WESTFIELD
CAPITAL MANAGEMENT

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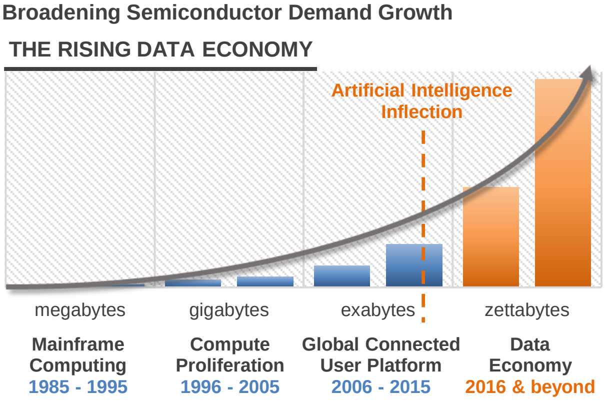
Semiconductors: Key Enablers of the Data Economy

We are increasingly living in a data-centric economy. From the highly targeted recommendations on Amazon, to the smart lights and security cameras in connected homes, to the fully autonomous car of the future, data is at the heart of it all. 90% of the data available in the world today was generated in the last 2 years – and it is expected to grow to 180 zettabytes (that is 21 zeros) by 2025.[i] To put a zettabyte into context, storing just one requires 1,000 data centers, or about 20% of the land area of Manhattan.[ii] Just as oil powered a growing physical infrastructure over the last century, data is powering the rapidly emerging digital world of the present and future (see Exhibit 1). The ability to harness these massive data sets into actionable intelligence is a critical source of competitive advantage for modern businesses and provides the opportunity to solve some of the world's most intractable problems. Semiconductors play an integral role in this evolving ecosystem, as all of this data needs to be processed, networked, stored and analyzed. As investors better appreciate these emerging secular drivers of semiconductor demand, we believe it could change the way they invest in and value semiconductor stocks.

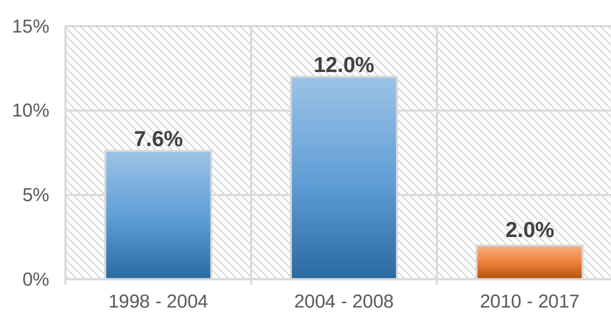
Exhibit 1: The explosion of data brought about by the new Data Economy is broadening out the drivers of semiconductor demand.
Broadening Semiconductor Demand Growth



Source: Lam Research as of 3/6/2018

From an investment standpoint, semiconductors have historically been a highly cyclical group with demand driven by shorter-cycle, consumer-centric end markets such as personal computers (PCs) and handsets, and supply growth dictated by Moore's Law (number of transistors double every 18 months). These ebbs and flows have been further exacerbated by inventory cycles and too many suppliers adding capacity at the wrong time. Fast forward to today and the demand drivers have broadened meaningfully. In today's data-centric world, semiconductor growth is increasingly driven by foundational investments in areas such as artificial intelligence (AI), autonomous driving, cloud computing, big data/analytics, and the Internet of Things (IoT). Supply growth has also become more constrained as the need for scale to remain competitive has driven consolidation, resulting in much improved industry structures (particularly in segments such as semiconductor equipment and memory). Higher capital intensity (and the slowing of Moore's Law) has also resulted in more prudent supply growth (see Exhibit 2).

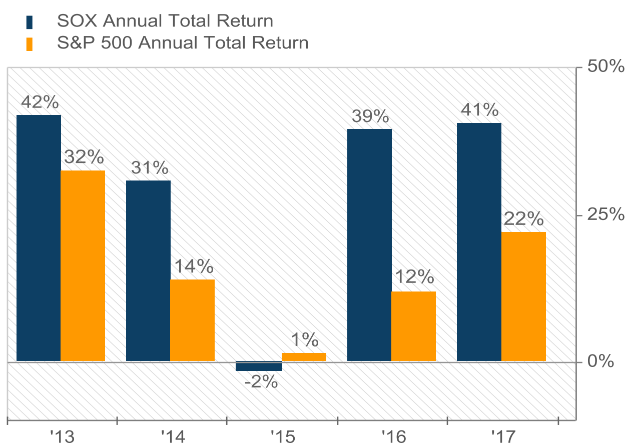
Exhibit 2: Capacity growth has averaged 2% per annum since 2010, compared to 7-12% in prior cycles.
Moderating Supply Growth
Wafer Area Growth Y/Y



Source: Semiconductor Industry Association as of 12/31/2017

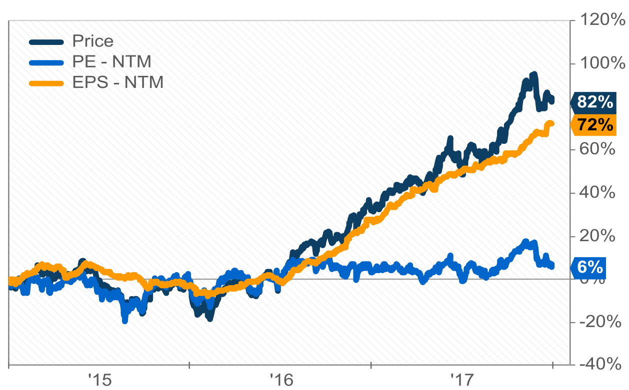
Semiconductor stocks have benefitted from the above dynamics and have been a leadership group in the market, outperforming the S&P 500 in 4 of the last 5 calendar years (by 72% over that time) and beating the market-leading Technology sector by nearly 18% over the last 3 years (see Exhibit 3). These returns have been driven primarily by earnings growth, with only a modest expansion in valuation multiples. As shown in Exhibit 4, the PHLX Semiconductor Index (SOX) rose 82% from the end of 2014 through 2017 while EPS grew 72%, resulting in a forward multiple that expanded a modest 6% over this time period. The overall market (as measured by the S&P 500) rose 30%, with EPS growing 14% and multiples expanding by 14%. As a result, the relative multiple of semiconductors stocks actually contracted over that time frame. We think semi valuations today remain reasonable and the stocks currently trade at a 9% discount to the market despite offering faster revenue and earnings growth. We believe this dynamic exists because investors are still not convinced that the secular drivers in a data-centric world can offset potentially peaking cycle dynamics. Semiconductor revenue growth peaked in the 2nd quarter of 2017, historically a good "sell" indicator for semiconductor stocks. However, we would argue that today's demand drivers differ from those of prior cycles which should help dampen cyclicality and extend the duration of these growth periods. In the market's tug of war with growth and value, semiconductors, in many ways, offer the best of both worlds.

Exhibit 3: SOX outperformed the S&P 500 4 out of last 5 calendar years.
PHLX/Semiconductor Index (SOX) vs. S&P 500



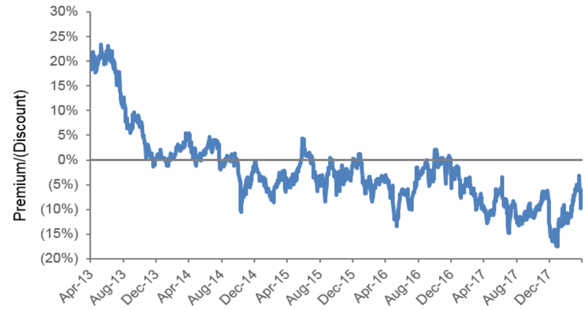
Source: FactSet as of 12/31/2017

Exhibit 4: Unlike the broad market returns over the last few years which have been driven by both multiple expansion and earnings growth, the SOX ascent has been earnings driven.
PHLX/Semiconductor Index (SOX) – Indexed as of 1/1/15



Source: FactSet as of 12/31/2017

Exhibit 5: SOX trades at a 9% discount to the S&P 500
SOX NTM P/E vs S&P 500 – From 3/13 to 3/18



Source: FactSet as of 12/31/2017

Semiconductors: The Building Blocks for the Data Economy

While we believe that the short-term cycle will always matter, there are clearly more secular drivers in place for semis today than in the past that could drive continued strong earnings growth.

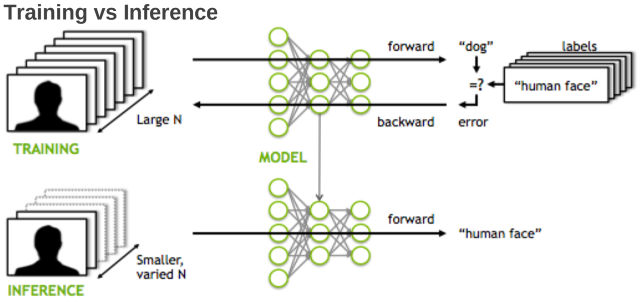
Artificial Intelligence (AI):

Artificial intelligence/deep learning is a key technology in turning the masses of data available today into predictive intelligence. AI has been around for decades in different forms but investment has really taken off over the last few years as increases in the amount of data available to "train" computers, more parallel chip architectures optimized for distributed AI workloads, and advances in algorithms have all converged to accelerate the AI learning curve. Companies are just scratching the surface in utilizing AI to drive sales and customer engagement as well as to reduce costs and to improve operational efficiency. Over time, these deep learning systems may be able to solve problems that are too complex for humans to analyze, making breakthroughs in areas such as genomics, climate change, and robotics. Market forecasters estimate the AI-enabled market (defined as direct hardware, software, and services sales) can grow from $6 billion in 2017 to approximately $36 billion by 2025.[iii]

Taking a step back, AI is the concept of computers exhibiting human intelligence, especially the ability to reason, recognize patterns, classify, and apply learnings to new situations, ideally with minimal human intervention. AI consists of two components: training and inference. Training is what it implies—computers are trained in the same manner the human brain learns. Networks of computers (simulating neural networks in the brain) are loaded with inputs (massive data sets); parameters/algorithms are created to optimize for a desired output; the resulting outputs are compared against desired outputs; and a feedback loop mechanism is created so the weightings of each node are adjusted and errors can be corrected. In the inference stage, computers apply the trained model that they have learned to new data in real-world situations (see Exhibit 6).

Exhibit 6: In training, many inputs are used in large batches to train a neural network. In inference, a trained neural network is used to discover information using new inputs fed in smaller batches.

Training vs Inference



Source: NVIDIA Corp. as of 4/16/2018

AI and Semis:

AI workloads are uniquely challenging, requiring very high parallelism (breaking down a task into many parts and processing each part simultaneously) as well as significant memory intensity. In a typical training network, millions of parameters have to be adjusted iteratively, requiring massive processing power and memory to train computers on these complex tasks. AI workloads can have as much as 4x more logic content and over 2x more memory content than traditional compute workloads.[iv] While the CPU (central processing unit) has dominated the serial processing of general PC and server tasks, new processors such as GPUs (graphics processing units), FPGAs (field-programmable gate arrays) and ASICs (application-specific integrated circuits) have emerged to address the massively parallel processing requirements of AI workloads (see Exhibit 7).

Exhibit 7: Traditional CPUs dominate the market today, but AI workloads are likely to increasingly migrate to processors custom designed to handle AI (highly parallel processing capability and low power).

Processors for Artificial Intelligence Workloads

Lower Customization, Lower Parallelism ↔ **Higher Customization, Higher Parallelism**

	CPU	GPU	FPGA	ASIC
Major Players	Intel AMD	Intel AMD NVIDIA	Intel Xilinx	Intel Google
Power Usage	100W+	200-300W	25W+	Likely <25W
Share of AI Workloads (Today)	91%	7%	1-2%	0-1%

Lower Efficiency, But Lower Cost ↔ **Higher Efficiency, But Higher Cost**

Source: Barclays as of 3/16/2017

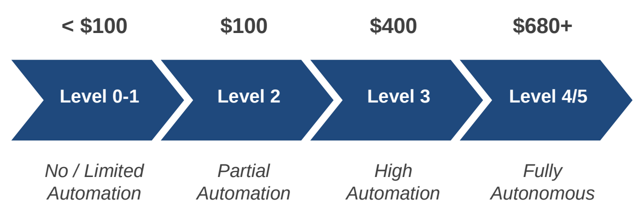
Autonomous Driving:

Self-driving cars are in many ways the ultimate AI application. The amount of data generated and consumed by autonomous vehicles is truly staggering. According to Intel CEO Brian Krzanich, a single autonomous vehicle will generate and consume 40 TB of data for every 8 hours of driving and 1 million autonomous cars will generate as much data as 3 billion people.[v] This massive data consumption occurs because these vehicles are trained on data that include all of the possible situational variables one encounters when driving and then must make split second decisions when put in real-world driving situations. The need for ultra-low-latency sensing, processing, communication, and memory is critical for fully autonomous functionality and semis are central components to these capabilities. As shown in Exhibit 8, it is estimated that semiconductor content per vehicle will grow from $100 in low-automation autos to $680+ in fully autonomous vehicles, representing a strong growth tailwind as the number of automated cars on roadways accelerates.

Exhibit 8: Semi content is expected to grow over 6x as cars become increasingly autonomous.

Increasing Electronic Content in Autos

Semi Content Per Vehicle



Source: Infineon as of 10/10/2017

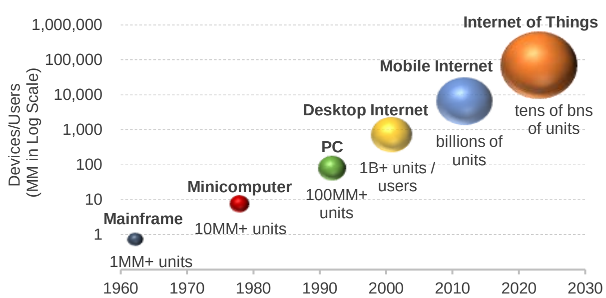
Internet of Things (IoT):

IoT represents the next wave in computing, moving from connecting billions of people and devices during the mobility wave to connecting tens of billions of objects in the IoT wave (see Exhibit 9). The building blocks are in place for IoT to become a reality with the availability of much lower-cost and lower-power sensors, processors, and connectivity chips to allow almost any object to become aware of the environment and communicate seamlessly to the cloud. The incremental silicon content in these devices represents an enormous unit opportunity (albeit at low prices) for the semiconductor industry. IoT is connecting everything from everyday objects like fitness trackers and home appliances to industrial products such as smart utility meters and factory automation equipment. As the installed base of IoT devices around the world continues to grow, so will the data generated by these devices. By 2025, research firm Machina estimates the world’s IoT devices will generate 2 zettabytes of data per year. Every industry will benefit from better access to this level of information, including:

- Smart factories which can have early visibility into equipment failures, reducing downtime, and be more connected to their customers, resulting in more customized products at lower cost
- Smart cities which can use IoT to provide information on traffic, environment, infrastructure, and public safety
- Smart transportation which can track truck fleet and cargo in an increasingly just-in-time world

Exhibit 9: The number of devices and users is exponentially increasing.

Computing Growth Drivers Over Time (1960 – 2030E)



Source: Morgan Stanley as of 4/9/2018

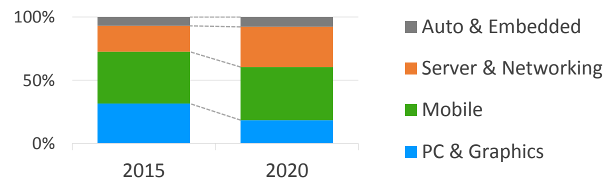
Memory: A New Paradigm

The memory industry was the poster child of a hyper-cyclical semiconductor sector with major boom and bust cycles driven by the vagaries of PC demand and untimely capacity additions. However, new demand drivers, such as AI, big data/analytics, and cloud computing—with higher performance and real-time memory requirements—have created more secular tailwinds and changed the elasticity equation in many end markets. Memory is often the bottleneck for these high performance applications so the value memory provides in total system performance has notably increased. In simple terms, there are two types of memory: DRAM is the memory used to store code and NAND is the memory used to store data for pictures, music, etc. As the performance requirements and demand drivers for memory continue to evolve, so too has the business mix of both memory markets.

On the DRAM memory side, PC demand at one time drove this industry, but the explosion in server bit growth as computing continues to migrate to the cloud is changing this dynamic. Servers have already surpassed PCs in terms of DRAM bit mix as DRAM content growth per server is accelerating and on pace to reach an estimated 35% per year by 2020 (see Exhibits 10 and 11). Autonomous vehicles and their high performance requirements are also an emerging demand driver for this market. According to Gartner, driverless cars contain over 80 GB of DRAM versus 5.5 GB in PCs and 2.5 GB in handsets, exemplifying the sharp increase in the memory demands of these emerging technologies.

Exhibit 10: Servers have already surpassed PCs in DRAM industry bit mix.

DRAM Industry Bit Mix

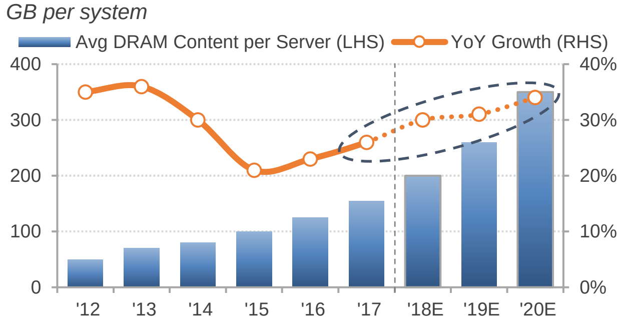


Source: Micron Technology, Inc. as of 2/2/2017

Exhibit 11: Content growth is accelerating to 35% y/y driven by higher content per server.

Server DRAM Content Growth

GB per system



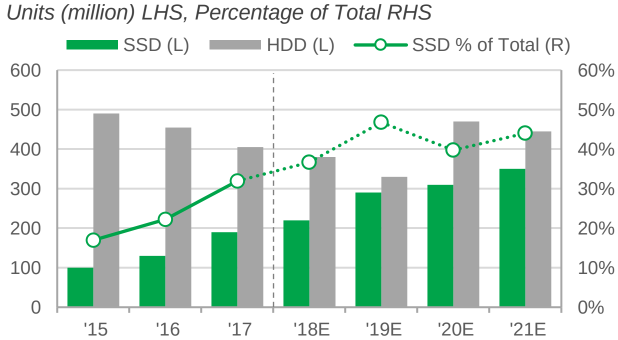
Source: IDC, Gartner, Mizuho as of 1/1/2018

On the NAND memory side, solid-state drives (SSDs) are rapidly penetrating the hard disk drive (HDD) market, opening up an entirely new multi-billion-dollar market opportunity for SSDs to penetrate. According to market research firm IHS Markit, SSD penetration was still less than 35% by the end of 2017 (see Exhibit 12) so there remains a long runway for growth. Enterprise and cloud-based storage and servers are increasingly utilizing SSDs for higher performance applications, to improve reliability and security, and to lower power consumption. This should drive NAND bit growth in the 40-50% range over the next several years.

Exhibit 12: Replacement of hard disk drives with solid state memory remains in the early innings, and is likely to accelerate as the cost curve for NAND continues to inch towards parity with HDD.

NAND Flash Penetration

Units (million) LHS, Percentage of Total RHS

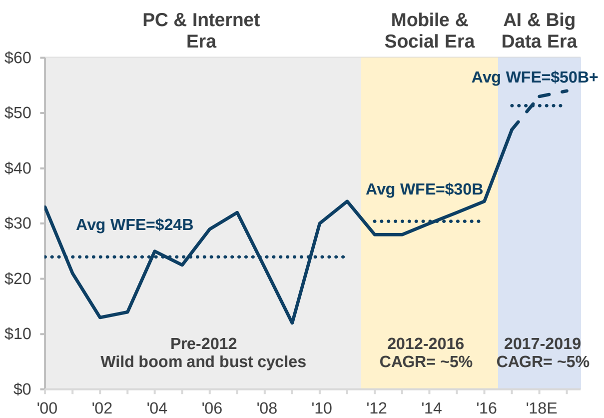


Source: IHS Markit as of 12/18/2017

Semiconductor Equipment:

The semiconductor capital equipment sector (comprising the technology tools required to manufacture semiconductor chips) has also historically experienced major boom and bust cycles. However, over the last 5 years, the sector has followed a much steadier growth trajectory (see Exhibit 13), driven by the broadening secular demand drivers discussed above as well as increasing capital intensity, the emergence of a domestic semiconductor industry in China, and more prudent supply growth.

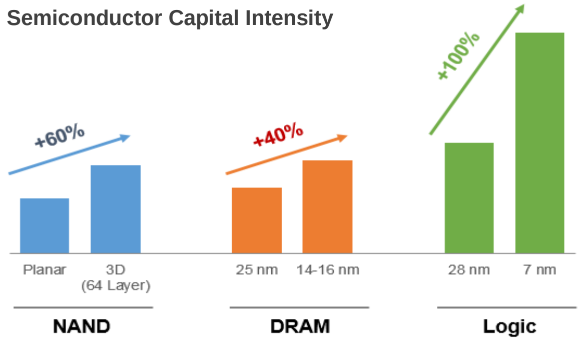
Exhibit 13: Much steadier, secular growth trajectory in the past five years vs. boom and bust periods of prior cycles.
Wafer Fab Equipment Spending (*billions*)



Source: Applied Materials, Gartner, Westfield as of 9/27/2017

The complexity of building the cutting-edge logic and memory chips needed in today's data economy is pushing the limits of physics and requiring new 3-D structures, driving capital intensity higher (see Exhibit 14). The growth of IoT devices and the sensors, microcontrollers, and connectivity chips that power them is adding significant unit volumes and keeping factory utilization higher for longer.

Exhibit 14: Increasing complexity led to higher capital intensity in successive technology node transitions
Semiconductor Capital Intensity

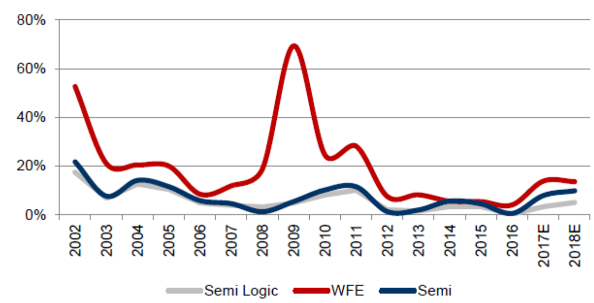


Source: Applied Materials as of 9/27/2017

Conclusion:

Semiconductors are helping to enable the data economy, providing new growth vectors for the industry. While the overall economic cycle will always matter, it is our belief that the broadening of demand drivers and better industry structures will result in less volatility across cycles going forward for the semiconductor industry. Over time, as investors better appreciate these dynamics, we believe it could change the way they invest in and value semiconductor stocks.

Exhibit 15: Much lower year to year variability in annual growth rates in recent years.
Standard Deviation of Semi Industry Revenue and Wafer Fab Equipment Spending
3-Yr Standard Deviation



Source: Semiconductor Industry Association, Credit Suisse as of 1/7/2018

[i] IDC, *Digital Universe* (August 4, 2016)
[ii] The Atlantic, *How Big Is A Yottabyte?* (May 17, 2011)
[iii] Grand View Research, *Artificial Intelligence Market Analysis By Solution* (July 2017)
[iv] Credit Suisse, *AMAT: Growing Earnings and Enabling AI* (September 25, 2017)
[v] Network World, *Just One Autonomous Car Will Use 4,000 GB of Data/Day* (December 7, 2016)