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Memory Tracker 17-03 - Memory in the cloud
Semiconductors Tracker - SPE sales to hit record high in 2018
Telecom Equipment 5G adding fuel in the tank

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31 March 2017

Age of Convergence

To drive the chip market to US$500bn

A new growth phase for semiconductors and Tech

We believe investors may still be underestimating the structural underpinnings behind semiconductor market growth in 2016-25. The rise of the Internet of Things (IoT) in the **Age of Convergence** is set to drive a ~10-fold increase in the number of connected devices, substantially expanding demand for chips including memory and processors. We see the semiconductor market growing 47% between 2016 and 2025, with a 4.4% CAGR propelling sales to US$500bn – a growth rate exceeding that for real GDP, steel and plastics. In tandem with this report, Srini Pajjuri has begun coverage of 13 stocks in the US semis sector.

The Age of Convergence is taking over the Age of Mobility

The **Age of Mobility** saw a melding of 1990s-2000s technologies (PCs, wireless and the Internet) to create true personal, mobile computing devices, with the smartphone becoming the archetypal product of the Age. Consumer enthusiasm for such devices, driven by the addictive allure of video and games, doubled the size of the chip market between 2002 and 2015 to over US$300bn. Now, in the **Age of Convergence**, ICT firms are harnessing technologies from the prior Age to build the emerging IoT – processors, sensors and connectivity made cheap through the vast production scale of smartphones. The encroachment of ICT into industries like cars and industrial equipment is opening up new areas of value creation (e.g. with Big Data and AI) and expanding value capture by chip firms. Intel's acquisition of Movidius and Mobileye, and the penetration of Nvidia GPUs into industrial, automotive and AI applications, highlight the trends in this Age.

The 4G migration, and the arrival of 5G in 2020, are key

Allen Chang's initiations on the Greater China telecom carriers and telecom equipment vendors (*Telecom Equipment – 5G adding fuel in the tank*, 23 March) highlight the potential presented by the 4G and 5G migrations for the tech and telecom sectors in the form of infrastructure systems, connected devices and new services. We see 20%+ CAGR in global Internet connection speeds, and a 10-fold increase in IoT end-points by 2020, backing 22% growth in data traffic. The migration to 5G will build on this momentum by enabling a further 10-100x jump in connection density and up to 10x increase in user-side data speeds, with much lower latency. This is likely to drive datacentre investments and promote emerging applications like autonomous cars (*Autonomous driving - 50% CAGR over 2015-20E*, George Chang, 19 Oct 16), aerial drones (*Drones – ignore them at your peril*, Allen Chang, 11 Aug 16), and remotely-operated heavy machinery.

We are bullish on the outlook for the semiconductor sector

A strong growth outlook is positive for the supply chain, from chipmakers to suppliers of equipment and materials (notably wafers). We see a multi-year uptrend in chip sector capex with China to become the largest market by 2020.

Chip sector Outperform picks include:

Stock	Ticker	TP (local)	Price (local)	Up/Dn	Analyst
TSMC	2330 TT	230.00	189.00	+22%	Patrick Liao
SMIC	981 HK	15.00	9.62	+56%	Patrick Liao
Powertech	6239 TT	111.50	88.30	+26%	Jeffrey Ohlweiler
SK Hynix Inc.	000660 KS	69,000	50,500	+37%	Daniel Kim
GlobalWafers	6488 TT	250.00	227.00	+10%	Patrick Liao
SUMCO	3436 JP	2,330	1,854	+26%	Damian Thong
Tokyo Electron	8035 JP	14,850	12,155	+22%	Damian Thong
ASM Pacific Technology	522 HK	130.00	105.70	+23%	Patrick Liao
Broadcom	AVGO US	265.00	220.04	+20%	Srini Pajjuri
Cavium	CAVM US	85.00	71.47	+19%	Srini Pajjuri

Source: Macquarie Research, April 2017

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The Age of Convergence marks a new growth phase for semiconductors

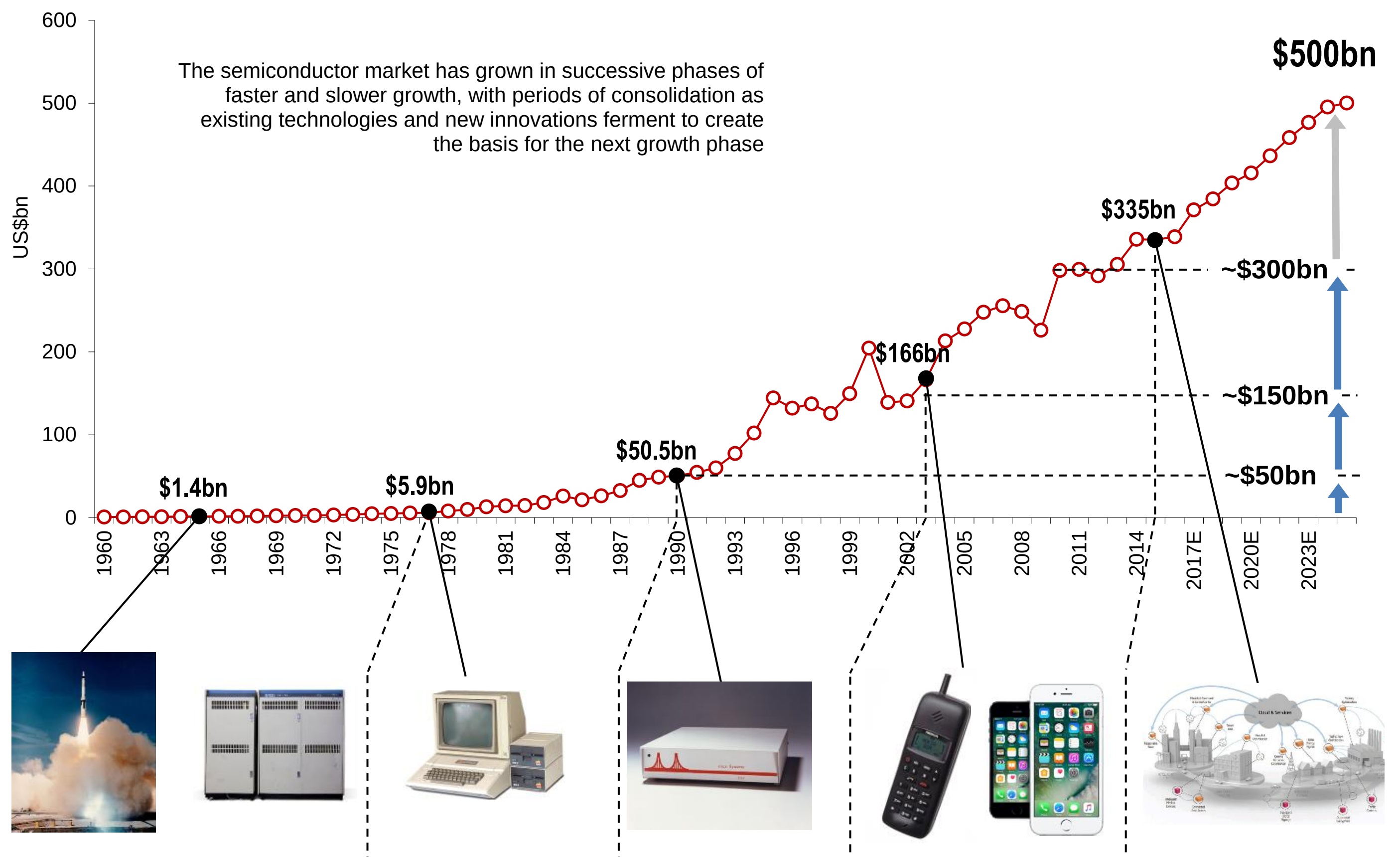
The Age of Convergence marks a period of faster growth for the semiconductor industry

As shown in Figure 1, the semiconductor market has grown in **successive phases of slower and faster growth**, which each phase of faster growth marked by a technological step-change caused by a reconfiguration or reapplication of existing technologies into new fields.

The **Age of Mobility** for instance melded technologies from personal computing (e.g. microprocessors), networking (e.g. TCP/IP and routers) and wireless communications (e.g. GSM and its successors, 802.11) to create WiFi-enabled notebook PCs, and soon after, smartphones.

We believe that a new phase of faster chip market growth – the **Age of Convergence** – has begun. Once again, we are seeing the melding of information and communications technologies (ICT) from the preceding Age – low-power processors, GPUs, cheap sensors, and ubiquitous high-speed connectivity – with disruptive impact on the automotive, manufacturing and healthcare sectors. We see the dynamics of this Age driving sustained increase in the semiconductor market to US$500bn by 2025.

Fig 1 Each Age drives a large increase in the semiconductor market



Age of the Military-Industrial Complex

Minuteman II ICBM (1965) the first to fly with integrated circuits – the program was the largest user of ICs in 1965

Age of Business Computing

Falling costs drove adoption of computers in enterprises.

(First) Age of Personal Computing and Networks

Apple II (1977) sparks the personal computing revolution; IBM PC follows (1981)

Age of the Internet / (First) Age of Mobility

Cisco releases first router (1984); World Wide Web launched (1990/91)

First GSM phone (1991)

Age of Mobility / Mobile Computing

Intel launches Centrino platform (2003); Apple launches iPhone (2007)

Age of Convergence

Facebook launches Open Compute Initiative (2011); IBM opens Watson API (2013); GE launches Predix (2015); Tesla launches Autopilot (2015)

Source: WSTS data, Macquarie Research, March 2017

A look back at a remarkable five decades

Thanks to Moore's law and software innovation…

Moore's law coupled with software innovations have driven over five decades of progress

In 1965 there were only ~20,000 computers in the world, which were expensive machines used for military, aerospace and corporate work. Based on the technology of the time, the idea that computers could reach universal ownership would have been laughable.

Since then, thanks to Moore's law – underpinned by steady advances in circuit miniaturisation – costs have fallen dramatically. By 2016, an Apple iPhone 7 Plus had ~320 billion times the performance/US$ of the Guidance Computer used on the Apollo moon missions, which in the early 1960s was the largest single user of integrated circuits.

Innovations in software have amplified these gains to collapse barriers to the mass diffusion of electronics. In 1984, during the (First) Age of Personal Computing and Networks, there were still just ~30m computers in the world. Today there are over 5 billion smartphones and PCs alone, the total number of mobile-connected devices has reached ~8 billion units, while the total number of networked devices exceeds 16 billion units.

Fig 2 A remarkable four decades - from the IBM System/360 to the iPhone

Source: IBM, United Nations, March 2017

…smartphones are now the dominant device for personal computing

The smartphone installed base is now 4x greater than that of PCs

Smartphones represent the marriage of the personal computing and mass wireless connectivity trends running since the early-1990s. The installed base of mobile phones exceeded the number of PCs as early as 1998. But it was not till the 2000s – and notably the arrival of Apple's iPhone – that hardware, software and design innovations came together to turn the smartphone into the dominant computing and communications device for the major part of the connected world.

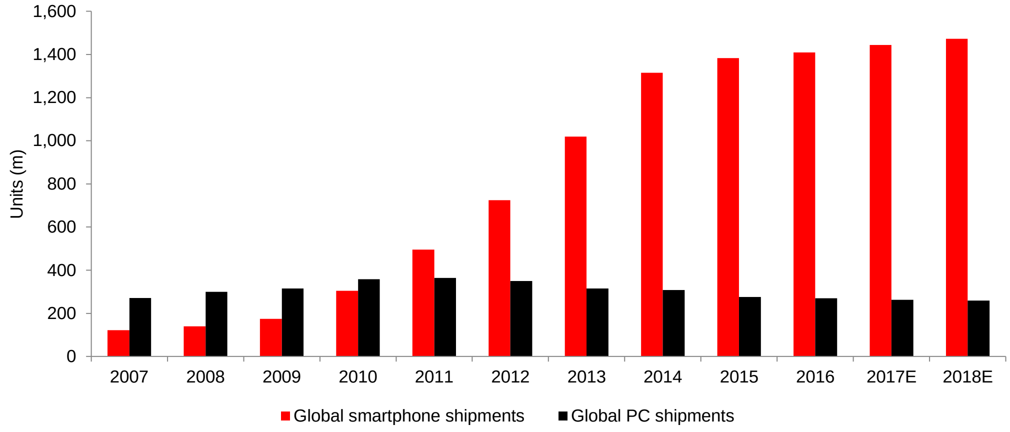
The smartphone market is now a mammoth 5x larger than the PC market in unit terms, and the installed base is 4x larger, with ~4bn for smartphones in use vs ~1bn in the case of PCs (Figure 3). Over 50% of all digital time is now spent on mobile, and smartphones are increasingly an indispensable part of daily life.

ITU data indicates that there are now over 7.5 billion mobile subscriptions and ~5.1 billion subscribers. Mobile subscriptions surpassed fixed-line subscriptions around 2002 (Figure 4). Mobile cellular connectivity is not yet universal, but at ~70% penetration it is not far from the ubiquity of electricity (>80% penetration).

Half the world is still yet to be connected to the Internet

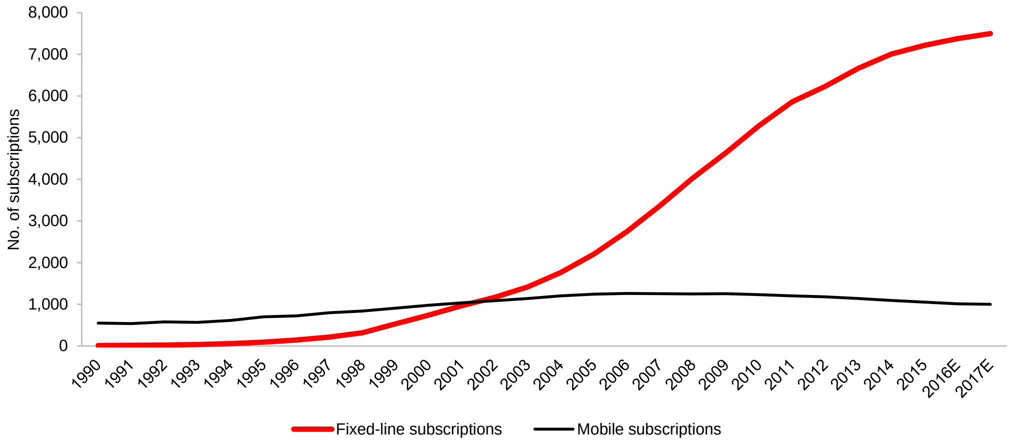
There is still significant untapped opportunity for connectivity and hardware demand – as of 2015, 53% of the world's population were still not using the Internet, according to the ITU. ~90% of the US, Japan and German populations were Internet-connected in 2015, but only 50-55% in China and Vietnam, ~35% in India and ~20% in Indonesia. We expect falling costs of connectivity and devices (including second-hand) will progressively expand the Internet-connected population.

Fig 3 Smartphone volumes vs PC volumes, 2007-2018E



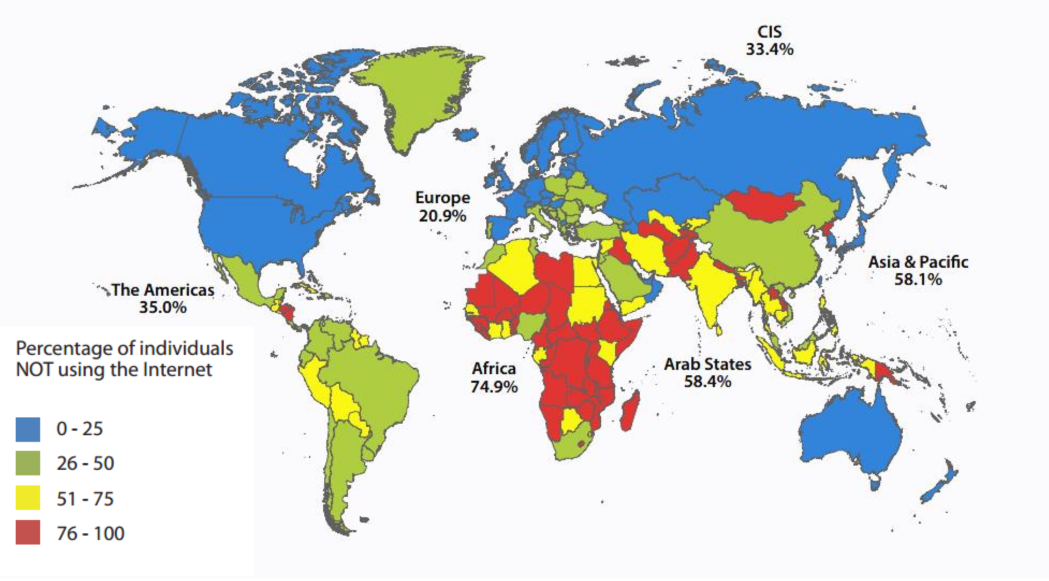
Source: IDC data, Gartner data, Macquarie Research, March 2017

Fig 4 Mobile subscriptions vs fixed-line subscriptions (million subscribers)



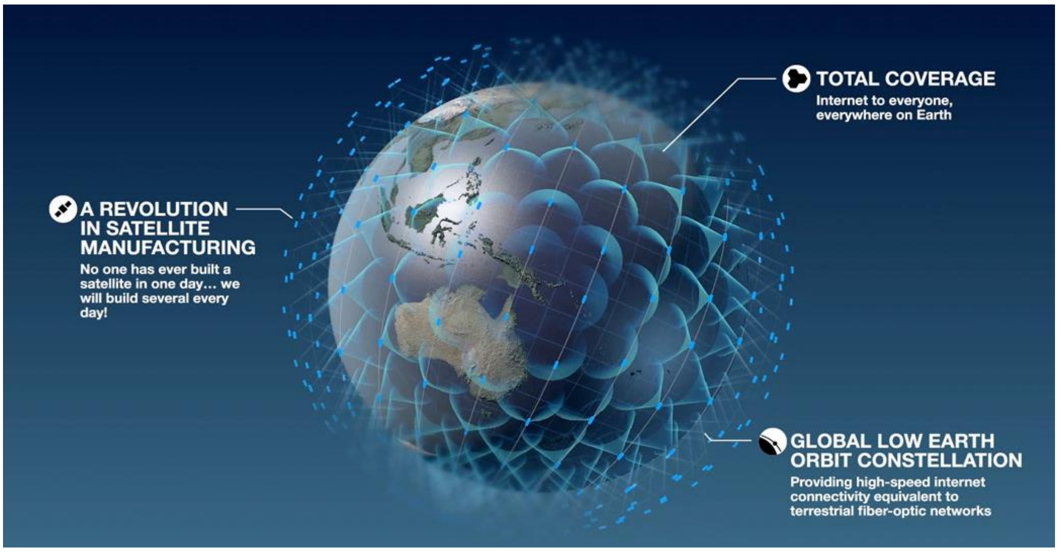
Source: ITU data, Macquarie Research, March 2017

Fig 5 As of 2015, 53% of the world's population were still not using the Internet



Source: ITU, March 2017

Fig 6 OneWeb aims to cover the earth with connectivity with over 2,00 Low-Earth and Medium-Earth Orbit satellites



Source: OneWeb, March 2017

We are watching with interest OneWeb, the Softbank-backed company aiming to bring the rate of global Internet access to 100% using a massive fleet of Low-Earth Orbit (LEO) and Medium-Earth Orbit (MEO) satellites. The strategy is unchanged even with the pending merger with Intelsat, an operator of geostationary satellites. In March 2017, OneWeb and Airbus broke ground on their US$85m joint venture factory in Florida that is intended to produce over 2,000 satellites at a rate of up to three satellites/day. OneWeb is aiming to drive satellite costs down through mass production at this facility.

The pathway to the Age of Convergence has been paved by insatiable demand for video games and video streaming

Smartphones are useful…

Smartphones are useful – like mobile phones, they enable convenient person-to-person to communications, and like PCs they allow access to the Internet, facilitate e-commerce transactions and open up new capabilities for social interaction. This usefulness has been a key factor for the adoption of the devices.

But the true "killer app" has been entertainment

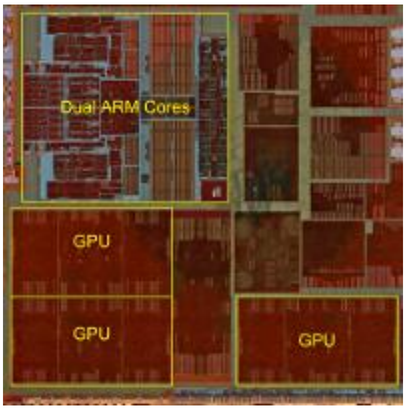
However, the most important factor for the popularity of smartphones has been their capacity to entertain. We note that:

- Internet video now accounts for a massive 70% of consumer Internet traffic.
- Games are the most popular App category on smartphones (25% of the Apps on the Apple App Store comprise games). Verto has highlighted that games rank second only to social media activity in terms of time spent on devices.

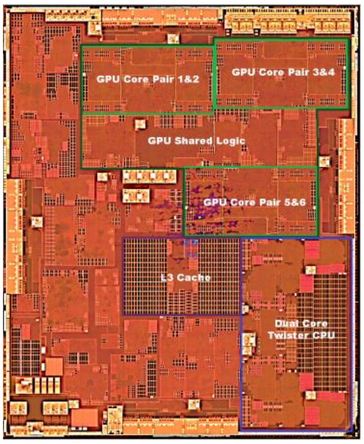
As we pointed out in our 2015 report *Graphics eating the* world, ever-increasing demand for video streaming and games has been the key factor driving advances in silicon content and smartphone capabilities, as well as network infrastructure investments. We estimate that the silicon area devoted to graphics processing units (GPUs) and other dedicated video processing circuits has been increasing steadily relative to that for CPU cores. More generally, strong demand for games has also driven demand for stand-alone (discrete) GPUs from NVIDIA and AMD.

The ubiquity of GPUs in PCs and smartphones, and the steep reduction in unit cost that has occurred due to mass production, has paved the way for architectural and software innovations that enable new applications, ranging from facial recognition, biometrics and depth sensing in smartphones to AI capabilities/deep learning in servers and supercomputers.

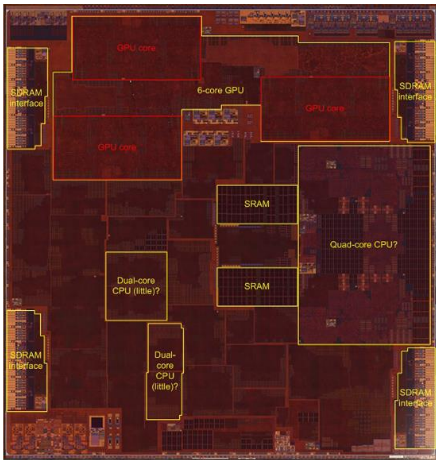
Fig 7 Silicon area for GPUs expanding relative to that for the CPUs



Apple A6 processor (2012)
96.7mm^2



Apple A9 processor (2015)
104.5mm^2



Apple A10 processor (2016)
~125mm^2

Source: AnandTech/Chipworks/iFixit, March 2017

Video is the dominant driver of Internet traffic

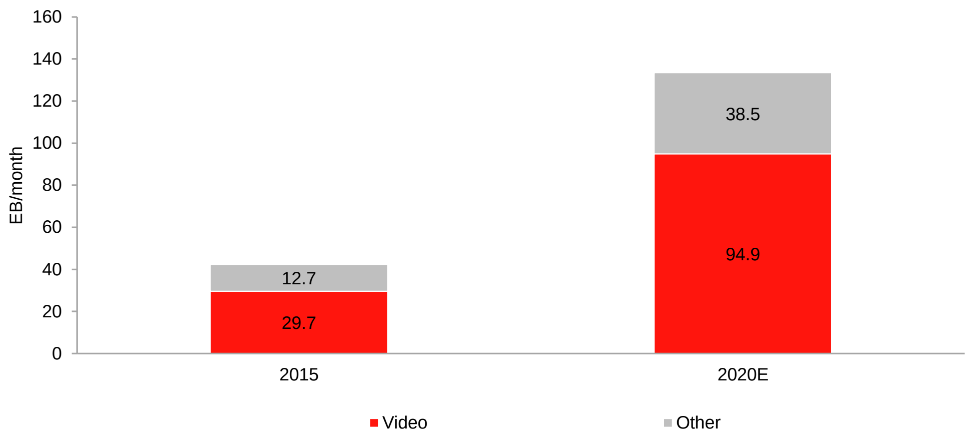
Video is now the dominant driver of Internet traffic

Internet video is now the dominant component of Internet traffic and overwhelmingly the major area of future growth, encouraged by rising connection speeds.

In 2008, Internet video accounted for just 21% of consumer Internet traffic, but in 2015 the ratio had reached ~70%. Cisco projects that video will account for more than 80% of consumer Internet traffic by 2020, growing at a CAGR of 26% and helping to drive a four-fold increase in overall Internet video traffic between 2015 and 2020.

In the case of smartphone traffic alone, over half of it comprises video, as highlighted by our colleague Tim Nollen (*Short-form video – Lifestyle on demand*, 24 March 2017).

Fig 8 Surging consumer video traffic, 2015 and 2020E



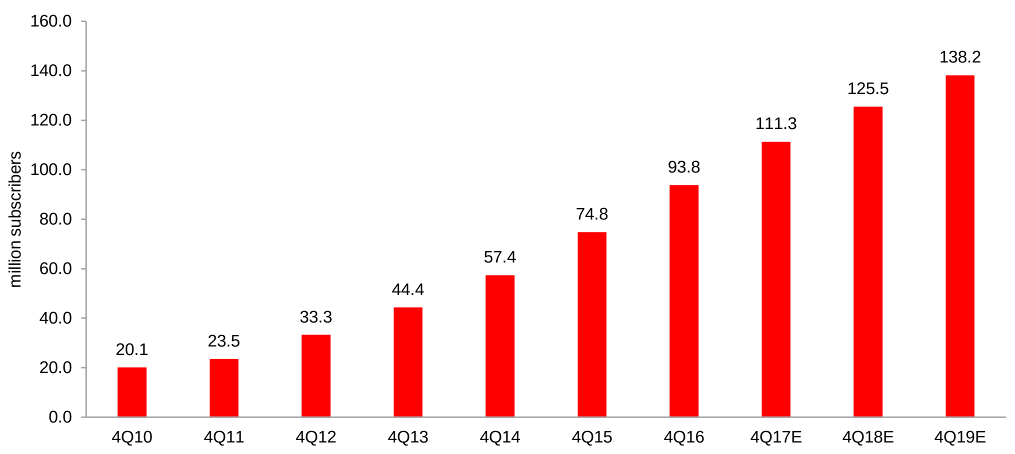
Source: Cisco, Macquarie Research, March 2017

In 2015, Netflix and YouTube alone accounted for an astonishing 55% of peak download data traffic in North America

In 2015, Sandvine data revealed that Netflix and YouTube respectively accounted for 37% and 18% of peak download Internet data traffic in North America – a whopping 55% in total. Including Amazon Video and Hulu would have brought the "over-the-top" (OTT) video total to 61%, vs just 30% in 2010. These ratios are likely to have increased in 2016, and we expect trends to be broadly universal across markets.

We note that Netflix's worldwide subscriber total has surged from 20.1 million at the end of 2010 to 93.8 million by the end of 2016, and our colleague Tim Nollen projects sustained growth to 138.2 million by the end of 2019 (Figure 9).

Fig 9 Netflix subscribers, growing from 20m at end-2010 to 138m by end-2019



Source: Company data, Macquarie Capital (USA), March 2017

Games are the killer app for smartphones

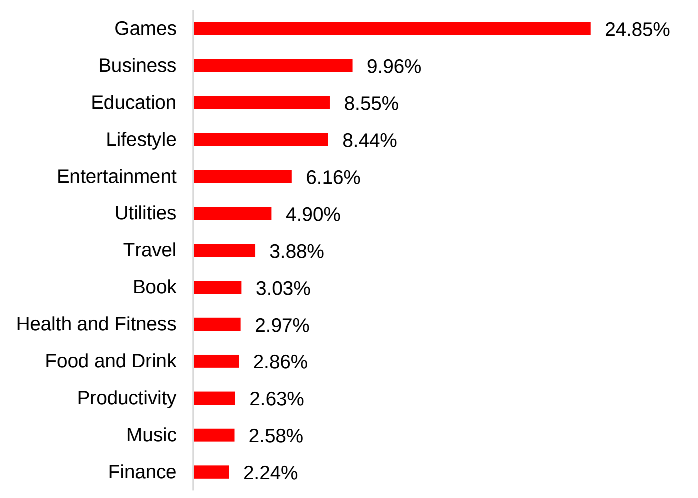
Video games account for 25% of the Apple App Store

Meanwhile video games have become a “killer application” for smartphones –a driver of both consumer adoption and the subsequent replacement cycle. As shown in Figure 12, the global games market at ~US$100bn dwarfs the global cinema box office and the global music market – the games market is some seven times larger than the music market. A key factor for the impressive growth in games has been the rise of mobile games.

In 2016, ~27% of the market comprised games for smartphones and wearables and mobile games overall (including handheld consoles) accounted for 37% of the market.

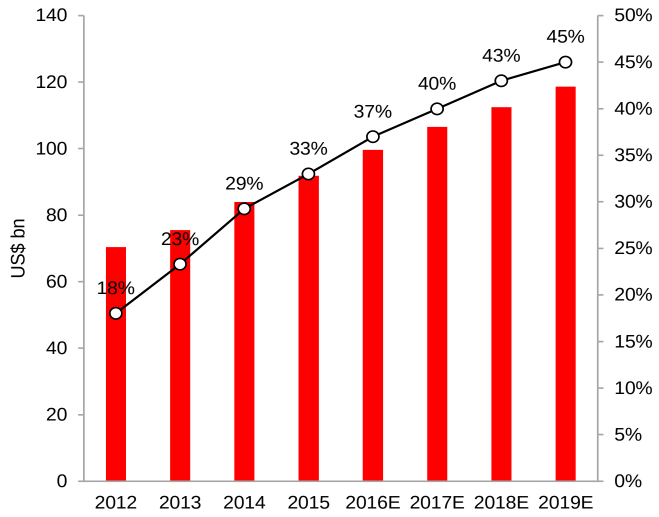
Games are the most popular category in both Apple’s App Store and Google’s Play store – accounting for ~25% Apple App Store apps, more than double the next biggest category.

Fig 10 Most popular App Store categories, Dec 2016



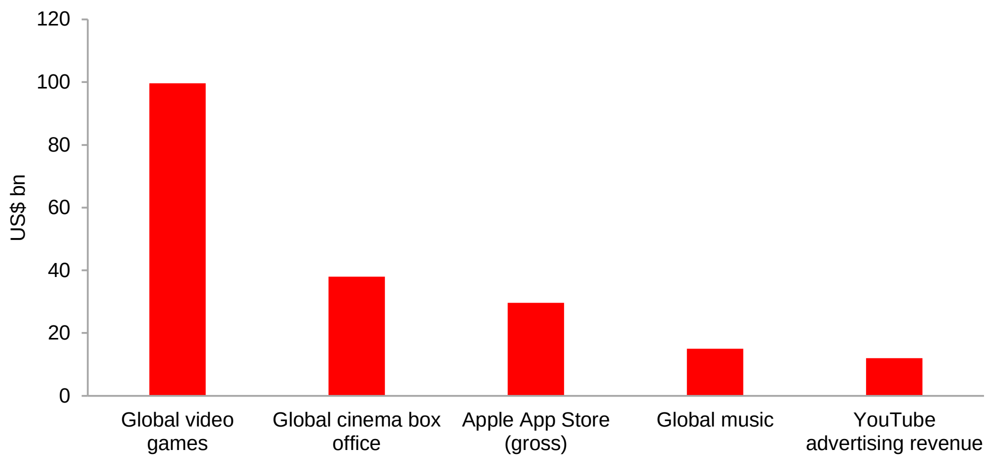
Source: Company data, Macquarie Research, March 2017

Fig 11 Video game market 2012-19E, including ratio due to mobile devices (smartphones, portable game consoles etc.)



Source: Company data, Macquarie Research, March 2017

Fig 12 The video games market dwarfs the global cinema box office and global music market



Source: Newzoo data, Macquarie Research, March 2017

Faster connections drives data traffic

Faster connection speeds and lower costs has propelled data traffic and opened up new applications

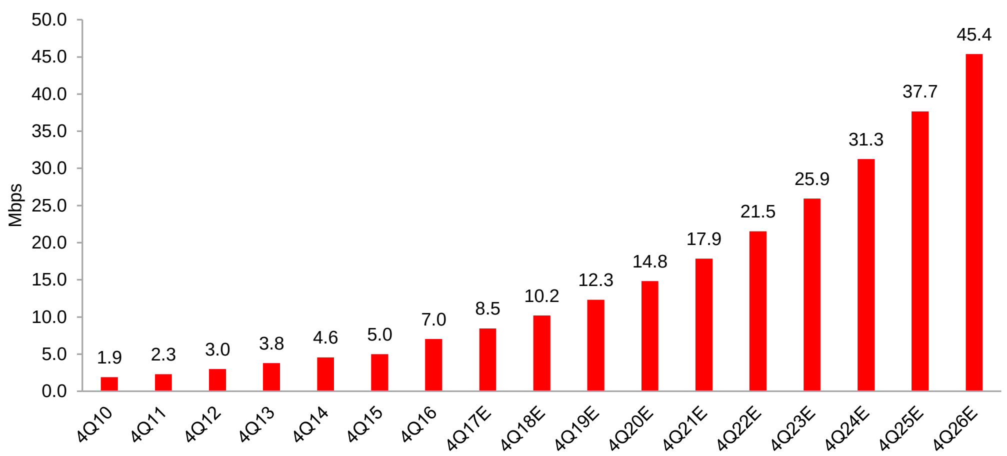
Robust demand for streaming, social networking, games and always-on connectivity has spurred network operators to invest in their mobile and fixed-line infrastructure – including investments in macro cell tower density and small-cell densification – driving up capacity and cutting costs. This in turn is encouraging even more demand for data and is expanding the range of applications to which connectivity has been applied, in a positive feedback loop.

According to Akamai, the worldwide average connection speed grew at a 24% CAGR between end-2010 and end-2016, from 1.9 megabits/second to 7.0 megabits/second – i.e. more than enough for the streaming of full HD Netflix video. This has driven a 4.5-fold increase in data traffic from 20 exabytes/month in 2010 to 89 exabytes/month in 2016.

Projecting a sustained 20.5% CAGR, we see the average connection speed increasing to ~15 megabits/second by 2020 and over 45 megabits/second by 2026. We see this driving 22% per annum growth in global data traffic to 194 exabytes/month by 2020.

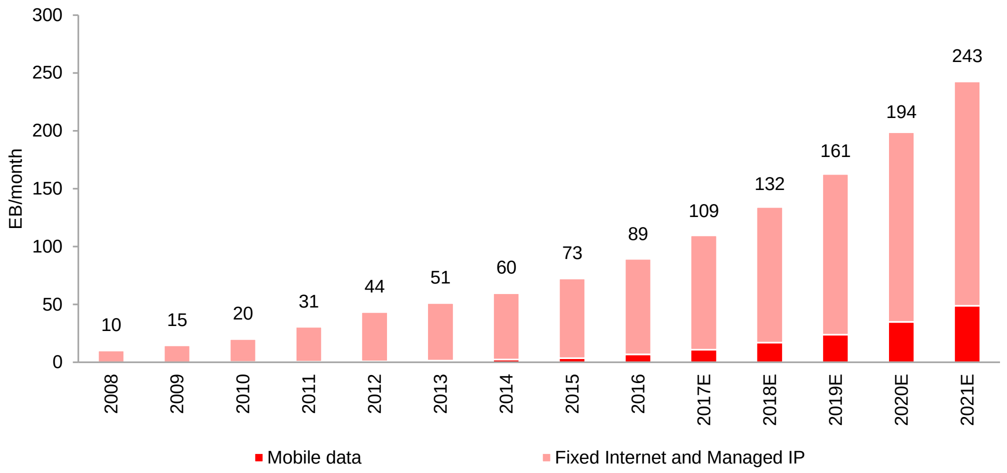
In February 2017, Cisco projected that due to the 4G migration (2.1 billion connections in 2016 → 6.1 billion in 2021), mobile data traffic alone would grow at a CAGR of 47% between 2016 and 2021 from 7 exabytes/month to 49 exabytes/month.

Fig 13 Faster connection speeds…



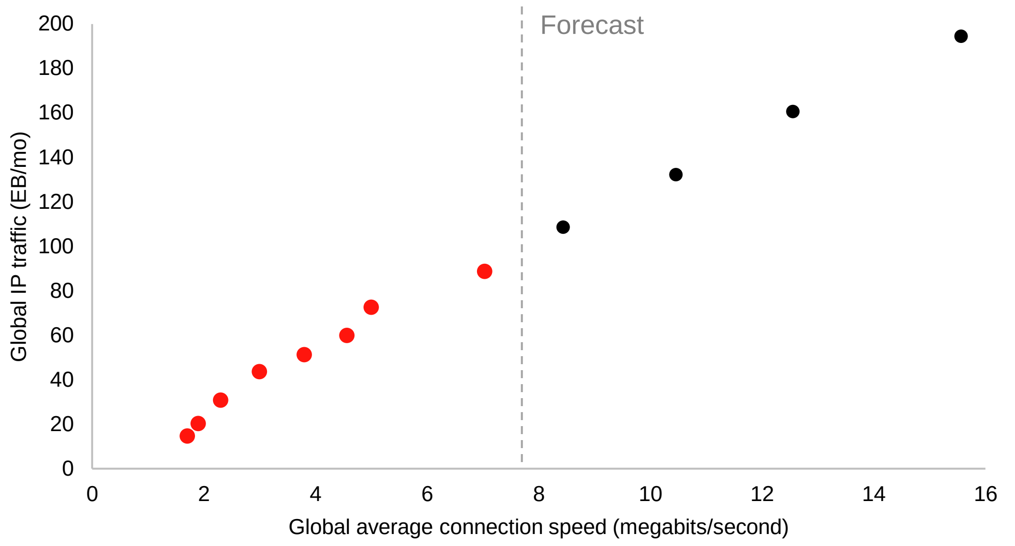
Source: Akamai, Macquarie Research estimates, March 2017

Fig 14 …spurs growth in data traffic



Source: Cisco VNI data, Macquarie Research estimates, March 2017

Fig 15 Data traffic vs average connection speed



Source: Cisco VNI data, Akamai data, Macquarie Research estimates, March 2017

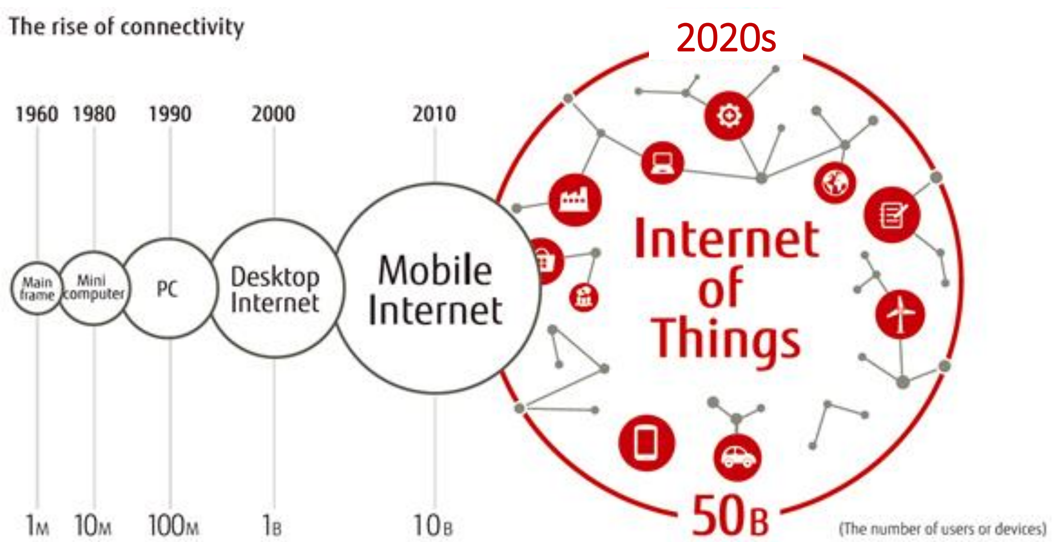
The emerging IoT will be the archetypal product of the Age of Convergence

Ubiquitous connectivity and falling cost has opened the way to the IoT

Ubiquitous connectivity and falling hardware costs have opened the way to the Internet-of-Things (IoT), comprising a vast diversity of device end-points beyond PCs and mobile handsets. This will bring the number of installed end-points to the 10s of billions from sub-10 billion today. Gartner has estimated an installed base of IoT endpoints of 6.4 billion in 2016, and is forecasting growth to 20.4 billion by 2020 (Figures 17-18). We expect significant innovation activity in the space in the coming years. For instance, Philips Lighting is partnering with the China Mobile Research Institute to explore potential for a standard for connected lighting, and is to demonstrate a street lighting concept in Beijing.

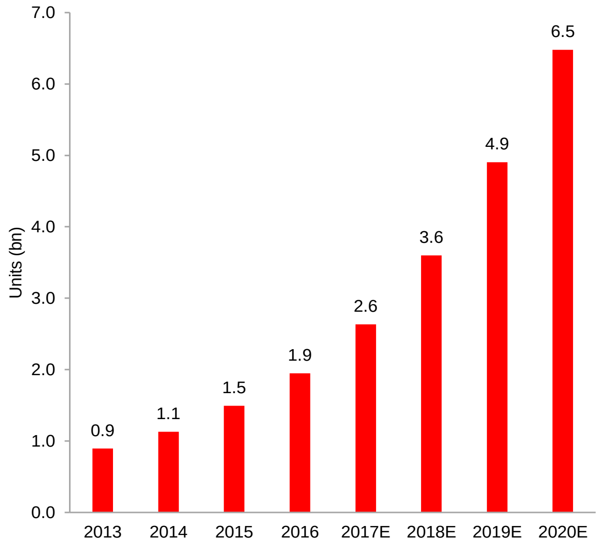
This trend is supported by the implementation of software-defined networking (SDN) to make network management more efficient, and the transition to IPv6 from IPv4 which dramatically expands the number of possible IP addresses by up to $7.9{\times}10^{28}$ times. IPv4 can only provide for 4.3bn addresses (due to the use of 32-bit addressing) but IPv6 allows for a theoretical maximum of $3.4{\times}10^{38}$ addresses (340 undecillion). Cisco has forecast that 48.2% of all devices and connections will be IPv6-capable by 2020, up from 23.3% in 2015.

Fig 16 The IoT will bring the number of endpoints to the tens of billions



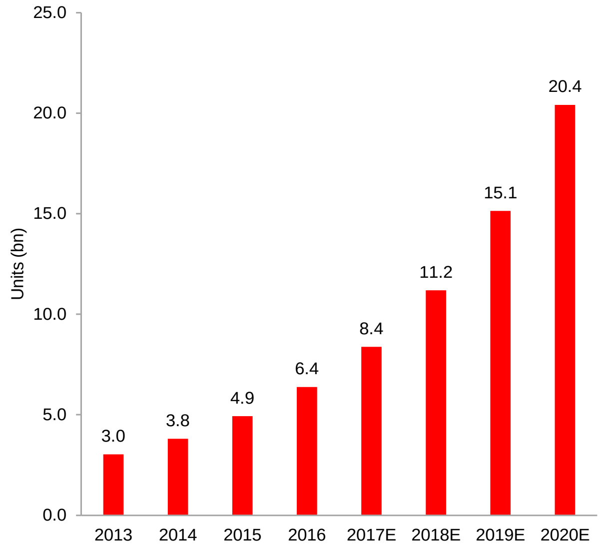
Source: Fujitsu, March 2017

Fig 17 IoT endpoint shipments, 2013-20E



Source: Gartner data, Macquarie Research, March 2017

Fig 18 IoT endpoint installed base, 2013-20E



Source: Gartner data, Macquarie Research, March 2017

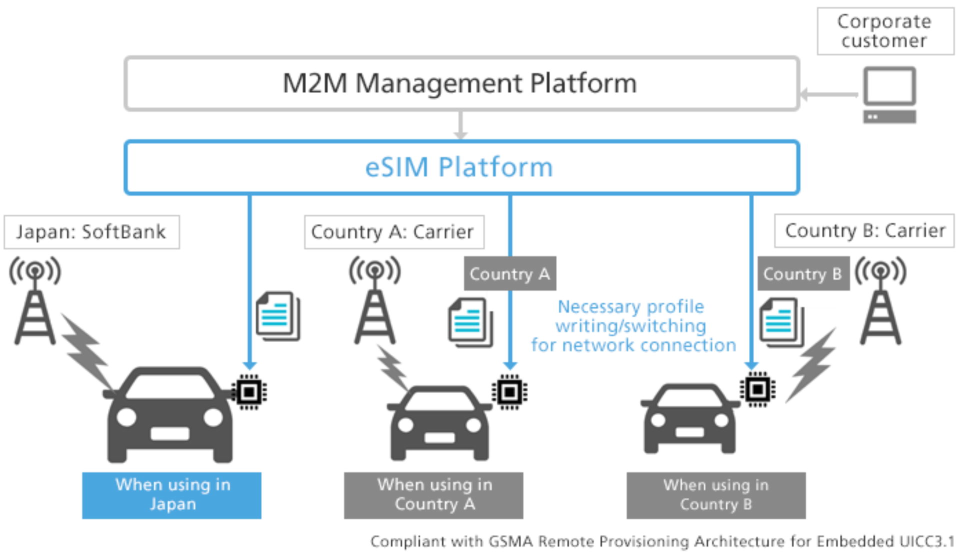
Fig 19 IPv4 vs IPv6

	Internet Protocol version 4 (IPv4)	Internet Protocol version 6 (IPv6)
Deployed	1981	1999
Address size	32-bit number	128-bit number
Address format	Dotted decimal notation (e.g. 192.111.72.1)	Hexadecimal notation (e.g. 4FFE:E300:B222:CD02:4321:5678:3402:ABCD)
Number of addresses	2^32 (~4.3 billion)	2^128 (340 undecillion: ~79 billion billion billion more than IPv4)

Source: Macquarie Research, March 2017

In tandem we expect vendors to offer solutions to ease the introduction of IoT devices and to ease their deployment and management – specifically, in areas such as provisioning and authentication, configuration and control, monitoring and diagnostics, and software updates. One example is the announcement by Softbank on 30 March that it is developing an embedded subscriber identity module (eSIM) platform that will allow remote provisioning/de-provisioning of IoT / machine-to-machine devices that contain already-integrated eSIMs.

Fig 20 Softbank's eSIM platform, to be deployed in 2017



Source: Softbank, March 2017

New paradigm for consumer electronics and services

The rise of the IoT is already transforming the CE industry

The rise of the Internet-of-Things is transforming the consumer electronics sector, notably by driving the trend towards “always-on” connections, use of AI/voice assistants (Apple’s Siri, Amazon’s Alexa, Google’s Assistant and Samsung’s Bixby), and growing adoption of digital streaming beyond consumer video.

Streaming is now restoring growth to the music market; in 2015, streaming revenues increased 45.2% YoY to US$2.9bn, quadrupling over four years and driving overall music market growth of 3.2%. Combined, Spotify and Apple Music paid subscribers exceeded 75 million in number earlier this year – doubling YoY.

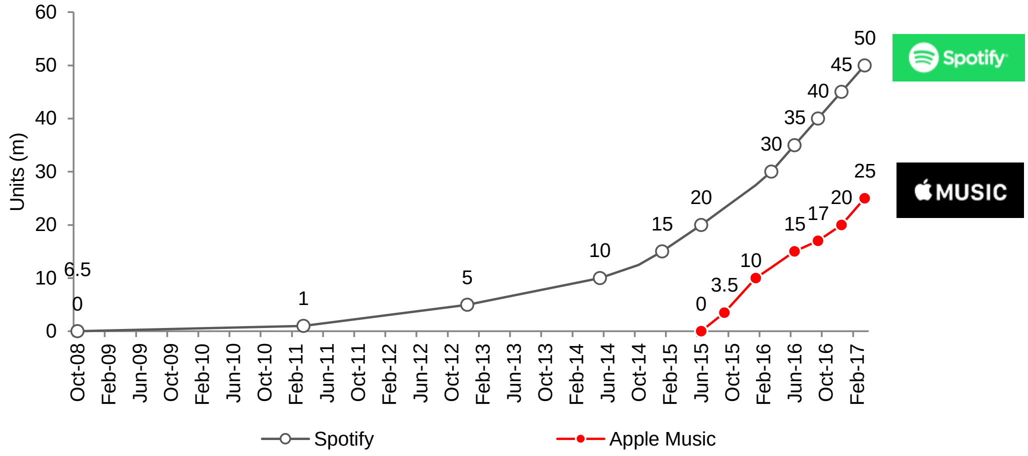
Fig 21 CE is being transformed by the rise of streaming

Source: Amazon, Sony, March 2017

Amazon has embraced the streaming paradigm with its Amazon Echo device and service, which combines voice recognition with digital services to expand the value of Amazon’s e-commerce and digital content platform. Over 8 million Echo devices have been sold since launch some two years ago. Google has since followed in 2016 with its own competing Google Home product.

We are also seeing greater impact of streaming in the video game industry. Sony’s PlayStation Now service continues to expand, and is now being extended to PCs and Macs. Meanwhile, Nvidia has unveiled their GeForce now cloud-based gaming service.

Fig 22 Apple Music vs Spotify subscribers



Source: Company data, Macquarie Research, March 2017

The rise of the Connected Car

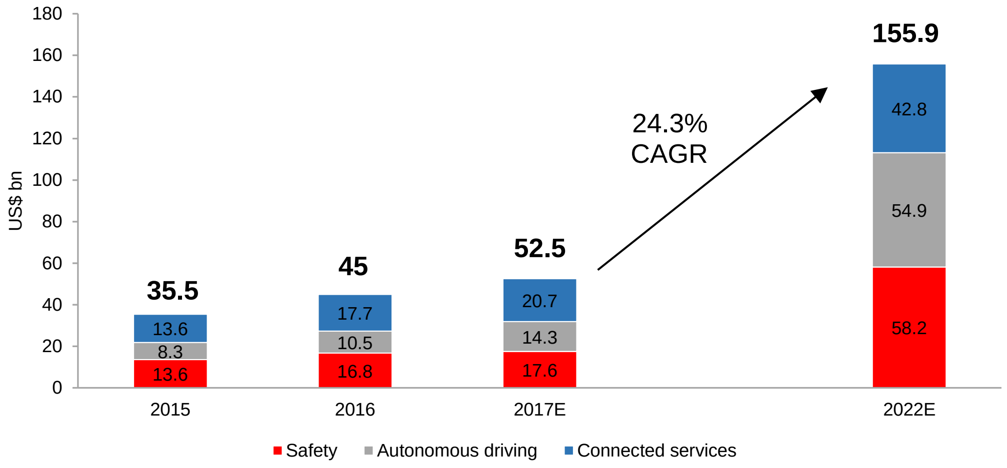
The Connected Car will become mainstream by the 2020s

The ubiquity of ever-faster wireless networks, and the prospect of lower latencies with 5G, will continue to drive adoption of wireless-enabled technologies in cars.

According to our US colleague Amy Yong, in 2015 ~15% of all vehicles produced were already 4G/LTE-enabled, with the ratio set to grow to 75% or more by 2020. Our colleagues have projected that this would open up the way to a sharply larger market (potentially US$60bn or more) for telematics and entertainment services alone.

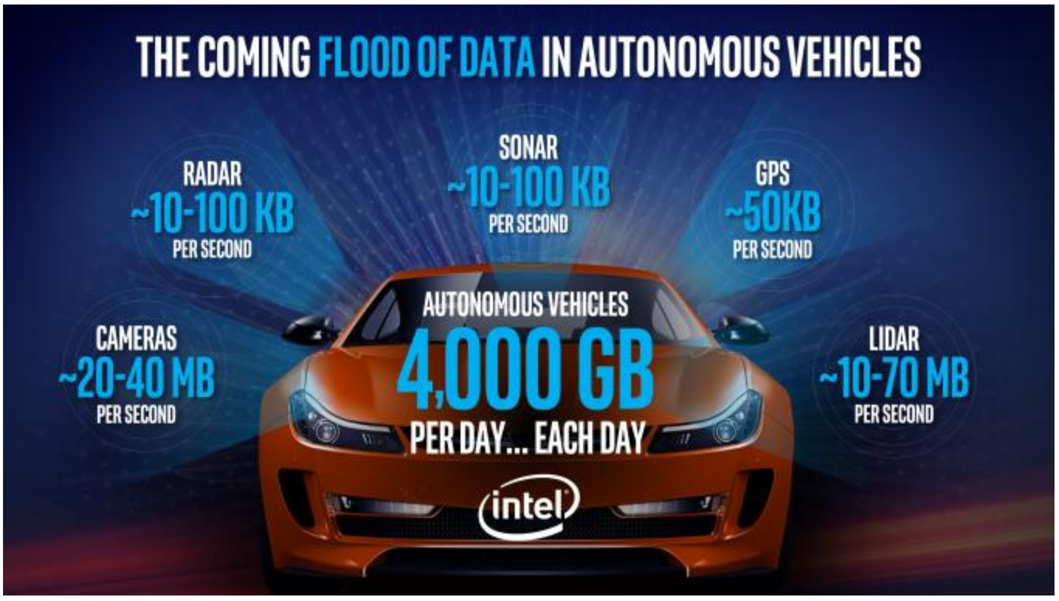
More recently PWC has forecast growth in the Connected Car market from US$52.5bn in 2017 to US$155.9bn by 2022 – a CAGR of 24.3%.

Fig 23 Connected Car revenues



Source: PWC data, Macquarie Research, March 2017

Fig 24 Autonomous vehicles will be prodigious data processing machines



Source: Intel, March 2017

Autonomous driving to follow

As highlighted by our colleague George Chang, the Connected Car is a stepping stone to more advanced driver assistance systems (ADAS) and then to self-driving capabilities. In the case of ADAS cars specifically, George forecasts a 50% CAGR between 2015 and 2020, with the number of ADAS cars sold annually to increase to 54 million units by 2020.

Automotive firms are harnessing technologies developed for the smartphone and PC markets and brought down to low cost due to immense production scale – image sensors, advanced displays, graphics processors and LTE mobile chipsets – to drive breakthroughs in vehicle capabilities. Digital cockpit / human-machine interface (HMI) systems are emerging as standard in luxury vehicles, and will become mainstream even in mass-market cars during the 2020s.

Meanwhile, cars will progressively acquire the computational power and sensing capabilities for ever-increasing autonomy. Intel has projected that a self-driving car will generate (and process) some 4TB of data every day (Figure 24), including 20-40MB/s in the cameras and 10-70MB/s in the case of LIDAR.

The above trends are challenging legacy players in the automotive supply-chain. As more value shifts towards suppliers of core electronic systems (e.g. processors and computer vision systems) like Intel, the scope for value-added further downstream diminishes. Automotive suppliers are responding by redoubling efforts in R&D, by acquiring technologies and firms, or by opening themselves up for acquisition (e.g. Samsung's acquisition of Harman).

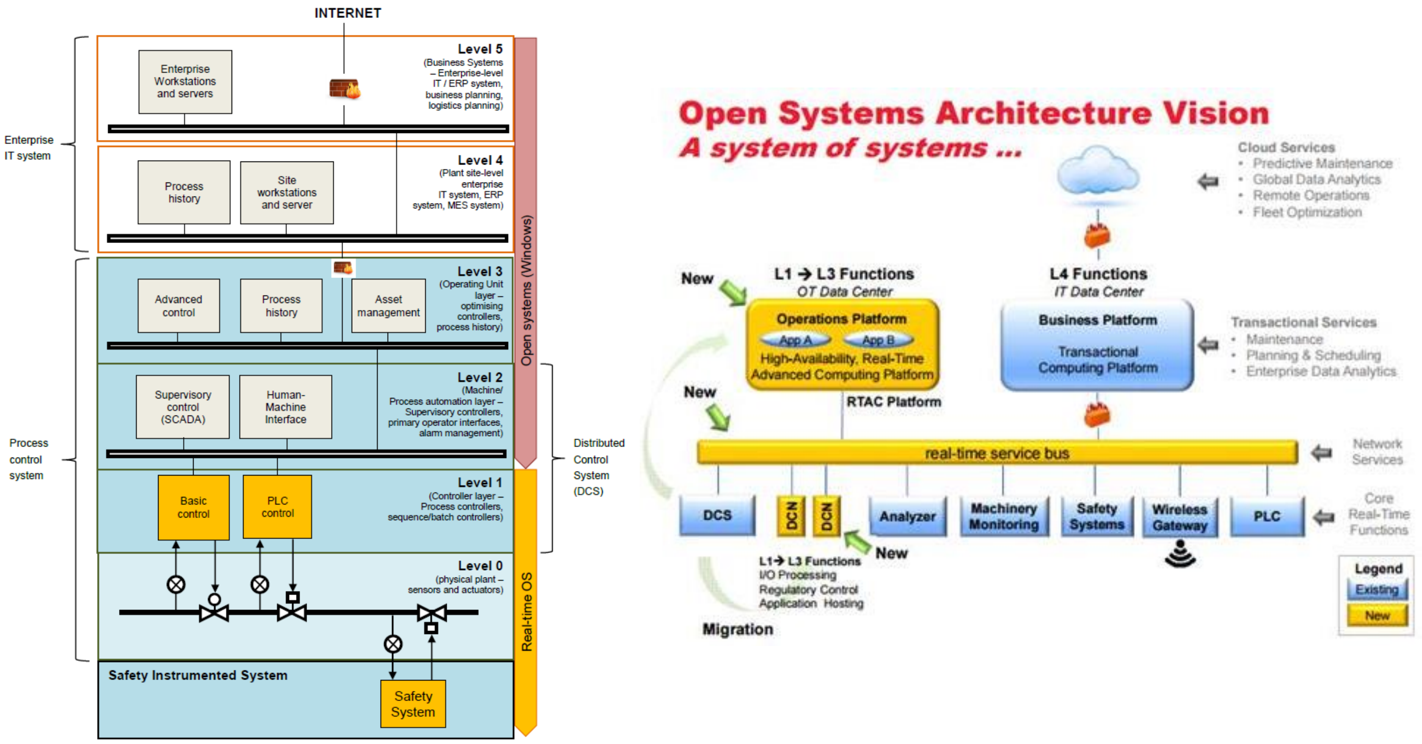
Digital disruption in Industry

Shift to open systems challenges legacy vendors

Technologies from the ICT world are now also disrupting manufacturing industries and traditional suppliers of manufacturing equipment. The biggest challenge, in our view, comes from the push towards open systems. This trend potentially curbs dollar spending on capex and shifts the expenditure away from established vendors of closed systems with proprietary hardware towards other suppliers, including producers of white-box hardware.

In 2015, we noted AT&T's push to re-architect their network based on software-defined networking (SDN)/network function virtualisation (NFV) technologies, involving use of open systems, virtualisation, and software API-based control. This has resulted in the development of ECOMP – AT&T's infrastructure delivery platform and a scalable, comprehensive network cloud service. More surprising, we saw ExxonMobil announce in February 2016 a project to develop a new open standards-based process automation platform. As shown below ExxonMobil is envisaging a less hierarchical and rigid automation system architecture, with easily replaceable components.

Fig 25 From a hierarchical closed system (left) to open systems



Source: ExxonMobil, Macquarie Research, March 2017

The disruptive promise of 5G

5G will unleash higher connection rates and dramatically higher device density

New technologies are enabling the push to 5G

To meet data for demand and to boost network operating efficiencies, telecom operators are now preparing for the roll-out of 5G networks in the 2020s, which are intended to provide for dramatic increases in network performance in combination with more efficient system management with the adoption of software-defined networking (SDN).

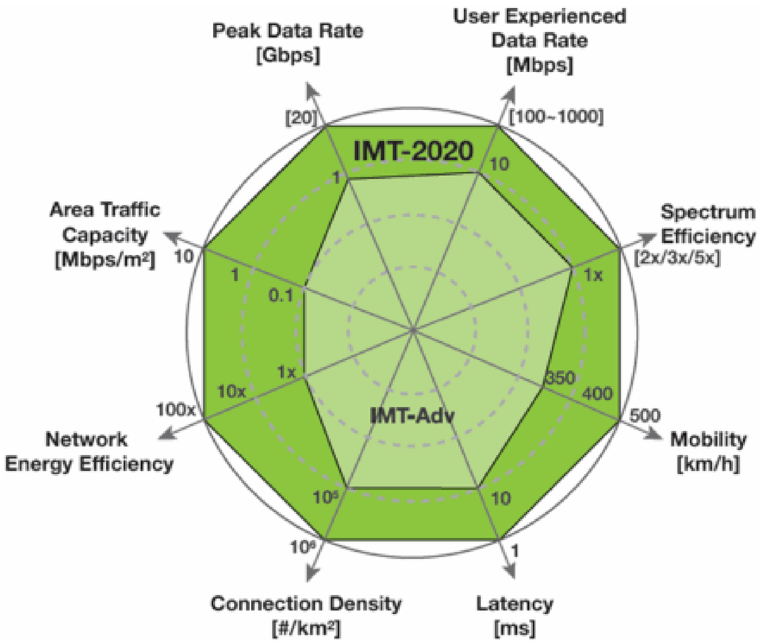
10x data rate and 10-100x more devices per square km

As highlighted by the February 2017 ITU draft report for IMT-2020 5G specifications, the targeted minimum technical requirements are as follows:

- Maximum achievable downlink peak data rate of 20 Gbits/s and uplink peak data rate of 10 Gbit/s per mobile base station. This compares with 1Gbits/s and 0.5Gbits/s, respectively, for LTE-Advanced (4G).
- Downlink user-experienced data rate of 100 Mbit/s and uplink user-experienced data rate of 50 Mbit/s – up to 10x greater than with 4G. The goal here is to ensure that users obtain high data rates as a matter of course rather than as a best-case.
- Area traffic capacity in downlink of 10 Mbits/s/m^2, ~100x greater than in the case of 4G.
- Minimum connection density of 1 million devices per square kilometer – i.e. 10-100x that achievable with 4G networks
- User plane latency of 4 milliseconds for “enhanced mobile broadband” and 1 millisecond for ultra-reliable and low-latency communications (URLLC). These are large improvements (vs 10ms for 4G), and will enable real-time remote operation of equipment and vehicles such as farming machinery and drones
- Control plane latency of 20 milliseconds, with recommendation for reduction to 10 milliseconds
- Support for mobility from “stationary” to “high-speed vehicular” (i.e. 120km/h to 500km/h), thereby improving connectivity within high-speed railcars

The improvements are summarised below.

Fig 26 5G will offer substantial gains in network performance



Source: ITU, Macquarie Research, March 2017

Fig 27 5G will offer substantial gains in network performance

		IMT-Advanced 4G	IMT-2020 5G
Maximum achievable peak data rate at base station, downlink	Gbits/s	1	20.0
Maximum achievable peak data rate at base station, uplink	Gbits/s	1	10.0
User-experienced data rate (dense urban), downlink	Mbits/s	10	100
User plane latency	ms	10	1-4
Control plane latency	ms	100	20
Connection density	devices/km^2	10K-100K	1 million
Area traffic capacity	Mbits/second/m^2	0.1	10.0

Source: ITU, Macquarie Research, March 2017

Rollout of 5G networks will be 'subsidised' by mobile video

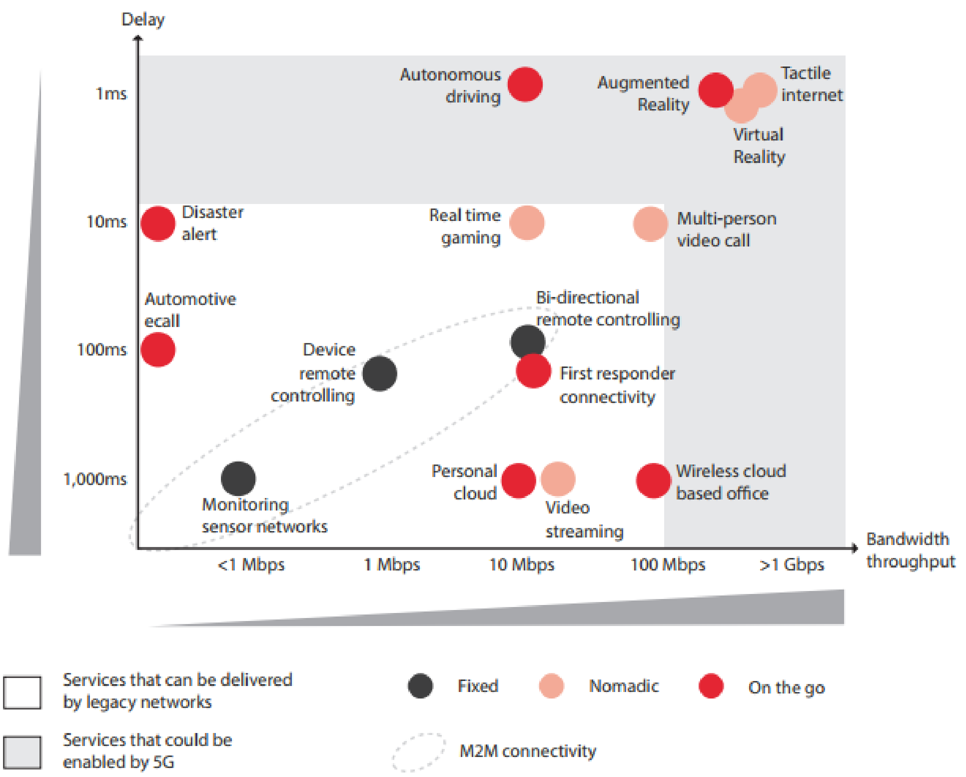
Mobile Internet video will provide the commercial justification for 4G and 5G investments, effectively 'subsidising' the roll-out of the infrastructure. But the network infrastructure will have much wider application once in place, backed by complementary technologies.

The ability of 5G to support 1 million devices per square kilometre (10-100x greater than with 4G) substantially expands the scope for a future "Internet-of-Things" to include a vast proliferation of sensors and data-collection systems.

In the earlier days of IT, data primarily comprised structured data inputted by humans into databases. However, in the Internet-of-Things, data is increasingly coming from real-world sources – potentially in real-time and in ever-shorter time intervals. This data will be used to feed machine learning/AI systems to drive operational decision-making and feedback.

In tandem, the low latency and high data rates possible with 5G networks will open up new applications, e.g. in the control of autonomous vehicles, the tele-operation of heavy machinery, and the remote monitoring and control of factories.

Fig 28 Low latency and high data throughput will expand the range of applications



Source: GSMA, March 2017

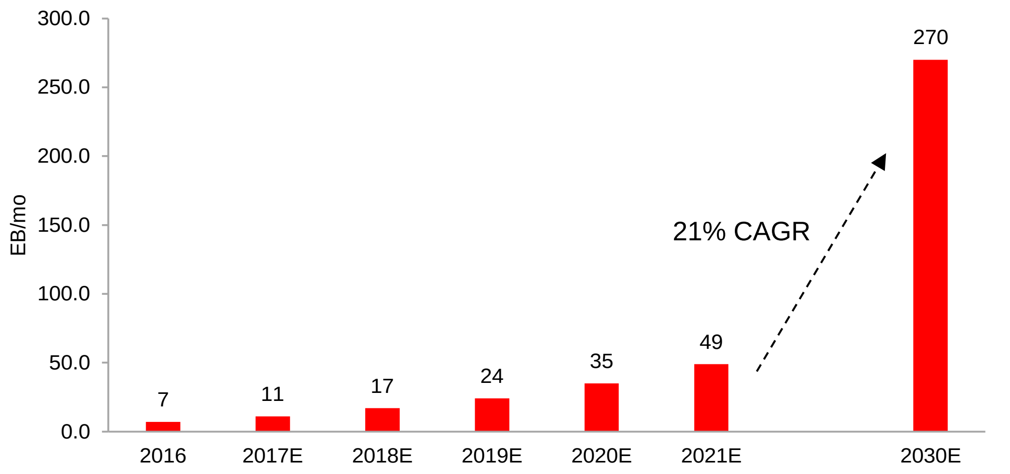
Adoption of 5G will still be very limited in 2020 but 5G may account for majority of data traffic by 2030

Adoption of 5G will remain limited in 2020-21; Cisco has projected that 5G will account for just 0.2% of connections in 2021 (25 million connections) and 1.5% of traffic. This compares to 4G with 53% of connections and 79% of total traffic.

However, by 2030 we expect 5G to account for the majority of data traffic, though the total number of connections may actually be dominated by lower-data rate IoT applications.

As it stands, Cisco is projecting that by 2021, a 5G connection will generate 4.7x the data traffic of a 4G connection – a gap that we expect to grow towards >8x by 2030. As such, we estimate that average mobile data traffic by 2030 may be 5.5x greater than in 2021 due to the 5G migration – implying a CAGR of 21%. Our forecast implies that mobile data traffic alone in 2030 of 270EB/mo will be three times more than total global data traffic in 2016 of 89EB/mo.

Fig 29 Mobile data traffic (Cisco VNI to 2021E, Macquarie for 2030E)



Source: Cisco data, Macquarie Research, March 2017

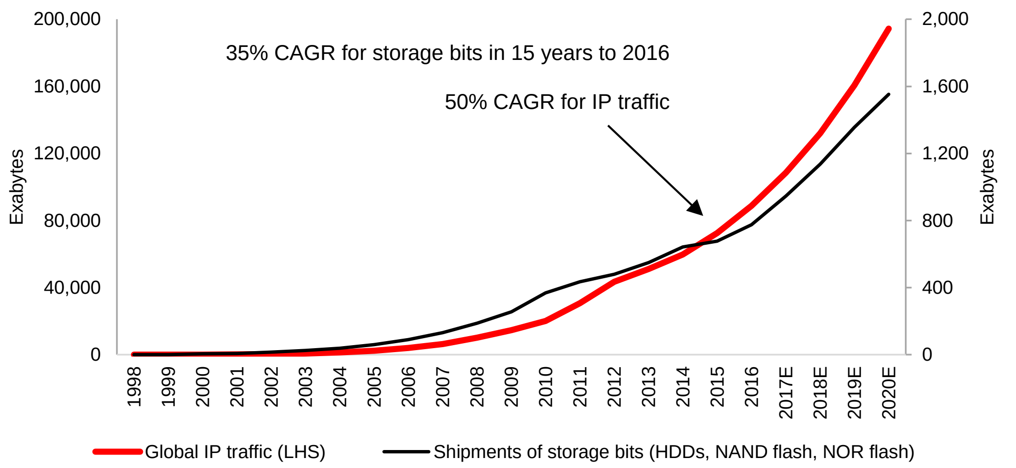
We expect substantial investments data processing/storage infrastructure

We see investments in areas ranging from data storage to machine learning

Over the next 10-15 years, we anticipate a step-up in spending on systems used to store and analyse the increasing quantities of data, as well as growing volume of systems that translate operational decisions into actions (from individual actuators to entire automated processes).

We accordingly expect stronger growth in processors (microprocessors, discrete GPUs and custom ASICs) as well as memories (notably flash memory used for low-latency data storage, as well as future storage-class memories). We provide forecasts in the next section.

Fig 30 Demand for storage bits has scaled with IP data traffic



Source: Gartner, Cisco data, Macquarie Research estimates, March 2017

The IoT opens the path to a US$500bn semiconductor market

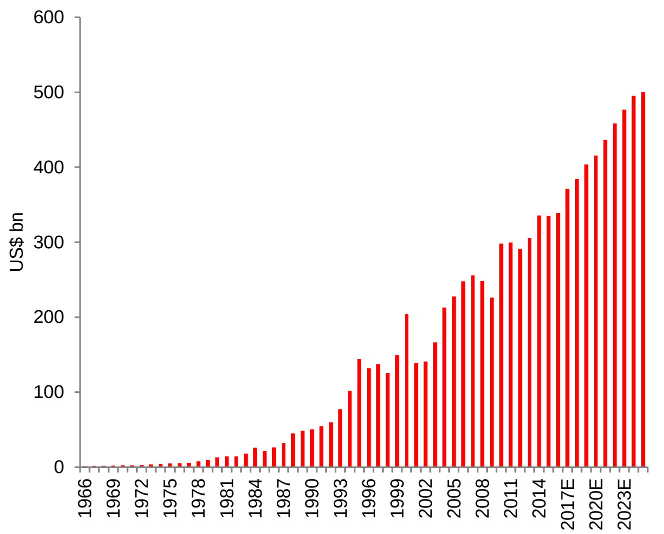
A US$500bn semiconductor market by 2025

We forecast a 4.4% market growth rate to 2025

We continue to view the semiconductor industry as foundational to global economic growth and technological advancement. As such, we expect the semiconductor market to grow significantly faster than global real GDP growth of 2.5-3.0%. Semiconductor shipments and silicon wafer growth are already outpacing growth in the production of steel and shipments of plastics (Figures 33-34), two other foundational materials of the world economy.

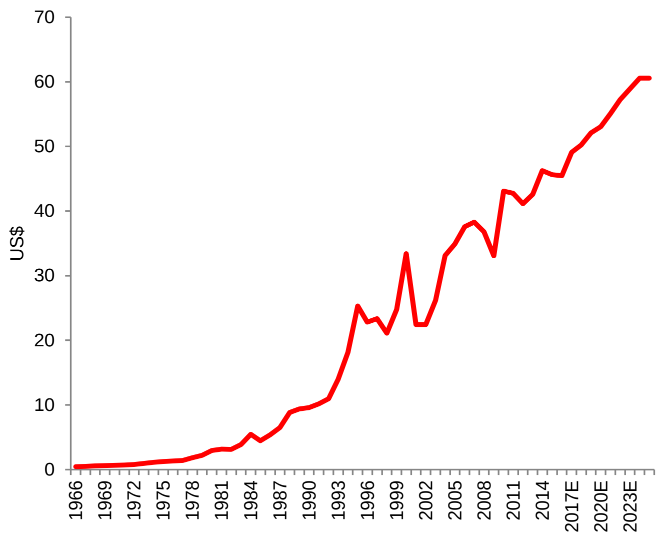
The semiconductor market reached US$399bn in 2016, and we forecast a 4.4% CAGR to 2025, faster than the 3.2% CAGR seen in 2007-2016. This implies a conservative 2.9% p.a. growth in per-capita semiconductor sales in 2015-2025 (Figure 32), broadly comparable to the 2.7% growth in the preceding ten-year period.

Fig 31 US$500bn semiconductors market by 2025



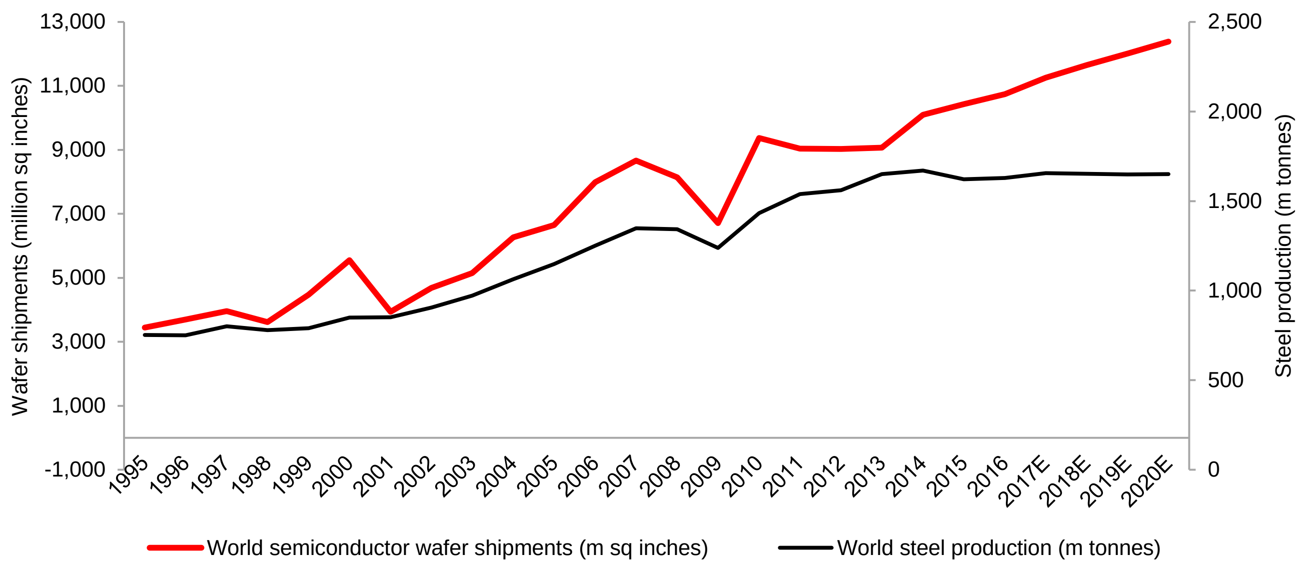
Source: WSTS data, Macquarie Research estimates, March 2017

Fig 32 Per-capita semis sales to exceed US$60



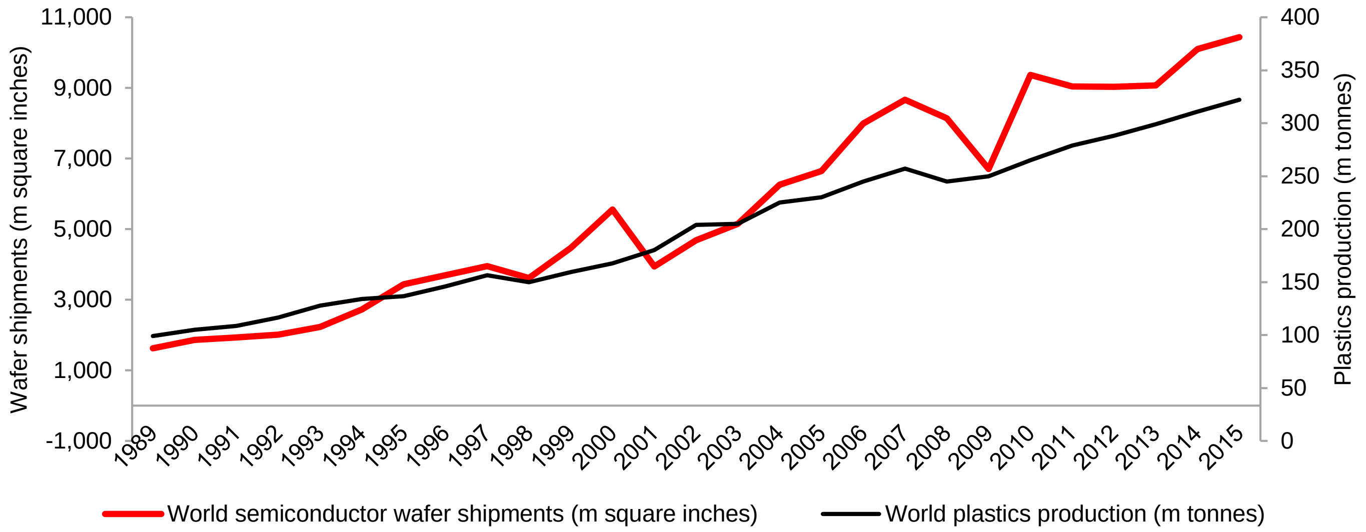
Source: WSTS data, Macquarie Research estimates, March 2017

Fig 33 Semiconductor silicon wafers – the key material for the Information Age – is outpacing steel



Source: SEMI data, World Steel Association data, Macquarie Research estimates, March 2017

Fig 34 Semiconductor silicon wafers outpacing plastics



Source: SEMI data, PlasticsEurope data, Macquarie Research estimates, March 2017

We approach the forecast from various directions.

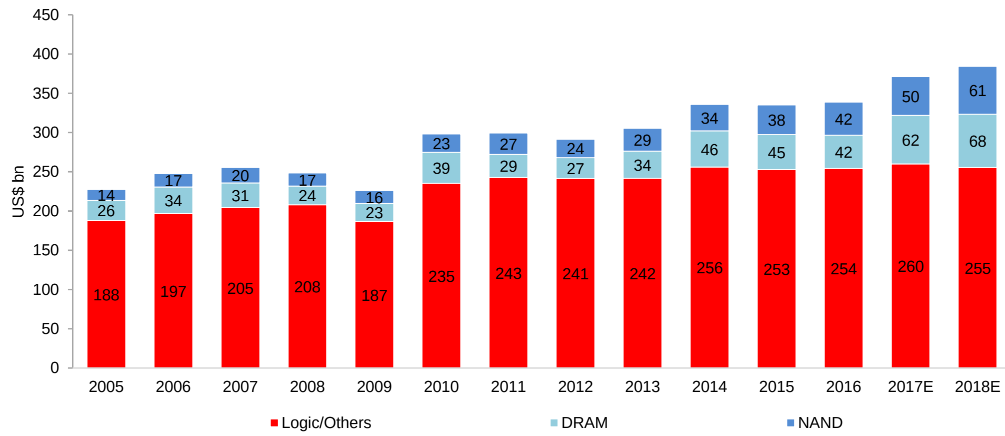
The team remains bullish on the outlook for semiconductor memories

A key component of our forecast remains robust expectations for semiconductor memory. Daniel Kim has just increased his forecasts indicating a DRAM+NAND flash market of US$129bn in 2018 – 11% above our February estimates and 52% above the US$85bn attained in 2016. Given this update, our semiconductor market forecasts for 2017-20 – which already include an above-consensus 9.5% growth estimate for 2017 – are under review.

As highlighted by our colleague Daniel Kim in his report *Memory Tracker – Sweet, sweet memory in 2017* (8 December 2016), adoption of 3D NAND flash is likely to accelerate displacement of hard disk drives in large-scale storage arrays due to superior data throughput, low latencies and high power efficiency. In 2010 NAND flash accounted for just 3% of all storage bits shipped, but the ratio will increase to 25% by 2020 (Figure 36).

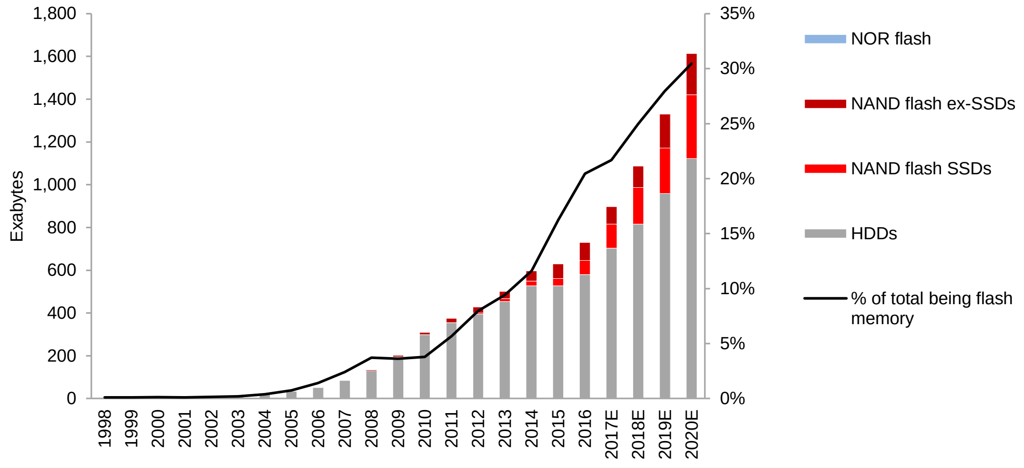
Robust data generation due to increasing activity tracking and a rising installed base of sensors is likely to fuel data storage demand, which will be linked also to continuing investments in datacentre capacity and new cloud services. In tandem, we expect strong demand for long-term data retention for commercial and legal reasons – e.g. Facebook now offers users the ability to capture, store and share videos on the timeline, which we expect to be accessible throughout the life of the user.

Fig 35 We expect strong growth in DRAM and NAND flash sales



Source: WSTS data, Macquarie Research, March 2017

Fig 36 NAND flash memory is capturing a larger and larger slice of the ever-growing storage market

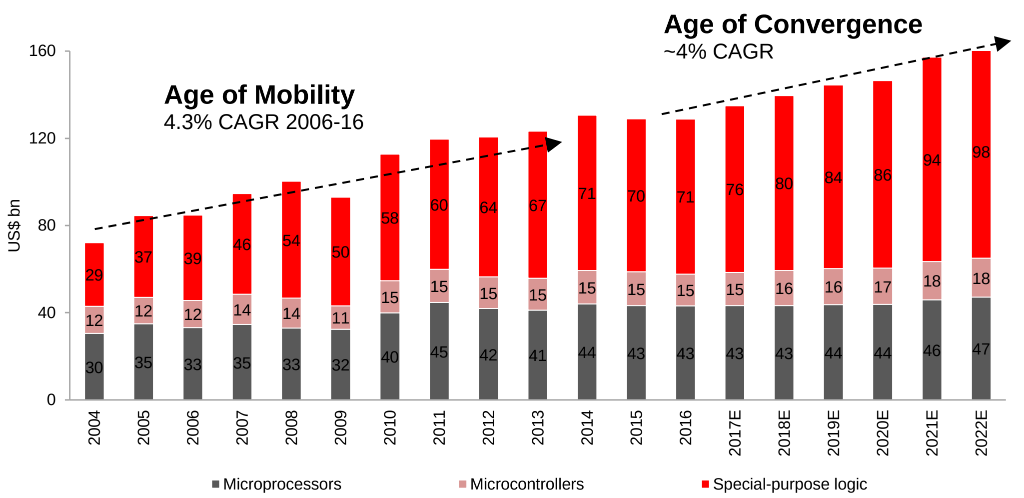


Source: Gartner data, Macquarie Research estimates, March 2017

We forecast a ~4% long-term CAGR in processors, with scope for upside

Meanwhile, we see sustained growth in demand for computational processing capacity to process the expanding flood of data. Within the ~3% growth in logic/others, we forecast ~4% growth in the WSTS classification triad of microprocessors, microcontrollers and special-purpose logic (including smartphone application processors and discrete GPUs). This conservative estimate is comparable to the 4.3% CAGR seen in the decade to 2016, and assumes comparable rates of data volume growth.

Fig 37 Sustained growth in demand for processing capacity



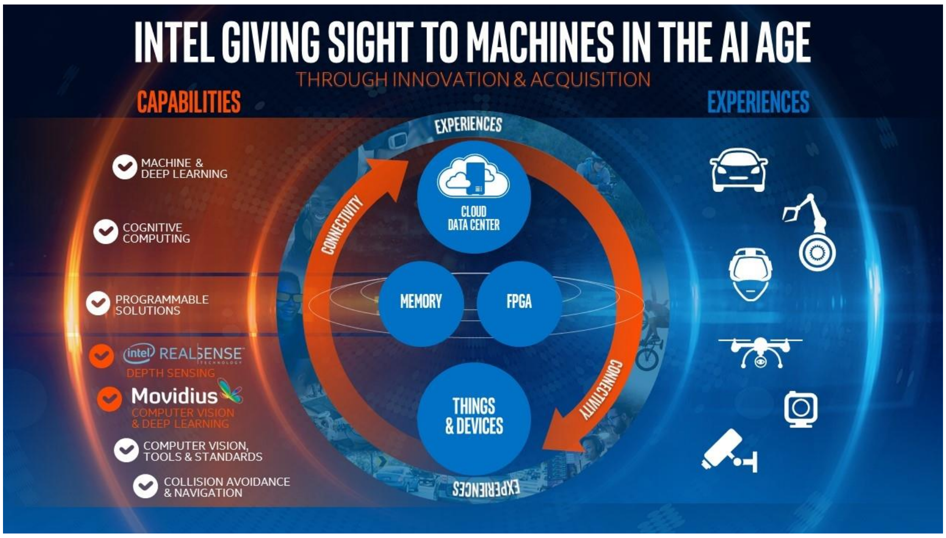
Source: WSTS data, Macquarie Research, March 2017

AI/deep learning provides for an enlarged market opportunity

On the one hand, we are encouraged by innovative deployment of consumer GPUs – originally developed for video gaming and brought to large production scale due to demand for gaming PCs and game consoles – into machine learning and AI. On the other hand, we see a continuing thrust by server processor leader Intel into the machine learning field; at its Investor Meeting in February, the company highlighted its positioning in a range of products for AI including its “Skylake” Xeon and “Knights Mill” Xeon Phi processors. Both developments are set to expand the market opportunity for processors.

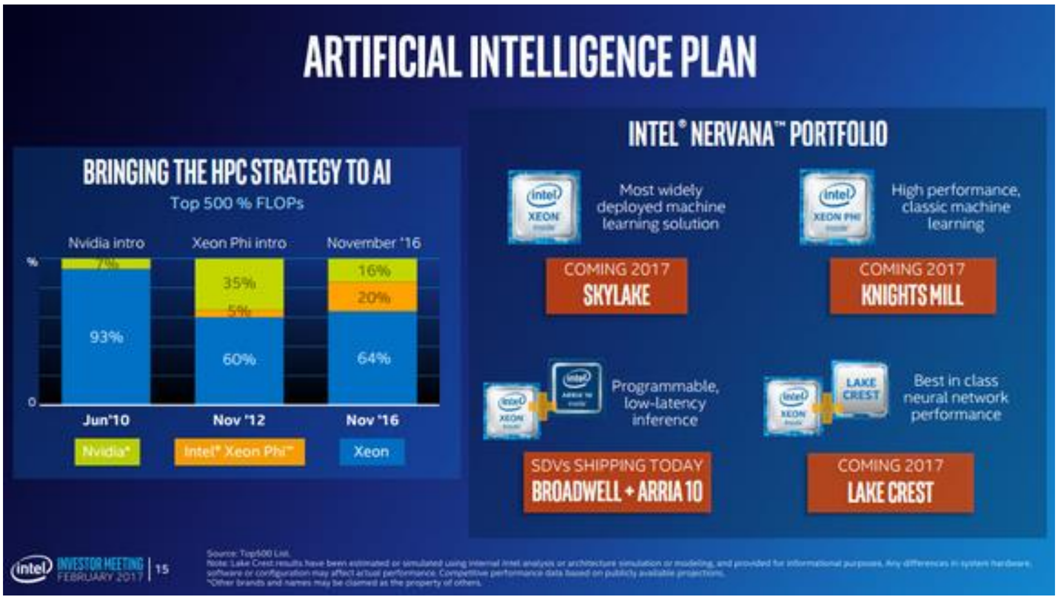
Intel is in fact taking a more direct approach in pursuing and developing applications for its processors, via acquisitions of SoC+application firms like Movidius – an emerging player in low-power, high-performance SoC platforms for accelerating computer vision applications – and Mobileye – a leading player in automotive machine vision solutions.

Fig 38 Intel's Movidius acquisition reinforced their position in machine vision



Source: Intel, March 2017

Fig 39 Intel's AI plan



Source: Intel, March 2017

The biggest market catalyst may come from the falling barriers to the use of AI due to efforts of Internet and software firms

Finally, and perhaps more notably, we see continuing efforts by software/Internet firms to make machine learning/AI accessible to a wider pool of companies and individuals, and relevant to a broader set of problems. These efforts include the development of software libraries and application programming interfaces (APIs), including open source offerings like Google's TensorFlow, and cloud-based services like Google's Cloud Machine Learning Engine backed by large investments in computing power.

For instance in November 2016, Microsoft and Nvidia announced that the former's GPU-accelerated Cognitive Toolkit would be available on its Azure cloud services and also would be offered for Nvidia DGX-1 servers. Meanwhile, at its recent Google Cloud Next event in February, Google showcased its Cloud Vision API and general availability of its Cloud Machine Learning Engine, while announcing that its customers would be able to access 64-core GCP virtual machines with up to 416GB of memory.

Other recent developments:

- In October 2016, Nvidia and FANUC announced a collaboration to implement AI on FANUC's Intelligent Edge Link and Drive (FIELD) system to increase robotics productivity and bring new capabilities to automated factories.
- In March, Facebook announced Big Basin, the successor to its Big Sur GPU server, which again uses Nvidia Tesla P100 GPUs. Facebook has already deployed thousands of Big Sur servers across its data centres to create an AI platform with 40 petaflops of distributed computing power. By comparison, the most powerful supercomputer today – the Sunway TaihuLight at China's National Supercomputing Center in Wuxi – peaks at 125 petaflops.
- On 6 March, Nvidia and Fujitsu announced that Fujitsu would use 24 Nvidia DGX-1 servers (and 32 Fujitsu Primergy RX2530 M2 servers) to build a 2 petaflops-capable "Deep Learning System" for Japan's RIKEN.
- On 24 March, Nvidia announced that Tencent would use its Tesla P100, P40 and M40 GPUs to deliver cloud-based AI services for enterprises.
- On 8 March, Nvidia and Microsoft announced chassis blueprints for a new open source Tesla P100-based hyperscale GPU accelerator – the HGX-1. This has been developed in conjunction with Microsoft's Project Olympus hyperscale computing initiative under the Open Computer Project.

Fig 40 Facebook's Big Sur AI computing system – Eight NVIDIA M40 GPUs in a 4U rack chassis

Source: Gartner data, Macquarie Research, March 2017

Fig 41 RIKEN's "Deep Learning System" – Capable of 4 petaflops

Source: Gartner data, Macquarie Research, March 2017

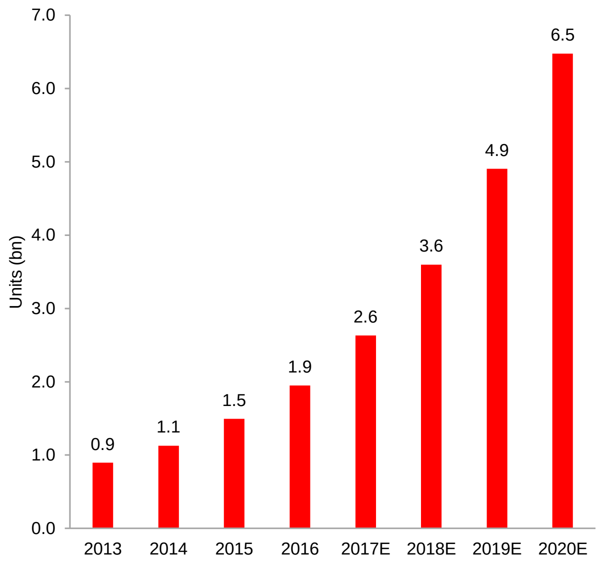
Our estimates looks conservative relative to Gartner and Cisco's 30%+ growth expectations for IoT endpoint units

From yet another perspective, our semiconductor market growth forecast can be seen to be conservative relative to recent market forecasts for IoT end-points. Gartner has for instance forecast a robust 35% CAGR for end-point shipments from 1.95bn units in 2016 to 6.48bn in 2020, driving the installed base up 34% p.a. from 6.4bn units to 20.4bn units.

Gartner sees IoT end-point hardware spending across all categories is projected to increase at a 21% CAGR from US$1.38tr in 2016 to US$2.93tr in 2020. Even assuming no growth in non-IoT hardware, the implied growth rate for all IT hardware seems to be ~10%. Our estimate is conservative relative to Gartner's projections.

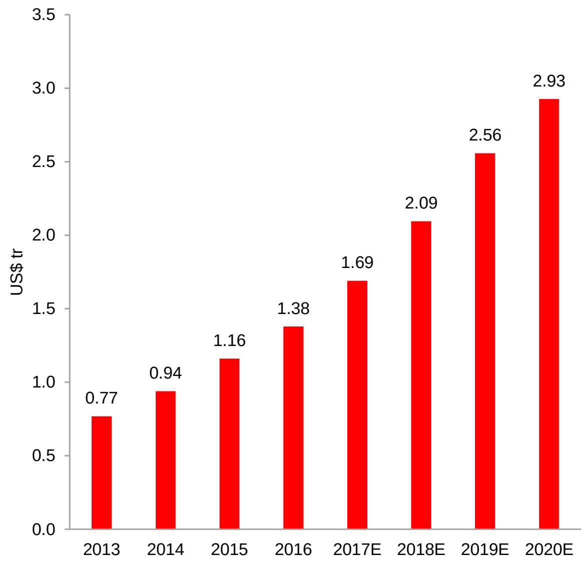
Meanwhile, Cisco has projected an installed base of 11.6bn mobile-connected devices by 2021, up from 8bn in 2016. This is more conservative than Gartner, but we note that net unit growth must still average at ~30% p.a. to attain Cisco's 2021 forecast. Cisco's forecast maps to their projection of a 47% CAGR for mobile data traffic in 2016-21.

Fig 42 IoT endpoint shipments, 2013-20E



Source: Gartner data, Macquarie Research, March 2017

Fig 43 IoT endpoint hardware spending, 2013-20E



Source: Gartner data, Macquarie Research, March 2017

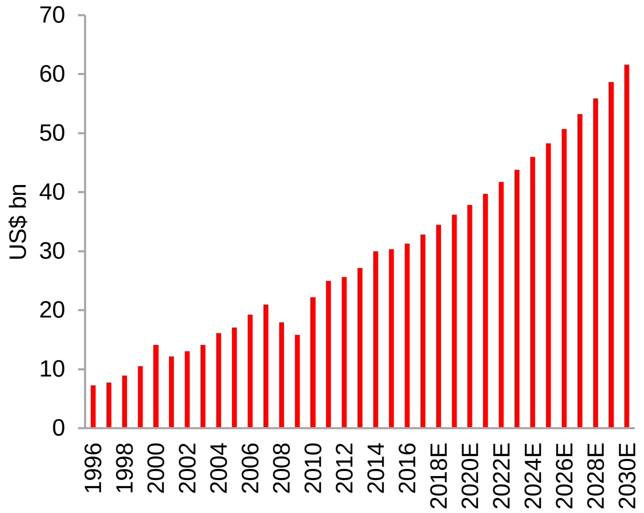
We expect automotive semiconductors growth (5% CAGR or higher in 2016-2030) to be a key driver

A final perspective is from the standpoint of automotive semiconductors – one of the market areas where we see faster growth than the overall market. Our baseline assumption is a 5.2% CAGR to 2030, taking the market to over US$60bn. We note that Intel has targeted a US$70bn market, implying a 6% CAGR. The difference is likely down to assumptions on the pace of adoption of advanced computing power/self-driving capabilities in the car.

Our estimates imply a 30% increase in semiconductor content/car between 2015 and 2025, to US$435/car. This is slightly faster than the 25% increase seen between 2005 and 2015. By 2030 the semiconductor content per car is likely to reach US$500-550 – some ten times that in the average mobile handset today.

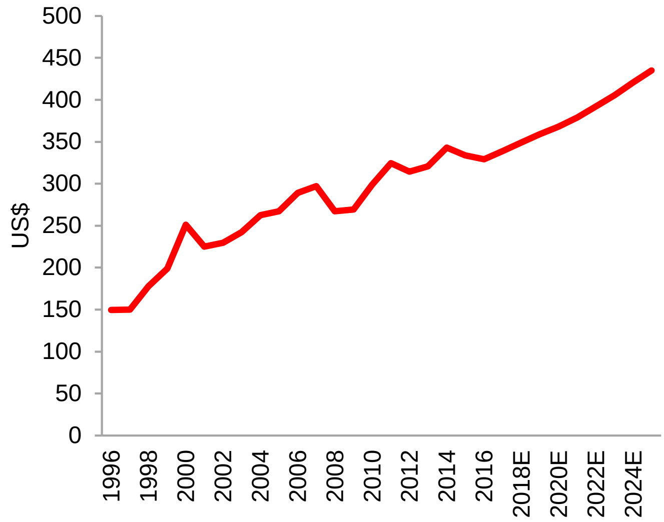
Apart from a boost from upgrades to the core processing capacity of cars, we see an uplift in semiconductor content from growing use of image sensors (from one or two image sensors per car to three or more by 2021 and likely even more by 2030), radar and lidar devices, and continuing adoption of advanced LED lighting (as highlighted by George Chang in his recent report *Japan auto lighting – Light in the fast lane*, 22 March 2017).

Fig 44 Automotive semiconductors market, 1996-2030E



Source: Gartner data, Macquarie Research, March 2017

Fig 45 Automotive semiconductors content per vehicle to reach US$435 by 2025



Source: Gartner data, Macquarie Research, March 2017

Strong support for chip sector capex and materials demand

We see chip sector capex rising to new highs

Based on the strong orders exiting 2016 and robust outlook for semiconductor market growth, we believe the semiconductor production equipment (SPE) market will grow 15% in 2017 to US$47.6bn – led by memory sector capex – and then 10% in 2018 to a record US$52.5bn, and finally peak in 2019 at US$55bn (*SPE sales to hit record high in 2018*, 16 March 2017).

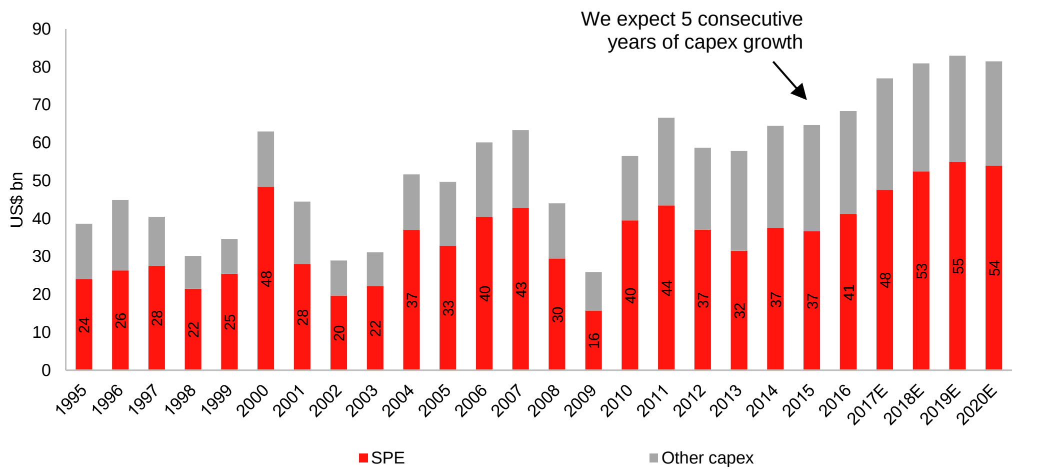
In addition, we expect China to be a major driver of SPE demand from 2018. We expect China to become the second-largest SPE market worldwide in 2018 (after Korea), and become the largest market by 2020. We see China accounting for over 25% of global chip sector capex by 2020, vs 15% in 2015.

Capex intensity tends to rise at the start of a new Age, and we expect a similar pattern now

As we highlight in Figure 47, the start of past 'Ages' have tended to see a pick-up in capex intensity, triggered by the chip industry's rising optimism regarding growth. We expect a similar pattern at the start of the Age of Convergence.

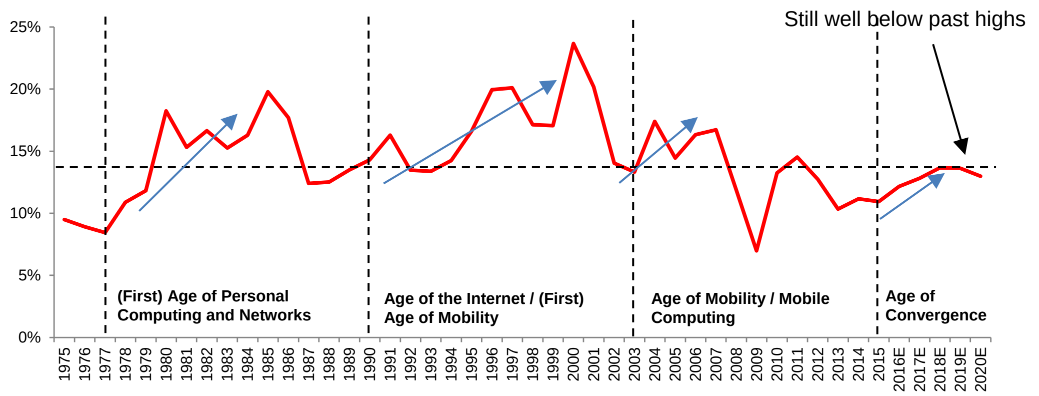
An acceleration of capacity additions and rising production in turn is favourable for suppliers of materials for chipmaking. As we have highlighted in our company reports for SUMCO, Shin-Etsu and GlobalWafers, we forecast wafer shipment area growth of 3-4% per year, with 300mm wafers specifically increasing from 5.2m units/mo in 2016 to over 6m units/mo by 2020. Given the absence of significant capacity expansion in the industry for many years, the wafer market has been running tight since 2016, resulting in the onset of price hikes.

Fig 46 We see chip sector capex attaining new highs in 2017-2019



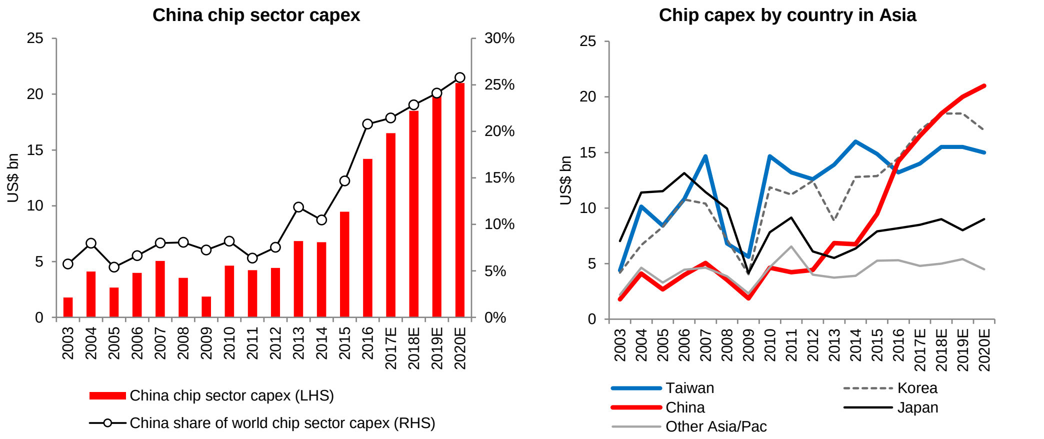
Source: SEMI data, Gartner data, company data, Macquarie Research estimates, March 2017

Fig 47 Capex intensity (SPE sales / semiconductor sales)



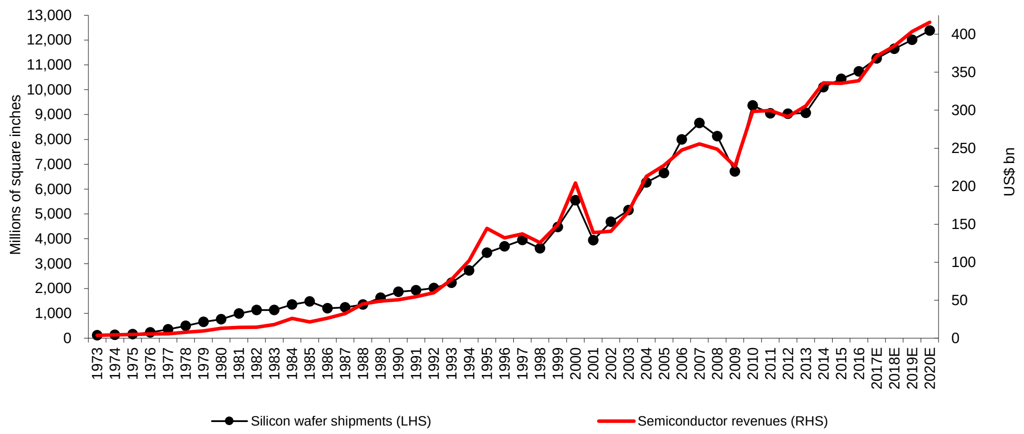
Source: WSTS data, SEMI data, Macquarie Research, March 2017

Fig 48 China may become the largest driver of chip sector capex by 2020



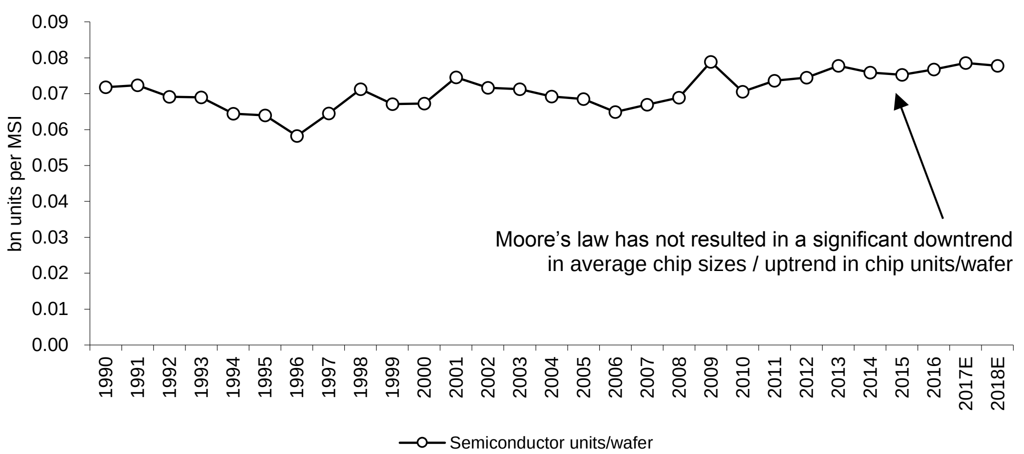
Source: SEMI data, Macquarie Research, March 2017

Fig 49 Wafer demand will track semiconductor sales



Source: WSTS data, SEMI data, Macquarie Research, March 2017

Fig 50 Semiconductor units/wafer – essentially a stable trend i.e. no net impact on wafer shipment volumes from circuit miniaturisation



Source: WSTS data, SEMI data, Macquarie Research, March 2017

Important disclosures:

Recommendation definitions

Macquarie - Australia/New Zealand
Outperform – return >3% in excess of benchmark return
Neutral – return within 3% of benchmark return
Underperform – return >3% below benchmark return

Benchmark return is determined by long term nominal GDP growth plus 12 month forward market dividend yield

Macquarie – Asia/Europe
Outperform – expected return >+10%
Neutral – expected return from -10% to +10%
Underperform – expected return <-10%

Macquarie – South Africa
Outperform – expected return >+10%
Neutral – expected return from -10% to +10%
Underperform – expected return <-10%

Macquarie - Canada
Outperform – return >5% in excess of benchmark return
Neutral – return within 5% of benchmark return
Underperform – return >5% below benchmark return

Macquarie - USA
Outperform (Buy) – return >5% in excess of Russell 3000 index return
Neutral (Hold) – return within 5% of Russell 3000 index return
Underperform (Sell)– return >5% below Russell 3000 index return

Volatility index definition*

This is calculated from the volatility of historical price movements.

Very high–highest risk – Stock should be expected to move up or down 60–100% in a year – investors should be aware this stock is highly speculative.

High – stock should be expected to move up or down at least 40–60% in a year – investors should be aware this stock could be speculative.

Medium – stock should be expected to move up or down at least 30–40% in a year.

Low–medium – stock should be expected to move up or down at least 25–30% in a year.

Low – stock should be expected to move up or down at least 15–25% in a year.
* Applicable to Asia/Australian/NZ/Canada stocks only

Recommendations – 12 months
Note: Quant recommendations may differ from Fundamental Analyst recommendations

Financial definitions

All "Adjusted" data items have had the following adjustments made:
Added back: goodwill amortisation, provision for catastrophe reserves, IFRS derivatives & hedging, IFRS impairments & IFRS interest expense
Excluded: non recurring items, asset revals, property revals, appraisal value uplift, preference dividends & minority interests

EPS = adjusted net profit / efpowa*
ROA = adjusted ebit / average total assets
ROA Banks/Insurance = adjusted net profit /average total assets
ROE = adjusted net profit / average shareholders funds
Gross cashflow = adjusted net profit + depreciation
*equivalent fully paid ordinary weighted average number of shares

All Reported numbers for Australian/NZ listed stocks are modelled under IFRS (International Financial Reporting Standards).

Recommendation proportions – For quarter ending 31 December 2016

	AU/NZ	Asia	RSA	USA	CA	EUR	
Outperform	57.53%	50.72%	45.57%	42.28%	60.58%	52.79%	(for global coverage by Macquarie, 8.71% of stocks followed are investment banking clients)
Neutral	33.90%	33.97%	43.04%	50.11%	37.23%	35.62%	(for global coverage by Macquarie, 8.05% of stocks followed are investment banking clients)
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