Large Companies –** The model only allows for the top 14 semiconductor device makers to be evaluated. These top 14 companies currently make up approximately 63 percent of the entire market. As economies of scope and scale become increasingly important to survive in the industry, consolidation will likely continue to whittle away at the smaller competitors. This input allows the user to select the total market share these top 14 IC makers will hold by 2025.
- **Revenue Growth/ Capacity Growth –** This selection connects the relationship between capacity growth and revenue growth. Looking back at recent history, total worldwide capacity (by silicon area) has typically grown twice as fast as the revenue for the equipment industry. Worldwide capacity has been growing at about 9 percent, while the equipment industry revenues have

been growing at roughly 4.5 percent. It is recommended that 50 percent is entered unless there is evidence to point to the contrary.

#### *4.2.2.4 Future Market Share Distribution Inputs*

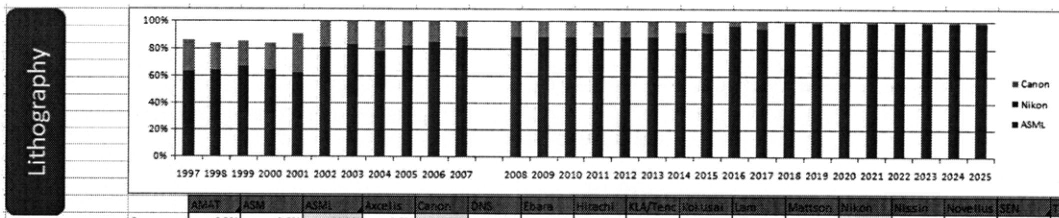
- **Market Share (see Figure 32) –** Within each functional area is a battle for market share. It is difficult to predict how market share will change over the next 20 years. This input allows for the modification of market shares in each functional area.

| | |
|---|---|
| Lithography | Custom Market Share |
| Implant | 450 market share according to 300 market share |
| Diff usion | Evenly split 450 market share |
| Thin Films | Evenly split 450 market share |
| Etch | Evenly split 450 market share |
| CMP | Custom Market Share |
| Metrology | Custom Market Share |

FIGURE 32, SUPPLIER COST MODEL MARKET SHARE DIVISION SELECTION INPUT

For each functional area, there are three possible selections:

- *450mm market share according to 300mm market share* – This option will break out the 450mm market share according to what a supplier's market share was as of 2008. This market share is normalized to the number of firms transitioning to 450mm tools. So, for example, if four companies, A, B, C, and D, have 30 percent, 30 percent, 20 percent, 20 percent of the market respectively, and only A and C transition, then A and C would have 60 percent and 40 percent of the 450mm market, respectively.
- *Evenly split 450mm market share* – This option assumes that once companies develop their new 450mm platforms, previous market shares no longer matter. Past technological advantage has no impact, and in the long run, any competitor that develops 450mm tools will have equal share of the 450mm tool market. So, using the previous example, if A and C transitioned to 450mm tools, but the others did not, then A and C would hold 50 percent and 50 percent of the 450mm market, respectively.
- *Custom Market Share* – To give the greatest flexibility, this option was added. This allows the user to define the exact 450mm market share for each company in each functional area. The below chart shows an example scenario for the lithography functional area.




| | AMAT | ASM | ASML | Axcelis | Canon | DNS | Ebara | Hitachi | KLA/Tenc | Kokusai | Lam | Mattson | Nikon | Nissin | Novellus | SEN | TEL | Ulvac | Varian | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Custom | 0.0% | 0.0% | 60.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 40.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |

FIGURE 33, SUPPLIER COST MODEL CUSTOM MARKET SHARE INPUT

- **Acquisitions (see Figure 34) –** As the industry consolidates and economies of scale and scope become increasingly more important, there will surely be some acquisition activity. This input allows the user to select the year and company that gets acquired by another company. The acquisition will result in market share increases for the acquirer in the amount of the acquiree's market share.

**Acquisitions**

| Acquirer | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMAT | | | | Ebara | | | Ulvac | | | | | | | | | | |
| ASM | | | | | | | | | | | | | | | | | |
| ASML | | | | | | | | | | | | | | | | | |
| Axcelis | | | | | | | | | | | | | | | | | |
| Canon | | | | | | | | | | | | | | | | | |
| DNS | | | | | | | | | | | | | | | | | |
| Ebara | | | | | | | | | | | | | | | | | |
| Hitachi | | | | | | | | | | | | | | | | | |
| KLA/Teno | | | | | | | | | | | | | | | | | |
| Kokusai | | | | | | | | | | | | | | | | | |
| Lam | | | | | | | | | | | | | | | | | |
| Mattson | | | | | | | | | | | | | | | | | |
| Nikon | | | | | | | | | | | | | | | | | |
| Nissin | Axcelis | | | | | | | | | | | | | | | | |
| Novellus | | DNS | | | | | | | | | | | | | | | |
| SEN | | | | | | | | | | | | | | | | | |
| TEL | | | | | | | | | | | | | | | | | |
| Ulvac | | | | | | | | | | | | | | | | | |
| Varian | | | | | | | | | | | | | | | | | |

FIGURE 34, SUPPLIER COST MODEL ACQUISITION SELECTION TABLE INPUT

## 4.3 Results and Discussion

The purpose of this section is to show some of the various scenarios through which the model was run. The variable inputs were discussed in Section 4.2.2 of the thesis. For the initial scenarios, the variables had the following base values:

| | |
|---|---|
| Wafer Area Gain | = 2.3 x |
| 450mm Tool Cost | = 1.5 x (except Lithography is 1.3x) |
| 450mm Tool Run Rates | = 1 x (except Lithography is .8x) |
| Cost CAGR / Run Rate CAGR | = 0 percent |

| | |
|---|---|
| Length of Cost & Run Rate CAGR effects | = 6 years |
| Cost CAGR after Cost & Run Rate CAGR affects | = 3 percent |
| Discount Rate | = 10 percent |
| Transition Year | = 2014 |
| Tool R&D Investment Curve | = As shown in Figure 28 |
| Tool Development Costs | = As shown in the third column of Figure 29 |
| 450mm Tool Developers | = As shown in Figure 29 |
| Capacity growth beyond 2012 | = 9 percent |
| 450mm growth improvement | = 20 percent |
| 450mm Adopters | = Good Adoption – As shown in Figure 31 |
| Re-Use | = As shown in Figure 31 |
| Growth of Large Companies | = 95 percent |
| Revenue Growth / Capacity Growth | = 50 percent |
| Market Share | = 450mm market share according to 300mm market share |
| Equipment Supplier M&A | = None |

These values were used in all of the scenarios unless otherwise indicated. If there are changes in the scenarios then the new values for the variables will be shown. There are a total of six scenarios discussed. They are:

Scenario 1 – Business as Usual

Scenario 2 – Only the Strong Survive

Scenario 3 – Testing the Variability to Demand Stimulation

Scenario 4 – Tool Cost and Run Rate Variability

Scenario 5 – A Highly Possible Scenario A

Scenario 6 – A Highly Possible Scenario B

Not all of the scenarios are intended to be realistic in isolation. Rather, each is intended to convey some learning that can be applied to each of the scenarios that follow. As discussed when the model was introduced in Section 4.2, the model is intended to be run iteratively. By running various scenarios, enough information can be extracted in order to have a more full understanding of the dynamics surrounding the 450mm transition. Through this process, equipment suppliers and IC makers can mutually gain a better understanding of the risks of the benefits of 450mm and therefore make more informed decisions going forward.

### 4.3.1 Scenario 1 – Business as Usual

The first scenario is designed to demonstrate how the capital equipment industry will be affected by the 450mm wafer size transition if the industry continues to operate exactly as they have been. Under this scenario there will be no consolidation, no changes in market share, and a long list of suppliers developing 450mm tools.

**Inputs:**

- All equipment makers with a market share of at least 3 percent on any 300mm tool platform will spend the money to develop the respective 450mm tool platform.
- A supplier's 450mm market share on each tool platform will be set according to the market share that each supplier has for the same 300mm tool.
- Demand for semiconductor products, by wafer area, will continue to grow at 9 percent annually as it has been growing for the last 5-10 years.
- Costs for tools will be 1.5x the 300mm version of the same tool platform. The exception to this will be lithography tools, which will only be 1.3x the 300mm version of the same tool platform.
- Tool Run Rates will be 1.0x the 300mm version of the same tool platform. The exception to this will be lithography tools, which will only be 0.8x the 300mm version of the same tool platform.
- Good 450mm adoption by the semiconductor product manufacturers. This basically means that all of the top 14 IC makers build 450mm capacity within the first four years of the 450mm launch. They accomplish this through their own fund raising, being acquired, or partnering with other IC makers.

**Results:**

Industry wide Net Present Value: $(24,823.77M)

Total tool platform development costs: $4,650M

The net present value of the 450mm investment is very negative for the capital equipment industry as a whole. This is not entirely surprising. The tools are now roughly twice as productive (same run rate, but more than twice the area out per hour) but the price of the tools have increased by less than 50 percent, on average. The suppliers are therefore selling about half the number of tools without a sufficient boost in revenue per tool to compensate for the reduced tool sales. The effect of the wafer size transition on the equipment industry's revenues by year is shown in Figure 35.

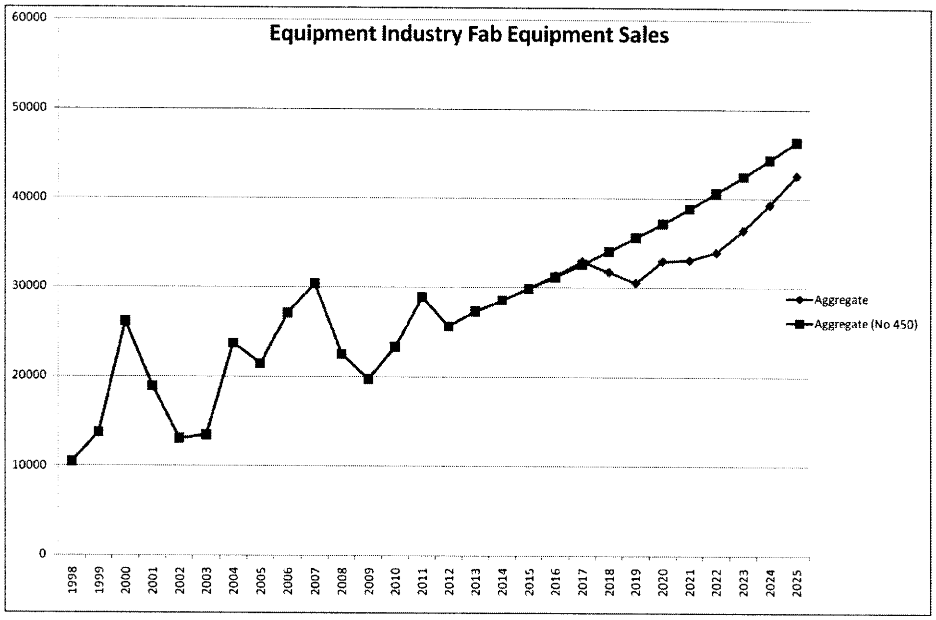
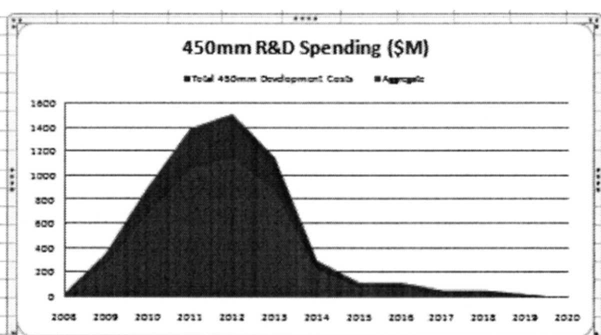



FIGURE 35, SCENARIO 1 – INDUSTRY FAB EQUIPMENT SALES

Even though the transition happens in 2014, equipment sales actually keep pace with, and even exceed the "no 450mm" case until 2018. This is because IC makers that adopt 450mm cannot reuse old equipment and are forced to buy large numbers of new equipment. When the IC makers build the first fabs, there will be no older generation 450mm tools available to process the less critical steps within the manufacturing process. IC makers will have no choice but to equip the entire 450mm fab with new, state-of-the-art 450mm tools. For the "no 450mm" case, IC makers have the flexibility to re-use older 300mm equipment.

After 2017, IC makers begin to accumulate older generation 450mm tools, and as a result, capital equipment spending in the years that follow goes down dramatically. On a positive note, by 2025, the gap in equipment spending between the "450mm" and "no 450mm" cases begins to narrow. This is due to an increased presence of worldwide 450mm manufacturing capacity, resulting in lower manufacturing costs that stimulate a greater amount of semiconductor product consumption in the marketplace. Eventually, due to a faster growth rate, the "450mm" case will exceed the "no 450mm" case equipment sales.

In addition to the lower industry revenues, tool R&D costs are very high due to the large number of suppliers investing in 450mm tool sets. Under this scenario, the aggregate cost of developing all of the 450mm tools is $4.65B, and the costs are spread out according to the chart in Figure 36. To put this spending in perspective, 300mm transition spending is estimated to have exceeded $10B (refer back to Figure 15). The majority of the 450mm development costs will be spent on tool development, and this scenario projects tool development costs to be less than half of total 300mm transition spending. One of the biggest arguments that 450mm opponents make is that 300mm development was extremely expensive, and 450mm will only be more complicated and more expensive. What these opponents do not consider is the fact that a lot of consolidation has occurred since that last wafer size transition, and much more consolidation will result if 450mm becomes a reality. With fewer suppliers and IC makers in the market, the number of developers should be significantly less than the previous wafer size transition. If this is indeed the case, then there is no possible way that 450mm development costs will increase exponentially over 300mm development costs. In fact, by this measure alone, the development costs should be much less than 300mm. Under this scenario nearly every supplier develops 450mm tools, but the actual number of suppliers creating 450mm tools should be much less, meaning the actual spending will be even less than this scenario projects.




| Total 450mm Cost to Top Suppliers ($M) |
|---|
| $ 4,650.00 |

| Total 450mm Development Cost |
|---|
| $ 6,045.00 |

30% Spending outside of tool R&D costs

**450 Development Costs**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aggregate | 23.25 | 279 | 697.5 | 1069.5 | 1162.5 | 883.5 | 232.5 | 93 | 93 | 46.5 | 46.5 | 23.25 | 0 |
| Other Sup | 6.975 | 83.7 | 209.3 | 320.85 | 348.75 | 265.05 | 69.75 | 27.9 | 27.9 | 13.95 | 13.95 | 6.975 | 0 |
| Total | 30.225 | 362.7 | 906.8 | 1390.4 | 1511.3 | 1148.6 | 302.25 | 120.9 | 120.9 | 60.45 | 60.45 | 30.225 | 0 |

FIGURE 36, SCENARIO 1 – DEVELOPMENT COSTS

The hypothesis posed at the beginning of this thesis stated that the aggregate NPV for the 450mm investment would be negative, and for scenario 1, this is indeed the case. However, it was also hypothesized that while the aggregate NPV would be negative, some suppliers would find 450mm to be profitable due to consolidation and shifts in market share. In this first scenario, it appears that the 450mm investment is ill-fated for all suppliers (see Figure 37). The top chart shows the absolute impact to each supplier, while the bottom chart shows the normalized impact. Under this scenario, market shares were fixed and consolidation was nonexistent, resulting in a poor outcome for all suppliers.

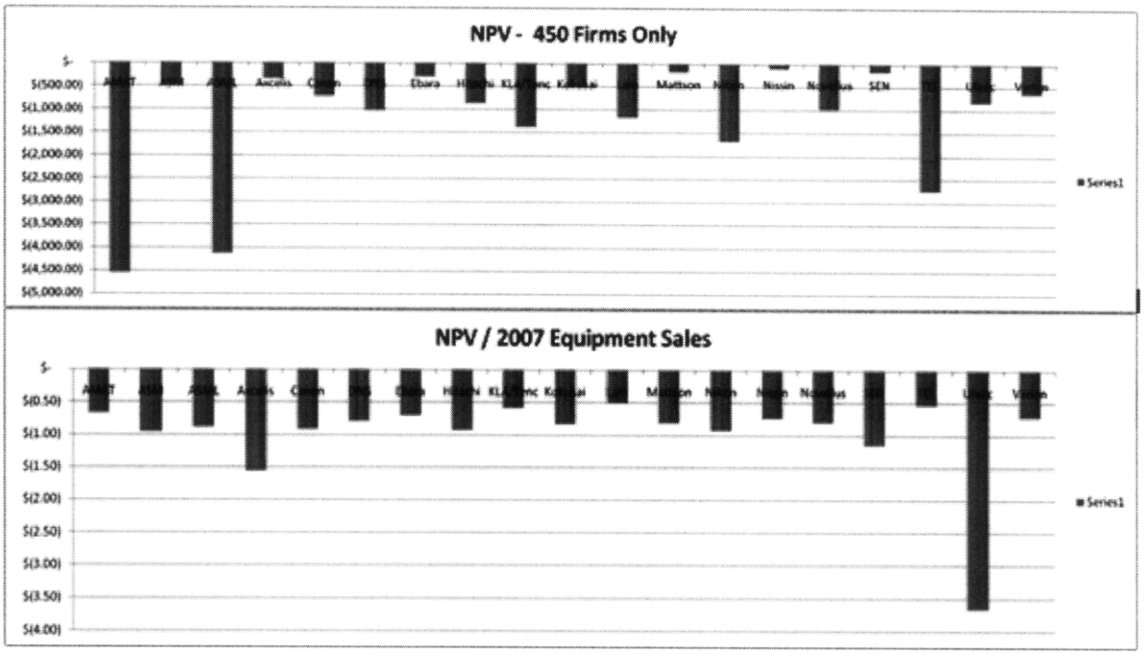



FIGURE 37, SCENARIO 1 – SUPPLIER NPV CHARTS

**Other Observations and Analysis:**

Scenario 1 is not very likely. Not all suppliers will develop 450mm tools and each supplier's market share will not remain unchanged going forward. 450mm will represent a strategic inflection point where market share wars can be waged and winners and losers determined. Scenario 1 ignores all of this. It shows that 450mm, in aggregate, is a bad investment for the industry. But the industry does not operate in aggregate, and there will be opportunities for suppliers to improve their position in spite of the seemingly bad investment.

Scenario 1 also demonstrates what type of catastrophe could befall the industry if all suppliers attempt to make the 450mm leap. In this scenario, the number of suppliers has gone well beyond the number of suppliers needed to remain in the "450mm adoption sweet spot," as discussed in Section 4.1.

The main takeaway from scenario 1 should be that in order for the capital industry to remain healthy, consolidation will be absolutely necessary.

### 4.3.2 Scenario 2 – Only the Strong Survive

Scenario 2 models the outcome if only those firms with dominant positions continue to operate. This means that the suppliers will build the tools that they have historically proven themselves most competent with and IC makers have invested most heavily in.

**Inputs:**

- All equipment makers with a market share of at least 15 percent on any tool platform will spend the money necessary to develop the 450mm tool platform.
- 450mm market share on each tool platform is evenly divided amongst the 450mm players.
- All other inputs will be identical to scenario 1.

**Results:**

Industry wide Net Present Value: $(20,210.28M)

Total tool platform development costs: $2,660M

Once again, the net present value of the investment is very negative for the industry as a whole. This is as expected, considering that the equipment sales are exactly the same as in scenario 1 (compare Figure 35 with Figure 38).

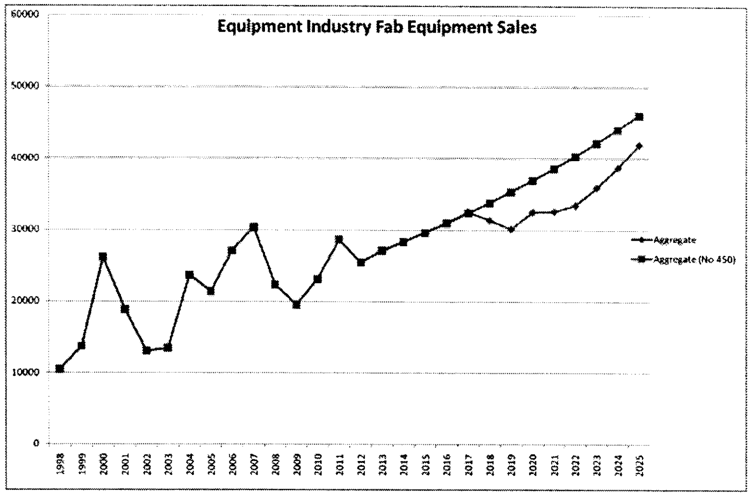



FIGURE 38, SCENARIO 2 – INDUSTRY FAB EQUIPMENT SALES

The two scenarios differ in the way that the revenues are distributed. This time, the most dominant firms get the lion's share of the wealth. The reason the NPV is less negative than the previous scenario is due to the fact that some suppliers currently have less than 15 percent market share on all platforms and could therefore justify no investment in 450mm whatsoever. This leaves the suppliers that make the jump with a larger share of the revenue.

With fewer suppliers going to 450mm, the aggregate cost for 450mm development decreased significantly in this scenario. The total tool R&D costs are $2.66B, nearly half that of the previous scenario.

Even though the aggregate NPV is negative, the suppliers with strong positions that gain market share see significant increase in their position (see Figure 39). Out of the 16 major suppliers that develop at least one major tool, 6 of them gain market share, and as a result have positive NPVs. It is the opportunity to gain market share that will motivate suppliers to be "greedy" and develop 450mm tools even when they know that the best case scenario for the industry as a whole is for everyone to not develop tools. The prospect of developing a new, more innovative tool platform and earn a much bigger part of the 450mm pie is just too tantalizing for most suppliers to resist, especially when they know that their competition is facing the same offer. In this scenario, market share gains allowed Nikon, Mattson, and Nissin to significantly improve their position in the market.

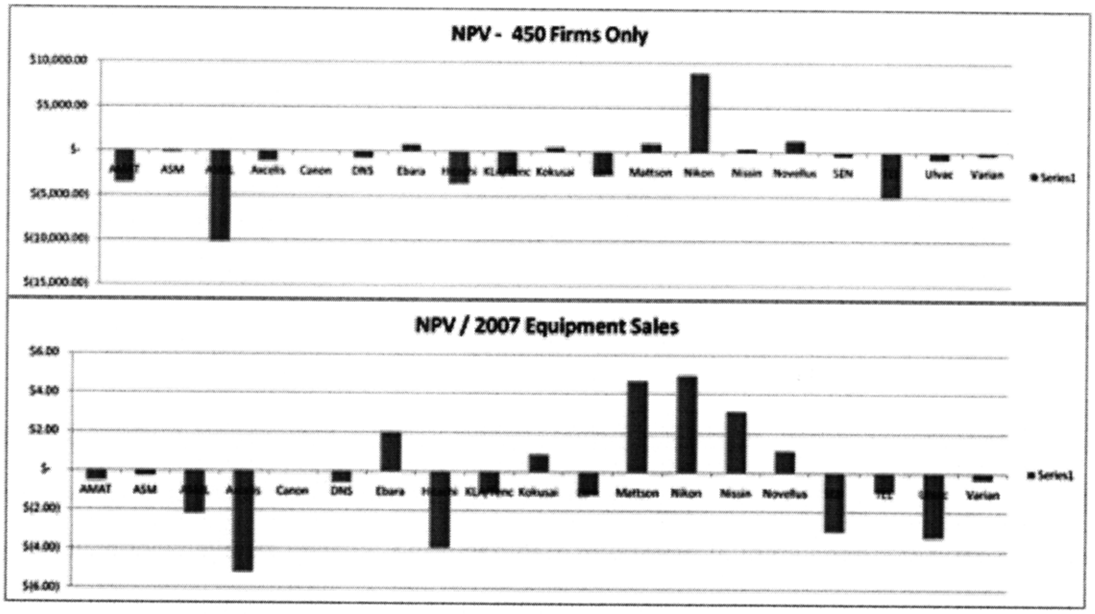



FIGURE 39, SCENARIO 2 – SUPPLIER NPV CHARTS

**Discretionary Note:**

The actual outcomes of individual suppliers in this scenario should be taken with a grain of salt. The expected 450mm market shares are evenly distributed among only those suppliers with at least 15 percent share of the 300mm market. This means that a supplier with 85 percent share could have split the 450mm market evenly with another supplier that had the other 15 percent, which while possible, is improbable. What should be taken away from this scenario is that an equipment maker's success on 450mm is highly dependent on their ability to increase their 450mm market share above what they had on 300mm.

### 4.3.3 Scenario 3 – Testing the Sensitivity to 450mm Demand Stimulation

One of the biggest arguments that IC makers use to defend 450mm is that 450mm will generate cost savings that will allow semiconductor prices to remain low, further driving the demand for semiconductor products. Clearly 450mm provides manufacturing efficiency savings, and lower prices will indeed stimulate more demand, but nobody knows exactly how much more demand will be stimulated as a result of the cheaper products. This scenario's purpose is to show how various 450mm demand stimulation possibilities will impact the future cash flows for equipment suppliers.

**Inputs:**

- 450mm demand stimulation input will be adjusted in 5 percent intervals, from 0 percent to 40 percent.
- This will be tested once for the scenario 1 set of equipment suppliers and once for the scenario 2 set of equipment suppliers.

**Results:**

Before delving too deep into the analysis of this section, it is important to understand what 450mm growth stimulation means. The stimulation is a percentage increase in demand for semiconductor products in proportion to the amount of 450mm manufacturing capacity installed worldwide. This means that if the 450mm stimulation is set at 5 percent, then there will be almost no impact in the transition year, but by 2025, if the 450mm capacity were to make up 50 percent of the worldwide installed capacity, demand for semiconductor products will grow by an extra 2.5 percent (5 percent demand stimulation growth multiplied by 50 percent of the worldwide capacity). It is this characteristic that allows the 450mm curves in Figure 41 and Figure 42 to drop after 2017 and then come roaring back in the years that follow, as the benefits of 450mm become more prevalent and the demand stimulation has a greater impact.

The overarching theme of this scenario is that the amount of demand that 450mm manages to stimulate will have an enormous impact on how attractive the 450mm investment is. The results show that the payoff for going to 450mm can range from $(40)B, with no demand stimulation and many suppliers in the 450mm market, to $163B with 40 percent more demand stimulated by 450mm and a select number of 450mm equipment suppliers (see Table 2). This is a huge swing in potential profit. Figure 40 shows that the NPV is increasing in an exponential fashion. It also shows that for the entire equipment industry to break even, 450mm must stimulate between 25 and 30 percent new growth.

Even if the demand is stimulated by less than 25 percent, good NPVs are still in reach for the best firms that manage to increase their market share through the 450mm transition. So the goal of this scenario is not to find the breakeven point for the industry as a whole, but it is to understand how elastic the NPV is to the 450mm demand stimulation input.

Figure 41 and Figure 42 show how the different 450mm demand stimulation inputs change the yearly industry revenues for scenario 1 and 2 development inputs.

| % 450 Demand Stimulation | NPV - Scenario 1 Suppliers | NPV - Scenario 2 Suppliers |
|---|---|---|
| 0% | $ (39,620.90) | $ (30,002.50) |
| 5% | $ (37,017.21) | $ (27,025.49) |
| 10% | $ (33,640.22) | $ (23,144.98) |
| 15% | $ (29,109.03) | $ (17,914.49) |
| 20% | $ (22,744.89) | $ (10,538.24) |
| 25% | $ (13,203.77) | $ 560.34 |
| 30% | $ 2,620.15 | $ 19,025.93 |
| 35% | $ 33,942.98 | $ 55,677.47 |
| 40% | $ 125,955.64 | $ 163,575.33 |

TABLE 2, SCENARIO 3 – SUPPLIER NPV BASED ON PERCENT 450MM DEMAND STIMULATION

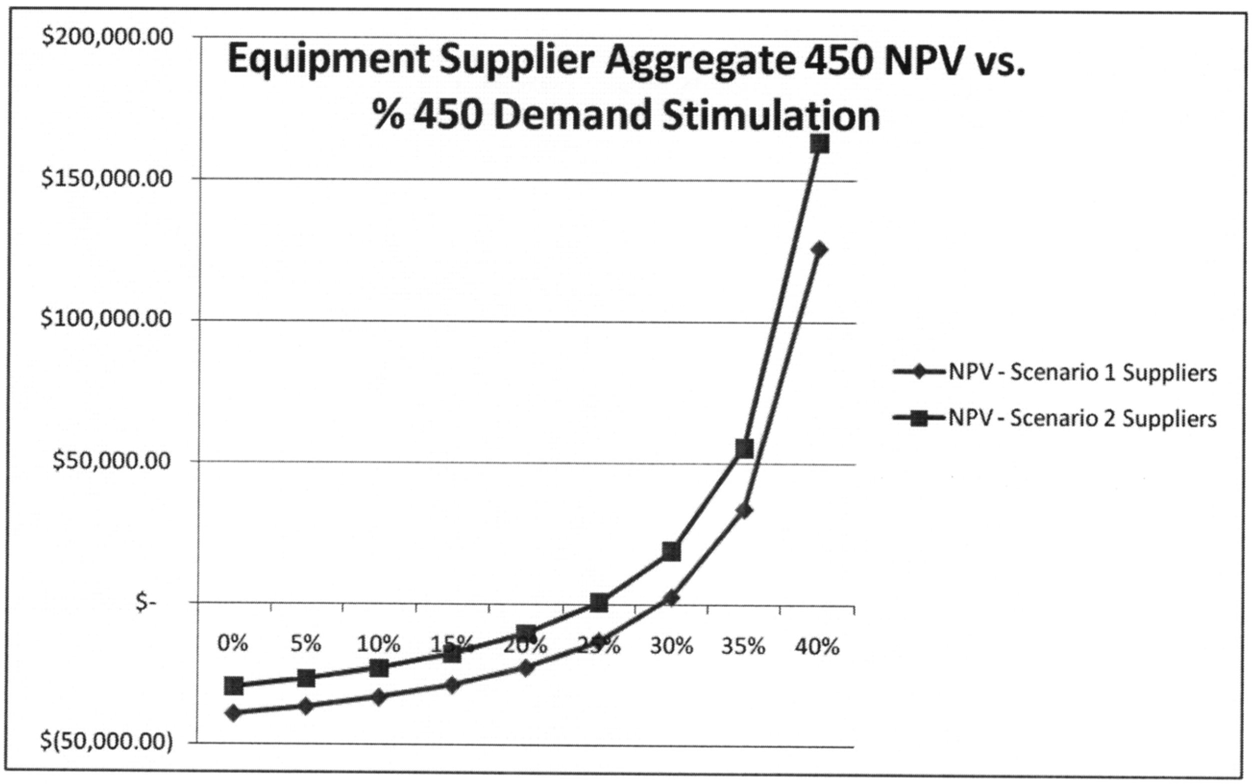



FIGURE 40, SCENARIO 3 – SUPPLIER NPV VS. PERCENT 450MM DEMAND STIMULATION PLOT

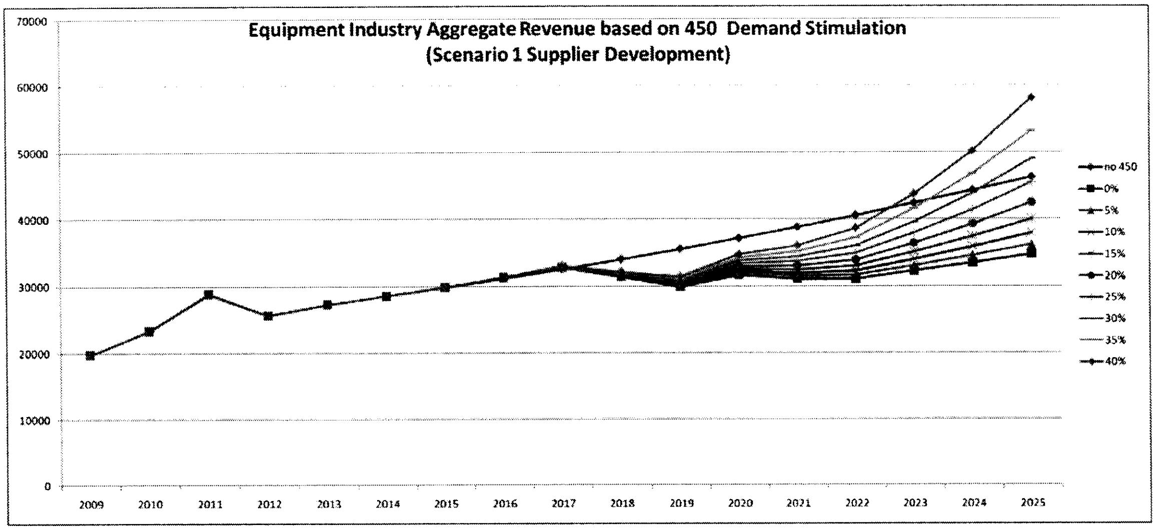



FIGURE 41, SCENARIO 3 – SUPPLIER AGGREGATE REVENUE ACCORDING TO VARIOUS 450MM DEMAND STIMULATIONS (USING SCENARIO 1 SUPPLIER TOOL DEVELOPMENT PLAN)

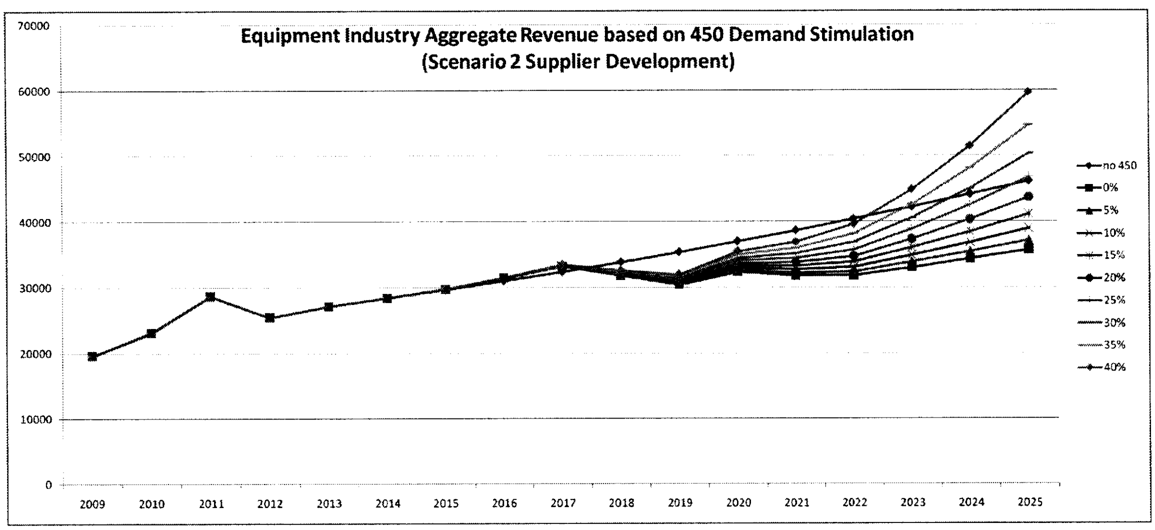



FIGURE 42, SCENARIO 3 – SUPPLIER AGGREGATE REVENUE ACCORDING TO VARIOUS 450MM DEMAND STIMULATIONS (USING SCENARIO 2 SUPPLIER TOOL DEVELOPMENT PLAN)

There are many opinions with regard to how much demand 450mm will stimulate, and unfortunately this scenario will not be able to clear up that disagreement. For most of the scenarios in this thesis, the 450mm demand stimulation input is fixed at 20 percent, as this seems like a reasonable increase in demand if worldwide electronics prices were to decrease by 6 percent (see Section 4.2.2.3 for more details of why 6 percent was chosen).

### 4.3.4 Scenario 4 – Tool Cost & Run Rate Variability

Tool Cost and Run Rate are also expected to have an enormous effect on the net present value of 450mm. As the tool cost divided by RR goes down, the NPV for equipment suppliers also goes down, while the value captured by IC makers rises. The opposite holds true for when the tool cost/RR goes up. This scenario will look at several productivity possibilities to gain a better understanding about the sensitivity of cost and run rate on the equipment suppliers' NPV.

**Inputs:**

- Productivity Inputs are varied according to Table 3:

| Tool Type | Run1 | Run2 | Run3 | Run4 | Run5 | Run6 | Run7 |
|---|---|---|---|---|---|---|---|
| Non Litho | 1.2x | 1.3x | 1.4x | 1.5x | 1.6x | 1.7x | 1.8x |
| Litho | 1.2x | 1.35x | 1.5x | 1.65x | 1.8x | 1.95x | 2.1x |

TABLE 3, SCENARIO 4 – TOOL COST/RR TEST VARIABLES

- 450mm market share is divided according to the market share that each supplier holds for each 300mm tool platform.
- All other inputs are identical to scenario 2.

**Results:**

NPV improves linearly as the cost/RR goes up (see Figure 43). Run 5 is the breakeven point, with a 1.6x (1.8x for litho) cost scalar. If the cost scalars end up being this high, equipment suppliers can look forward to healthy revenues; however, the inefficiency of the tools would negate most, if not all, of the benefits of 450mm for IC makers. In fact, IC makers would have little incentive to purchase equipment if the cost scalars are that high. Equipment suppliers must be capable of producing equipment that is more productive than run 5.

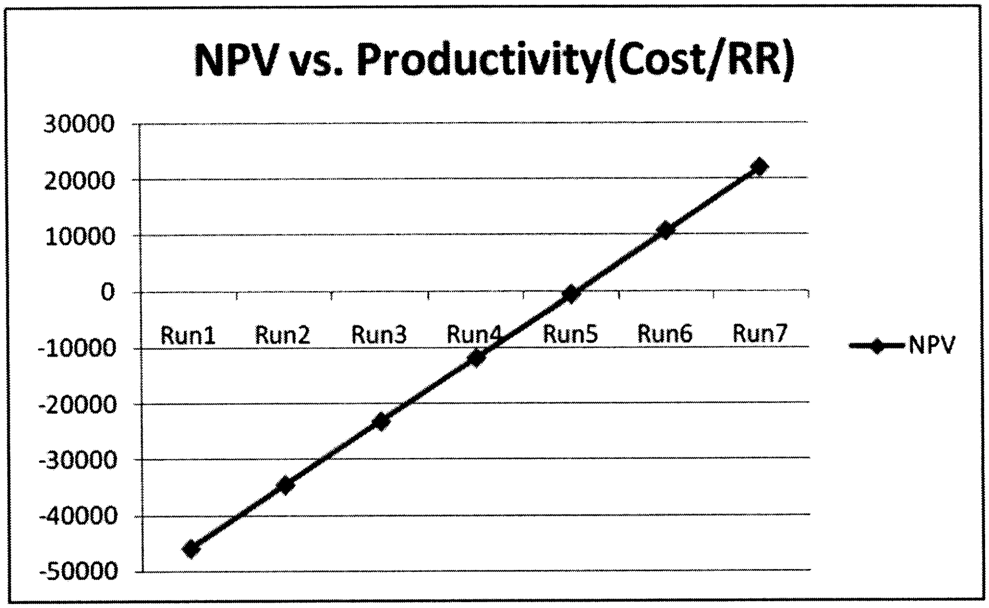



FIGURE 43, SCENARIO 4 – NPV VS. (COST/RR) CURVE

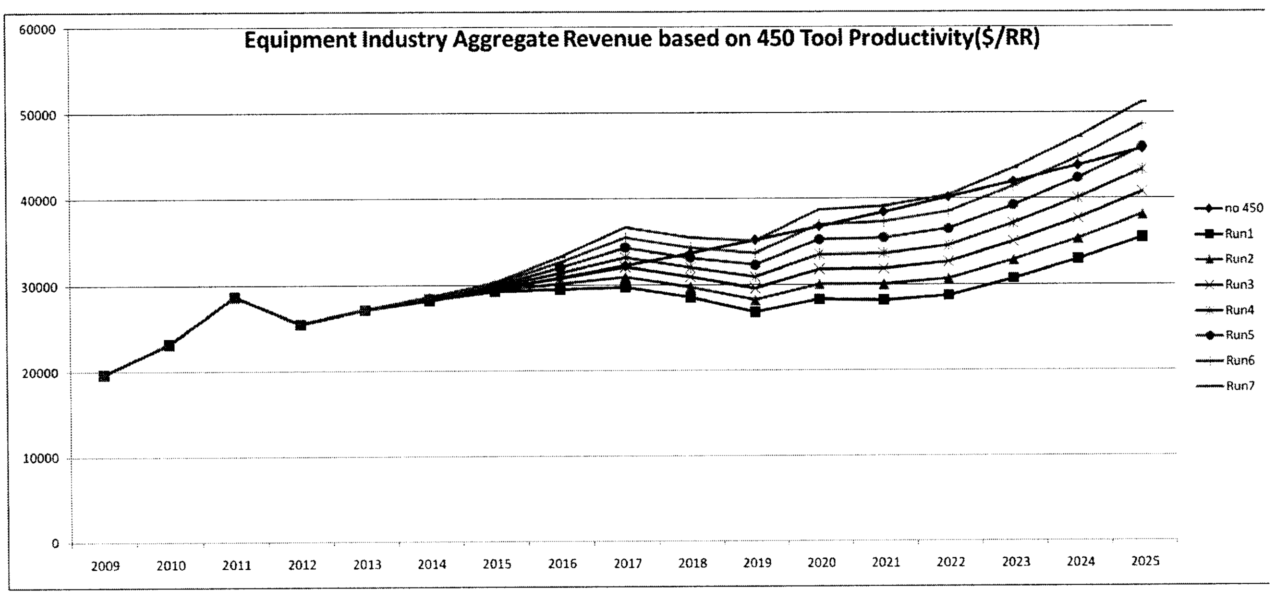



FIGURE 44, SCENARIO 4 – INDUSTRY REVENUES BASED ON VARIOUS (COST/RR) PLOTS

Figure 44 shows how the different run rate and cost inputs change yearly industry revenues. Tool productivity has a dramatic impact on the profitability of the 450mm investment

When it comes to improving the productivity of the tools, the suppliers are caught between a rock and a hard place. They don't want to develop tools so productive that they run themselves out of business, but they also don't want to lose market share due to a competitor developing a tool that is more productive than their own. For now there is enough competition in the industry to sufficiently incentivize equipment suppliers to develop the most productive tools possible.

### 4.3.5 Scenario 5 – A Highly Possible Scenario A

The first four scenarios were used to get a better understanding of the dynamics surrounding the 450mm transition and to demonstrate different sensitivities of key inputs. This scenario will attempt to set inputs according to what realistically could happen. The intention is to run this scenario, gather the data, determine where different issues and concerns might arise, and run the model once more with new adjustments to the inputs.

**Inputs:**

- A total of 81 unique tools will be developed for the 39 major tool platforms. This means an average of 2.2 suppliers will develop each major tool platform. This is a compromise between scenario 1, where 132 unique tools were developed, and scenario 2, where 74 unique tools were developed. For this scenario, suppliers with at least 15 percent market share on a major platform were selected to develop the 450mm tool. Beyond the 15 percent selection criteria, other suppliers were selected in order to fill in gaps where less than two suppliers were developing a major tool platform or where a supplier that was likely to develop the tool was not included for just missing the 15 percent cut off. These additions make the scenario more realistic than just having an arbitrary market share cutoff point.
- 450mm market share is largely divided according to the market share that each supplier holds for each 300mm tool platform. One exception to this is lithography, where Nikon is allowed to gain back some of the share it had lost to ASML. This may or may not happen, but there is a good possibility that 450mm could be the equalizer in the lithography area. The other exception is in the CMP area. Ebara has been making progress and has been advancing in on AMAT's dominant position. This scenario assumes that Ebara will gain 45 percent of the 450mm market share while AMAT takes the other 55 percent.
- 450mm growth stimulus will be 15 percent.

- Demand for semiconductor products will continue to grow according to Table 4. The 300mm baseline growth is the input. This represents the amount of growth that would occur without any 450mm capacity. Growth is set at 9-10 percent until 2015. Coming out of the current recession, there is likely to be a small boom in demand for semiconductor products around that time. However, from 2016-2025 the demand is likely slow. Without the 450mm capacity installed, the cost of manufacturing 300mm products will rise. The rise in manufacturing costs results in higher prices, which decreases demand. The second row, growth with 450mm growth stimulus added, is not an input. It has been included here to show how much growth 450mm has stimulated. The growth represented in this row is a function of a number of variables, but most influential is the 450mm growth stimulus of 15 percent and the IC maker 450mm adoption schedule. Notice that by 2020 there is significant growth due to 450mm, largely because by this time there is a good amount of installed 450mm capacity.

| | 2011 | 2012-2015 | 2016-2019 | 2020-2025 |
|---|---|---|---|---|
| 300mm Baseline growth expectation | 9 percent | 10 percent | 8 percent | 7 percent |
| Growth with 450mm growth stimulus added | 9 percent | 10.01 percent | 8.81 percent | 11.12 percent |

TABLE 4, SCENARIO 4 – 300MM BASELINE GROWTH EXPECTATIONS

**Results:**

Industry wide Net Present Value: $(20,238.00M)

Total tool platform development costs: $2,940M

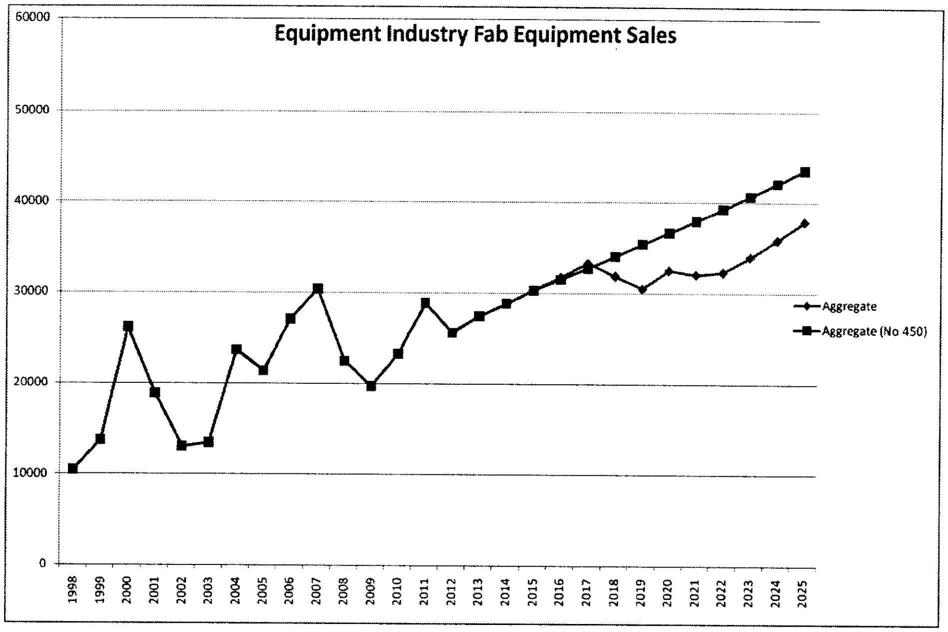



FIGURE 45, SCENARIO 5 – INDUSTRY FAB EQUIPMENT SALES

Even with relatively realistic inputs, the NPV of the 450mm investment is still very negative. The hypothesis of this thesis was that the overall NPV would be negative, but due to consolidation and market share changes, many winners would emerge with positive NPVs. Looking at Figure 46, it is indeed true that there are some winners in this scenario, namely Nikon, Ebara, and DNS; however, the winners are far outnumbered by the losers.

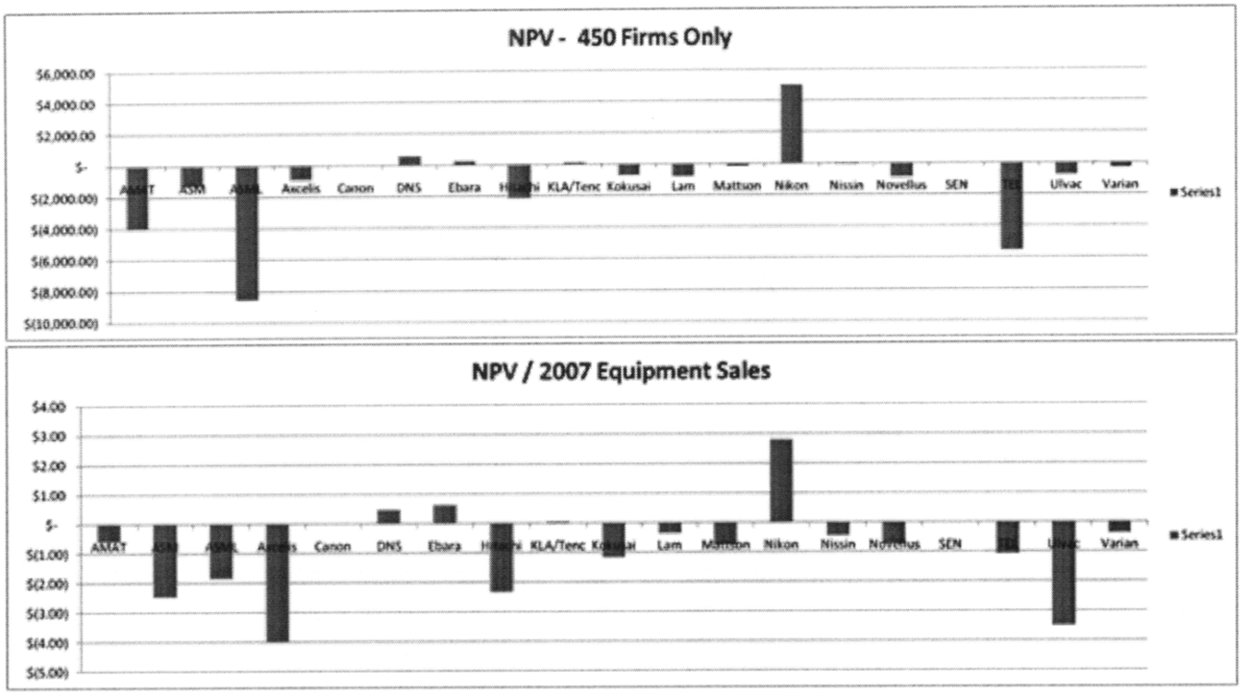
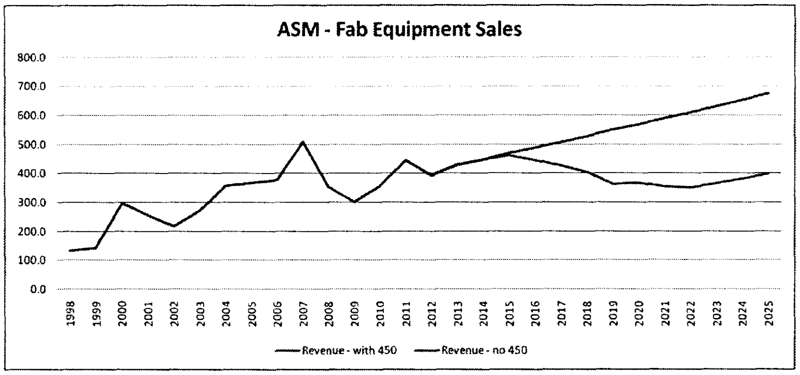



FIGURE 46, SCENARIO 5 – SUPPLIER NPV CHARTS

450mm is a risky investment for equipment suppliers, and if they approach the investment similarly to this scenario, the equipment industry will continue to operate in an unsustainable manner. The problem here is that while each supplier is more selective about which tool platforms to develop for 450mm, there is very little real consolidation. The only supplier in this scenario that exited the market was Canon. Without sufficiently consolidating, the industry will continue to split reduced revenues (see Figure 45). If the industry continues to operate in this unhealthy state, consolidation will eventually happen anyway, but in the meantime, the battling suppliers will be less capable to fund more research and development, innovation will stagnate, and profitability will suffer.

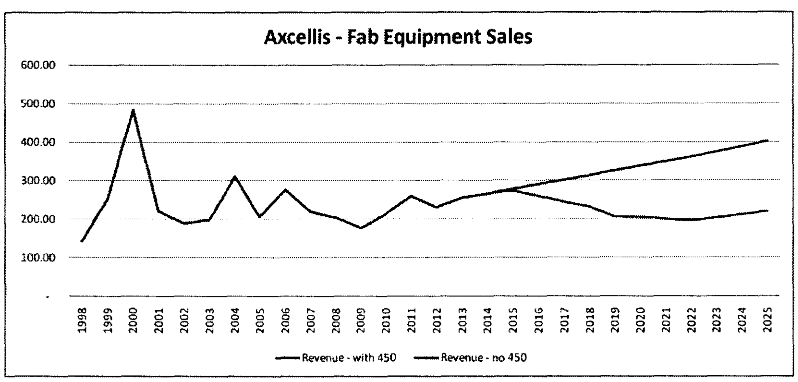
With this backdrop in place, let us take a look at individual suppliers to see which suppliers suffer the most from this transition. We can apply these findings to the next scenario by adjusting for potential acquisitions. Keep in mind that the alterations to the model are intended to demonstrate what could happen to different suppliers. There are many factors that the model does not consider that could move one supplier's position relative to another's.

**ASM:**



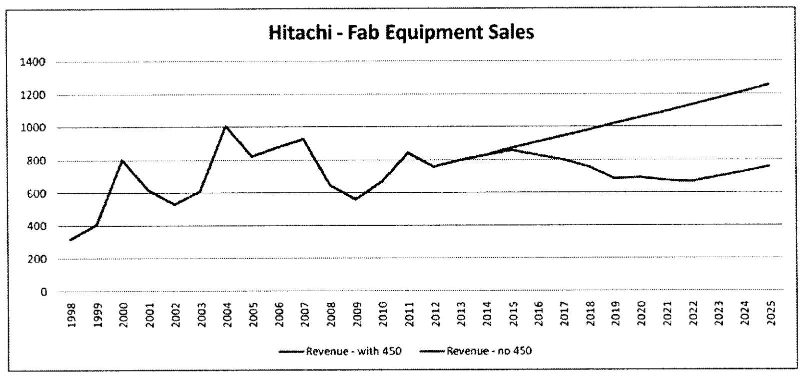

In scenario 5, ASM suffered significant revenue losses. With revenues projected to remain lower than their pre 450mm level, even beyond 2025, they will have a difficult time sustaining and growing their business. Furthermore, ASM has already been an acquisition target, as recently as last year. With the recent financial turbulence and the highly competitive market conditions, it would not be unlikely to see AMAT renew acquisition talks with ASM in the next year or two. The next scenario assumes that ASM is acquired.

**Axcelis:**



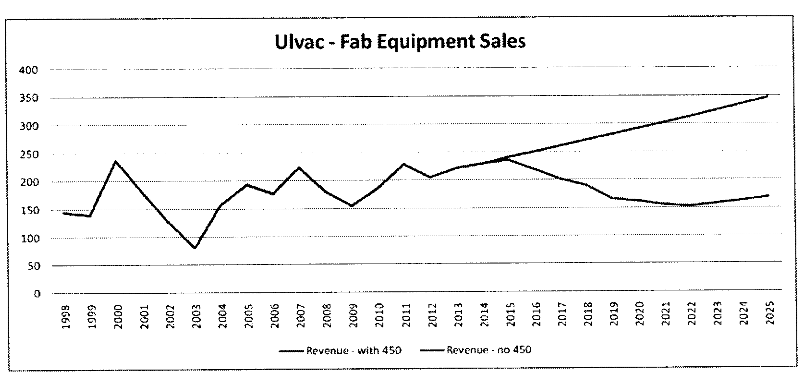

As of 1997, Axcelis had a 33% market share for implant tools, but their market share has steadily decreased from that time to what is now roughly 12% market share. Furthermore, Axcelis has only turned a profit two times in the last eight years. Due to financial difficulties, Axcelis will face challenges to survive in the market even if the industry remains on 300mm wafers, and Axcelis probably won't have the cash to undergo the 450mm development. According to the results of this scenario and an understanding of other external factors it appears that Axcelis will be much better off finding a more financially stable partner or selling their business altogether.

**Hitachi:**




There are many strong suppliers in the etch market and KLA-Tencor holds a dominant position in metrology. Hitachi is a large enough corporation that they could continue to throw money into the equipment business in hopes that the outcome would be different than scenario 5 suggests. If Hitachi believes they are better positioned than LAM or TEL in the etch space and have new metrology tools that are superior to what KLA-Tencor will produce, then investing more money into their capital equipment business would be the best option. If this is not the case, the model suggests that Hitachi should consider an exit strategy. Like most large corporations, Hitachi is suffering due to the recent financial crisis, and cutting out a piece of the corporation with a weaker outlook would allow the company to focus on other core competencies.

**Ulvac:**



With Ulvac's small market share, competing against its much larger rivals for 450mm market share may be difficult. Scenario 5 suggests that Ulvac will not do well if they attempt to transition to 450mm.

#### 4.3.6 Scenario 6 – A Highly Possible Scenario B

This scenario will attempt to arrive at an even more likely outcome than scenario 5 by applying what was learned in that scenario to this one.

**Inputs:**

- Hitachi and Ulvac will exit and make no 450mm tools.
- Implant will undergo serious consolidation prior to the 450mm transition. Nissin will acquire Axcelis. SEN will not make the 450mm transition. Varian and Nissin will be the only implant tool makers after these changes.
- Implant market shares will be fixed such that Nissin – now with their new acquisitions – will get 30 percent of the 450mm implant market while Varian will receive the other 70 percent.
- AMAT will acquire ASM prior to the 450mm transition.
- All other inputs are exactly the same as in the previous scenario.

**Results:**

Industry wide Net Present Value: $(15,144.49M)

Total tool platform development costs: $2,860M

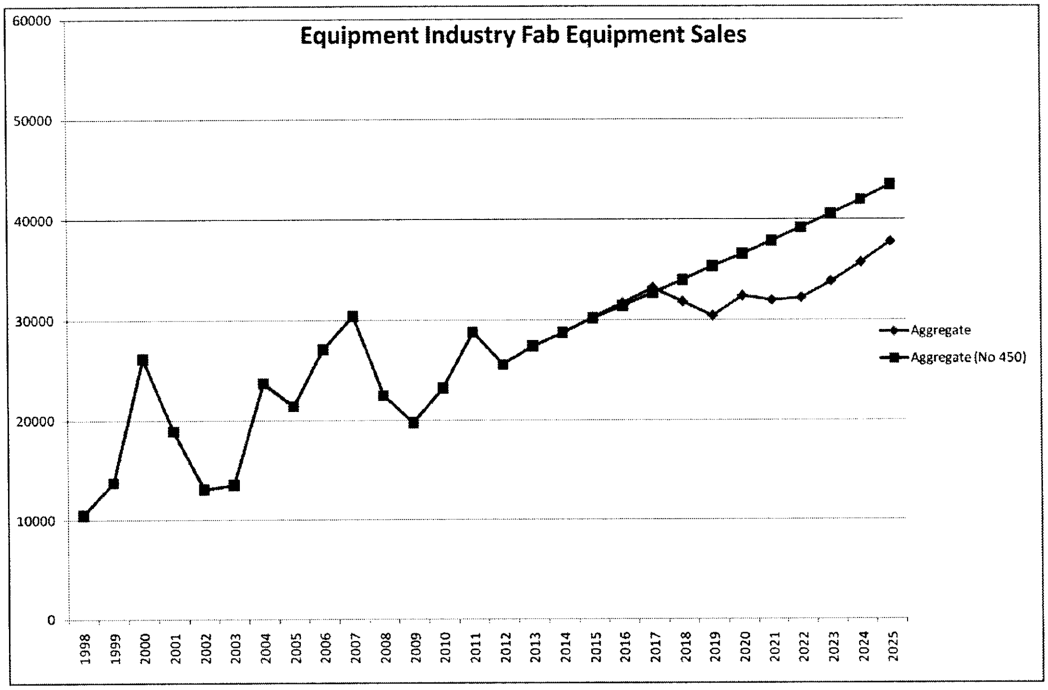



FIGURE 47, SCENARIO 6 – INDUSTRY FAB EQUIPMENT SALES

The revenues earned as a result of 450mm are the same as in the previous scenario, but what has changed is the number of suppliers sharing the revenue. The recent consolidation has allowed many suppliers to improve their total sales and obtain more dominant positions in their respective markets. For example, KLA-Tencor takes advantage of Hitachi exiting and increases their market share and industry earnings in metrology. Nissin also gains significantly and now has a more dominant position in the implant market space. Additionally, Nikon and Ebara see large increases in their market position as they gain share on their only competitors, ASML and AMAT, respectively.

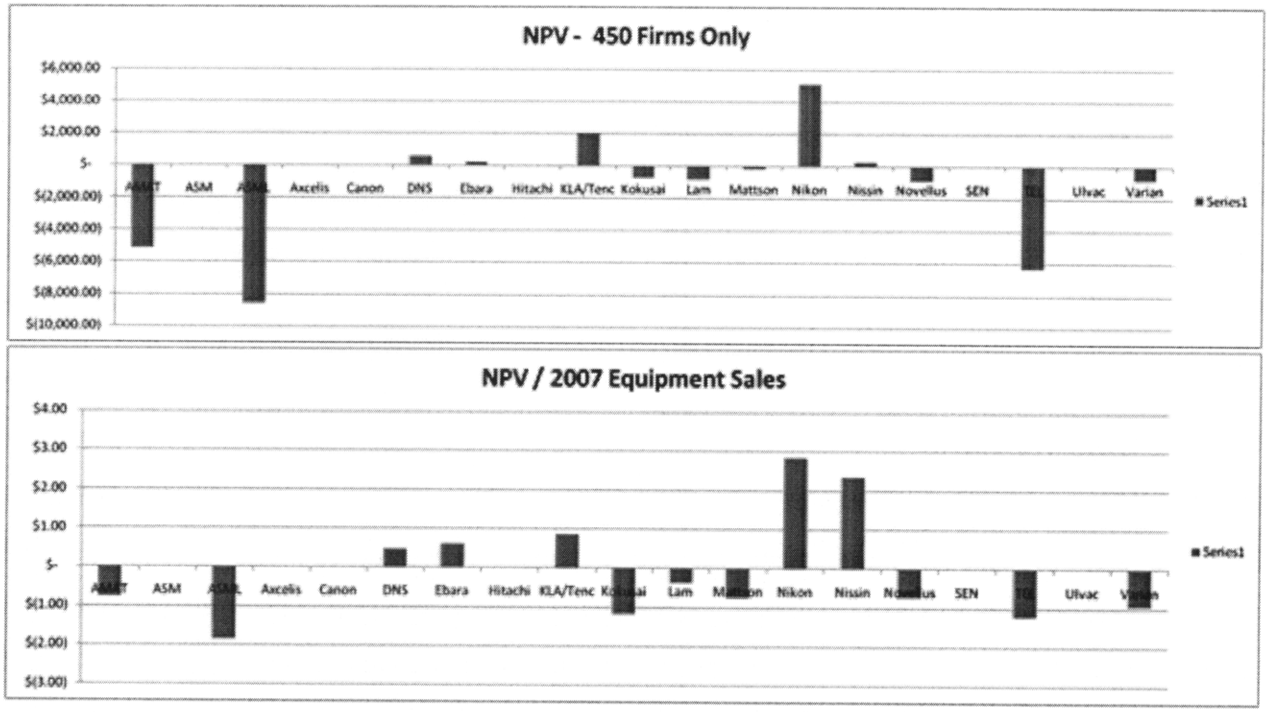



FIGURE 48, SCENARIO 6 – SUPPLIER NPV CHARTS

**Final Thoughts on Scenario 6:**

The results of this final scenario are certainly not carved in stone. To some extent, deciding which suppliers will exit the market is arbitrary. It is very possible that the suppliers selected to exit the market in this scenario will, in actuality, do fine, while other suppliers struggle and exit. The intent of these scenarios is not to isolate and criticize specific equipment suppliers. Instead, these scenarios are intended to paint a picture of what could happen when the industry goes to 450mm. It is the author's belief that a similar story to this one will ensue. Furthermore, it is in the best interest of the industry to see this kind of consolidation. The additional consolidation seen in scenario 6 resulted in an average of two suppliers per tool platform. With enough consolidation, similar to what occurred in this scenario, post 450mm revenue will sustainably support the equipment manufacturers that survive the 450mm transition. Over time the extra demand stimulated by low cost 450mm manufacturing will lead to even better revenue opportunities for these remaining firms.

# 5. Conclusions and Next Steps

This chapter will bring the thesis to a close by presenting conclusions and final recommendations. The final subsection will discuss potential areas for future work that would enhance the conclusions generated in this thesis.

## 5.1 Conclusions

This thesis was written to provide a better understand of whether 450mm is a good move for the semiconductor capital equipment industry. Equipment suppliers have argued that the 450mm investment offers little benefit to suppliers, as IC makers capture most of the value. The largest IC makers contend that 450mm will provide many long term benefits for equipment suppliers because growth stimulated by low cost 450mm manufacturing will increase equipment supplier revenues. Each of these arguments contains some merit, but the situation is more complicated than this. This thesis has shown that 450mm will allow some suppliers to make a substantial return on investment, while others will suffer due to consolidation and shifts in market share.

The remainder of this section will attempt to pull together much of what has been discussed throughout this thesis. First, it will address the outcomes that would be expected if the industry does not move to 450mm followed by the outcomes expected if the industry does move to 450mm. It will conclude with a final recommendation for what the author believes must happen for the capital equipment industry to remain healthy in the long term.

**What happens if the industry doesn't go to 450mm?**

If the size of the wafer is not increased in the near future, manufacturing costs will stop declining as rapidly as in the past, chip prices will increase, and long term demand for semiconductor products will slow even further. The semiconductor industry's history of growth and prosperity has been fueled by its astonishing ability to innovate and create increasingly more capable devices manufactured in increasingly more cost efficient ways. Manufacturing cost efficiencies have largely been generated through shrinking devices – allowing for more devices to fit on a single wafer – and increasing wafer size. Without wafer size increases, the only major source of manufacturing cost improvements will be device shrinking, but device shrinking is expected to encounter major obstacles over the next decade. For one thing, the cost of shrinking devices every few years is rising exponentially, and this trend is expected to continue. Lithography tools, for example, will have to shift to extreme ultraviolet radiation (EUV) tools very soon, a transition that has been delayed as long as possible due to its expected high development costs. Even beyond the high development costs required for shrinks, it is unclear how much a process already working at the atomic level can be improved. If a transition to larger wafers is not made and device shrinking is no longer viable, then the industry will no longer have a reliable way to keep chip manufacturing costs declining. This will severely hurt long term industry growth.

Many equipment suppliers are in opposition to the 450mm investment because they worry it could be the downfall of their business. However, if a supplier's business is fragile enough to worry that 450mm will put an end to their business, then their business is probably not healthy enough to last very long under the current competitive market anyway. The equipment industry is already in an unhealthy state. It is overloaded with competition and suffering from a slowdown in industry growth. The equipment industry will become even more congested and sick unless growth can be stimulated once again. Without this growth, a long and painful process of industry consolidation will ensue. During this drawn out consolidation process, all equipment suppliers will suffer as competitors continue to enact pricing pressure on each other. The industry will eventually consolidate enough to be healthy again, but it could take many years, and possibly even decades, to reach that point.

If demand continues to slow, and equipment suppliers continue to face extremely intense competition, then cash for investment and R&D will suffer as well. This could be costly for long term industry growth. A reduction in R&D will stifle innovation and prevent future manufacturing process improvements. Less productive tools and higher manufacturing costs will increase chip prices and reduce demand, which will reinforce an ugly downward spiral. Chip makers could see the same trend in their industry, which would magnify the problem even further.

**What happens if the industry does go to 450mm?**

Transitioning to 450mm will substantially accelerate the rate at which the equipment industry consolidates. The scenarios of Chapter 4 clearly demonstrate that the suppliers foregoing the 450mm investment will not be able to survive in the industry. Many suppliers will decide early on that they are not financially stable enough, or technologically capable enough to go to 450mm and will seek partners or exit the market. This will be the beginning of the consolidation process. More consolidation will happen later on after IC makers have begun to select the suppliers with the most capable 450mm toolsets. Because the customer base has shrunk – due to consolidation among chip makers – many good 450mm toolsets will go unselected. Scenario 6 suggests that only two suppliers per tool platform can realistically survive. Given the small number of chip makers capable of building 450mm fabs and buying 450mm tools, this number could be even smaller. It should be expected that during the years leading up to the 450mm transition a rapid consolidation process will occur, but once 450mm tool selection is complete, the equipment industry will be in a much more healthy and stable state.

Another dramatic effect of moving to 450mm will be a reduction in equipment industry revenue. Because 450mm tools will be more productive, IC makers will purchase fewer tools to keep up with chip demand. The decrease in industry revenue appears very substantial; however, it looks worse than it is. Even though industry revenue will experience a sizeable drop in the first five to ten years following the transition, there will be fewer equipment suppliers sharing that revenue due to consolidation. Industry revenue will be down, but each supplier's position will not necessarily be negatively impacted. Furthermore, despite the early loss in revenue, equipment suppliers will be well situated for future growth. As 450mm capacity builds up, the cost efficiencies of 450mm manufacturing begin to be realized. Lower manufacturing costs will result in greater chip demand and improved equipment sales growth.

**Final Recommendation:**

It may not be the popular opinion at the moment, but it is the author's belief that equipment suppliers should begin to prepare for and embrace the 450mm transition. 450mm is a sheep in wolf's clothing. On the surface it looks like it will destroy the equipment industry by forcing high development costs with the prospect of negative payout. However, 450mm will help the equipment industry to quickly be more healthy and viable for the long term. 450mm is like an awful cough syrup; it might taste bad, but it's for the best.

The equipment industry is not in a healthy state right now. Delaying the transition will only further delay the industry from getting back to health. Yes, many suppliers will not survive through the 450mm transition, but fighting or pushing out 450mm won't help them either. They are not currently in a good position to survive long term under the current industry and market conditions.

Finally, once the 450mm consolidation has finished, the well managed and innovative suppliers that survive will have a bright future to look forward to. Not only will their market position be improved, but with lower cost 450mm manufacturing in existence, they will have even better growth to look forward to.

## 5.2 Future Work

There are several areas of future research that could be conducted to enhance the conclusions generated in this thesis.

This thesis only analyzes half of the situation. It is looking solely at the impact of 450mm on equipment suppliers. Equally important is the impact 450mm will have on semiconductor device makers. Clearly an increase in global demand for semiconductor products is good for both parties, but for other things, such as tool productivity, what is beneficial to suppliers is not necessarily beneficial to IC makers. To make the work of this thesis more meaningful, a similar model could be created to determine how the IC maker's circumstances change as the equipment supplier's circumstances change. Ideally this model would show how much value device makers are likely to extract from 450mm. The device maker model, together with the supplier cost model, could be used to determine an ideal amount of financial assistance that device makers should be willing to lend to equipment makers to ensure that an equal amount of risk is incurred throughout the 450mm transition.

Another area of future research could be in investigating and developing more accurate inputs to the supplier cost model. The outputs of the supplier cost model are very dependent on how the inputs are configured. Specific inputs that should be investigated further are long term silicon chip demand, equipment development costs, and future tool productivity.

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