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Equity Research
Industrials
Robotics

AHEAD OF THE CURVE SERIES™

DEUS EX MACHINA, PART I

DECEMBER 6, 2018

Industrial robotics is a nearly $50B global market growing at a roughly 15% CAGR, dominated by large, non-US suppliers out of Japan and Europe.

Increasing global demand for more complex products and rising emerging market wage trends support continued robotic investment - not necessarily at the expense of total jobs.

China is the largest demand market, but only just recently claimed the widest installed base. Emerging Asia rapidly expanding as trade fears drive supply chain retooling.

Subsequent reports will focus on warehouse and collaborative robotics, two developing markets with exciting early stage investment opportunities and a fragmented landscape.

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INDUSTRY UPDATE

December 6, 2018

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DEUS EX MACHINA, PART I - AHEAD OF THE CURVE SERIES + COWENVISION VIDEO

THE COWEN INSIGHT

Part I of a collaborative, multi-part series examining the global robotics landscape. As robots continue to evolve from programmed pieces of hardware used to accomplish simple tasks towards vision based, adaptive tools to increase broader process efficiency, it opens up new investment opportunities in a rapidly changing environment that is being defined today. Part I focuses on industrial robots.

Global Megatrends Ultimately Will Require Increased Robotic Investment - Landscape Combines Multinational Powerhouses and Innovative Upstarts Ripe for New Investment

A rising global middle glass demands more complex, customized, higher precision products. Consistent wage inflation in traditional manufacturing centers supports the call for increased robotic deployment both on a gross basis and in terms of density (robots per 10k workers). Advances in robotic capability and affordability, coupled with decreased leverage from foreign labor as wages scale support a potential re-shoring of manufacturing towards traditional importers of products (like the US) and more regionalized production bases as power cost begins to replace baseline labor cost as the hinge variable. Across the manufacturing landscape, a lack of skilled labor is highlighted as a bottleneck, and a recent study by Deloitte and The Manufacturing Institute calls for 2.4MM unfilled manufacturing jobs by 2028 (despite continued robotic deployment). E-Commerce trends exacerbate the issue - for scale, in the US alone over 10B hours per year are spent shopping at grocery stores - if this is shifted away from individuals and towards fulfillment how is that accomplished? It would require essentially every unemployed person in the country 16 years and older working 40 hours a week to satisfy that demand.

The robotics landscape is both old and new, established and developing. Industrial robotics - the focus of this report - forms the backbone of the industry - a ~$50B global market growing in the mid teens dominated primarily by large Japanese and European players with a focus on automotive and electronics industries. Warehouse / logistics robots and collaborative robots represent emerging sectors (in addition to the $50B industrial market) with far more market fragmentation and likely corporate action over the next several years. These will be the focus of upcoming reports as part of the series we launch here.

There is Clearly a Major China Story, but it's Much More Nuanced and Complex Than One Might Think; Emerging Asia Stepping In Meaningfully

China is the global leader in robotic demand at nearly 40% of the 421k units estimated shipped in 2018 by the International Federation of Robotics (IFR) - more than Japan, Korea, the US, and Germany (the next largest) combined. However, despite consistently strong annual demand, China only recently surpassed Japan as the region with the largest installed base (nearly 500k installed industrial robots out of IFR's 2017 global estimate of ~2.1MM). At an estimated 97 installed industrial robots per 10k manufacturing employees, IFR sees China only slightly above the global average of 85 in terms of robotic density - roughly 2x below the US and 7x below South Korea. That suggests that each 1 robot added per 10k employees in China would represent an incremental 1+% to global demand. Given China's position in global auto and electronics markets - the most dense by application - expansion here is likely and should help offset cyclical dynamics to some extent.

Global trade tensions with China have forced multinational companies to re-contemplate existing supply chains and evaluate other low cost manufacturing countries. Vietnam, for example, saw robotic investment move from an average of <400 multipurpose robots annually over 2012-2015 into the 7th largest robotics market in the world in 2017 at over 8k units. That is a 12x change in market share vs. 5 years ago.

While there is likely to be a reversion, we note that robotic installed base in Vietnam is still only 1/3 that of Thailand and that Vietnam, Malaysia, and Thailand combined (3 countries highlighted by several companies as benefiting form China trade tension) have a total installed ~10% that of China. Should rhetoric escalate, the call for increased investment in jurisdictions like this seems compelling.

Newest Applications Combine Machine Vision, Automation, Artificial Intelligence, and Cloud Based Analytics as the Value Moves Away From Traditional Robot Arms

Differentiating characteristics within the robotics sector continues to evolve as new technologies are brought to market - this is no longer strictly a hardware focused decision for customers. High-end solutions today typically involve elements spanning vision, automation, AI, IIoT, etc. where traditional market boundaries are eroding and more complex corporate partnerships are increasingly common. Investment to broaden capabilities is likely (for example ROK recently invested $1B in PTC and has partnerships with companies like Fanuc, MSFT, CSCO, etc.) and siloed business models seem more challenged. Over time (and discussions we've had with manufacturers and users at several trade shows support this view), the robot itself will become more commoditized and the value will be driven by its application / integration into a broader automation / analytics platform. Whereas historically "blind" robots moved according to specific programming language, deployment of 2D vision and now 3D vision with AI capability and cloud connectivity has created new value streams that suppliers of each aspect will likely battle to provide.

We are now entering the new era of AI computing and we should expect a very rapid pace of change over the next decade. Within Computer Vision, several applications are emerging including automatic inspection of manufacturing facilities using drones; mechanical process automation using industrial robots; visual surveillance; medical image analysis & diagnostics; navigation for autonomous vehicles and much more. We think that Computer Vision, when combined with Deep Learning models embedded within machines/equipment/devices, could have major disruptive impacts in many industries such as transportation, manufacturing, agriculture, healthcare and logistics.

Diverging Views on Social Ramifications - Are Robots Job Destroyers?

Robots replace humans in certain applications by definition, but the true impact to jobs is harder to determine. In the US, manufacturing jobs have consistently declined as a % of total employment from a high of nearly 40% during WWII to 8.5% currently. We'd argue this trend was much more the result of a long-term move towards outsourcing production to lower cost countries rather than a shift from humans to robots.

According to the IFR, we've seen a near tripling of the robotic installed base in the US since 2004, and since that time manufacturing job openings as a % of total manufacturing jobs have doubled (currently at the highest level since 2000) and has held relatively steady vs. total job openings despite a 300bps decline in total relative employment. Hiring in the manufacturing sector over the past 5 years has averaged 8.5% vs. <5% for the total private sector and despite the most manufacturing hiring this year since 2007, the spread of openings over hiring stands at the widest we've seen with data back through 2000. US manufacturing wage growth, which lagged total private sector growth by ~40bps a year, on average, over the past 10 and 20 years, has been outpacing the private sector over the past 3 years. Evidence of re-shoring is supporting manufacturing employment metrics, but the data in totality suggests a stable core despite continued robotic deployment.

The critical question that needs to be addressed is the skills gap - as relatively simple, repetitive tasks are replaced by robots and new opportunities are created at higher levels, is the labor pool there to fill them? Continued re-shoring opportunities likely depend on it and the answer, at least at this point, is certainly not a clear yes.

Executive Summary

Key Investment Considerations for PMs

1. Robotics combines well established global markets (industrial – the focus here) with emerging, evolving, fast paced ones (warehouse/logistics, collaborative) that we will dive into in subsequent reports. (link)
2. Provides access to build outs of emerging production centers – potentially critical as supply chains are retooled in response to global trade tensions. (link)
3. Robotics investment should grow faster than spending in underlying markets and provide an element of offset as efficiency measures are targeted in down cycles. (link)
4. Can be viewed as an epicenter of cutting edge investment across multiple powerful themes: electrification, vision, AI, automation, cloud analytics – all of which are deployed in robotic platforms. (link)
5. Large scale transition from labor to robotics generally comes with negative near-term job implications and requires re-training to fill skills gaps. (link)
6. From the US standpoint, we are almost strictly importers of robotic content – with domestic production immaterial on the global scale. (link)

With today's report, we embark on a deep, multi-part look at the global robotics sector – a logical extension of our work to date on themes like industrial automation, advanced machine vision, and sensors & connectors. We collaborated with Cowen's Software team for context on emerging artificial intelligence applications and see this space as another (like automation) where lines between sectors are blurring. We believe robotics, and the Industrial Internet of Things applications stemming from it, will be at the core of industrial innovation for the foreseeable future and ultimately redefine how we manufacture products, fulfill E-commerce demand, and interact with machines. Part I of our series focuses on industrial robotics, which at roughly $50B globally (including related systems), is by far the largest and most well-established. Subsequent reports will examine the warehouse/logistics market (we had several leaders on a panel at our recent Industrial Innovation & Technology Summit – see here) and the collaborative sector – both of which are rapidly developing.

The industrial robotics landscape is fairly consolidated, both in terms of OEMs and markets deployed. Production is dominated by roughly 10 or so global players, predominantly in Japan and Europe, 75% of global demand and installed base comes from the top 5 markets (China, Japan, Korea, US, and Germany), and 60-65% collectively from the automotive and electronics industries. The IFR estimates that global demand for industrial robots will increase at a ~14% CAGR through 2021, with fairly balanced percentage growth across major geographic regions, but with Asia supplying 80% in gross terms (largely consistent with existing market share). While these estimates are certainly at risk to cyclical macro changes, low robot density in China (despite a large total installed base it sits just above the global average and multiples behind the leaders), consistently inflating emerging market wages, and a scramble to mobilize non-China supply chains in light of recent geopolitical maneuvering support a more fundamental investment case and growth thesis. As low cost labor prices continue to move higher, robotics become more cost effective, and tax regimes become more globally consistent, it opens up discussions about re-shoring and localized production bases – where the decision on where to produce becomes less about labor cost and more about high-end labor availability and electricity cost.

Any meaningful discussion about robotics is incomplete without a corresponding look at embedded intelligence, vision capabilities, end-effectors/accessories, and connectivity / analytics – where we expect the value of the total solution to ultimately gravitate. Artificial Intelligence, and the many technologies associated with it, has advanced more in just the last few years than in the last few decades, and commercial focus on AI is now mainstream. Affordable storage infrastructure (i.e. IaaS), high-density processing power (i.e. GPUs), democratization of algorithmic models (i.e. Tensorflow) and access to vast amounts of data are the major ingredients to the proliferation of new AI- and automation-based applications. Furthermore, advancements in computer vision, speech recognition and natural language processing technologies are key catalysts in streamlining communications between machines and humans and physical and digital paradigms. The ability to leverage these new capabilities into an accessible (typically cloud based) IIoT solution to optimize total system efficiency is now more critical than ever and a clear focus of nearly all market participants (both users and suppliers).

Underlying all of this is a deeper socioeconomic question around jobs – one that economists continue to debate. We tend to agree with the view (explained in more detail here) that while robotic / automation deployment is a near-term job destroyer (think bank tellers when ATMs were unveiled and assembly line workers in an auto facility before robots), the longer-term impacts are likely positive. Bank branches proliferated as operating costs went down (less jobs per bank but far more banks) and automation brought cars to the masses which required meaningfully more plants and higher global production, and ultimately more (albeit different) jobs.

Continued robotic deployment likely supports the trend of bifurcation within manufacturing jobs – where middle income jobs are replaced with a combination of higher and lower wage jobs that are more variable, less standardized, and less susceptible to automation. The net result is likely higher median compensation (and US data shows manufacturing wage growth outperformance vs. the broader private sector after lagging the past 10 and 20 years), but also a skills gap that may be challenging to fill absent changes to training and education programs – a lack of skilled labor is among the most consistent bottlenecks cited by industrial CEOs.

Figure 1 Industrial Robotics Overview

Annual Demand, in $MM

	2011	2012	2013	2014	2015	2016	2017
North America	$1,485	$1,629	$1,749	$1,800	$2,077	$2,329	$2,512
y/y growth		*9.7%*	*7.4%*	*2.9%*	*15.4%*	*12.1%*	*7.9%*
% of total	*17.9%*	*19.4%*	*19.9%*	*19.2%*	*18.5%*	*17.4%*	*15.0%*
China	$1,067	$1,177	$1,878	$2,712	$3,086	$3,673	$4,492
y/y growth		*10.3%*	*59.6%*	*44.4%*	*13.8%*	*19.0%*	*22.3%*
% of total	*12.9%*	*14.0%*	*21.3%*	*29.0%*	*27.5%*	*27.4%*	*26.9%*
Japan	$1,487	$1,432	$1,136	$978	$1,201	$1,426	$1,607
y/y growth		*-3.7%*	*-20.7%*	*-13.9%*	*22.8%*	*18.7%*	*12.7%*
% of total	*18.0%*	*17.1%*	*12.9%*	*10.4%*	*10.7%*	*10.6%*	*9.6%*
Republic of Korea	$496	$377	$511	$386	$893	$1,039	$1,177
y/y growth		*-24.0%*	*35.5%*	*-24.5%*	*131.3%*	*16.3%*	*13.3%*
% of total	*6.0%*	*4.5%*	*5.8%*	*4.1%*	*8.0%*	*7.8%*	*7.0%*
Germany	$1,140	$1,250	$1,390	$1,329	$1,193	$1,246	$1,821
y/y growth		*9.6%*	*11.2%*	*-4.4%*	*-10.2%*	*4.4%*	*46.1%*
% of total	*13.8%*	*14.9%*	*15.8%*	*14.2%*	*10.6%*	*9.3%*	*10.9%*
Total World	**$8,278**	**$8,386**	**$8,806**	**$9,362**	**$11,213**	**$13,392**	**$16,714**
y/y growth		*1.3%*	*5.0%*	*6.3%*	*19.8%*	*19.4%*	*24.8%*

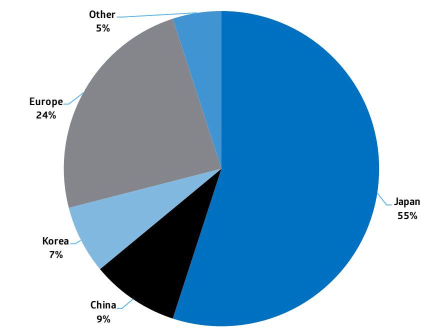
Installed Base, in # units

	2011	2012	2013	2014	2015	2016	2017
North America	184,679	197,962	215,817	236,891	260,642	285,143	307,105
y/y growth		*7.2%*	*9.0%*	*9.8%*	*10.0%*	*9.4%*	*7.7%*
% of total	*16.0%*	*16.0%*	*16.2%*	*16.1%*	*16.0%*	*15.6%*	*14.6%*
China	74,317	96,924	132,784	189,358	256,463	339,970	473,429
y/y growth		*30.4%*	*37.0%*	*42.6%*	*35.4%*	*32.6%*	*39.3%*
% of total	*6.4%*	*7.8%*	*10.0%*	*12.9%*	*15.7%*	*18.6%*	*22.6%*
Japan	307,201	310,508	304,001	295,829	286,554	287,323	297,215
y/y growth		*1.1%*	*-2.1%*	*-2.7%*	*-3.1%*	*0.3%*	*3.4%*
% of total	*26.6%*	*25.1%*	*22.8%*	*20.1%*	*17.6%*	*15.7%*	*14.2%*
Republic of Korea	124,190	138,883	156,110	176,833	210,458	246,374	273,101
y/y growth		*11.8%*	*12.4%*	*13.3%*	*19.0%*	*17.1%*	*10.8%*
% of total	*10.8%*	*11.2%*	*11.7%*	*12.0%*	*12.9%*	*13.5%*	*13.0%*
Germany	157,241	161,988	167,579	175,768	182,632	189,270	200,634
y/y growth		*3.0%*	*3.5%*	*4.9%*	*3.9%*	*3.6%*	*6.0%*
% of total	*13.6%*	*13.1%*	*12.6%*	*11.9%*	*11.2%*	*10.4%*	*9.6%*
Total World	**1,153,097**	**1,235,389**	**1,332,218**	**1,472,088**	**1,631,650**	**1,828,024**	**2,097,552**
y/y growth		*7.1%*	*7.8%*	*10.5%*	*10.8%*	*12.0%*	*14.7%*

% of Industrial Robots by Sector, 2017

	Food & Beverage	Automotive	Electronics	Plastic & Chemical	Metal	Other
China	1.8%	33.8%	27.2%	7.4%	12.7%	17.2%
South Korea	0.4%	32.0%	51.9%	3.7%	2.7%	9.3%
Europe	6.3%	40.7%	3.5%	11.7%	16.4%	21.4%
North America	4.3%	49.5%	15.7%	7.8%	7.7%	15.0%
Japan	2.1%	33.6%	32.9%	6.8%	10.9%	13.8%
Total World	**3.1%**	**36.4%**	**24.2%**	**8.1%**	**10.3%**	**17.8%**

Global Industrial Robot Manufacturing Share by Country, 2017



Major Players
China
Saisun
Efort
GSK
Estun
STS
Greatoo
Japan
Mitsubishi Electric
Omron
Fanuc
Kawasaki Heavy Industries
Yaskawa
Europe
Kuka
ABB

Key Players (Industrial Robotics / Accessories - Private Co)

	Grippers	Force Sensors	Vision	Software	Automation	End Effector Swap
Right Hand Robotics	✓	✓				
Robotiq	✓	✓	✓	✓		
Soft Robotics	✓					
Vecna Robotics					✓	
Veo Robotics			✓			
Rethink Robotics (IP purchased by HAHN Group)	✓					✓

Relevant Exposures Across Our Coverage

	Products Supplied	% of Total Company Revenue
AME	Motors, controllers, actuation, software	Low single digits
APH	Connectors, sensors	Low single digits
CGNX	2D & 3D Vision (with deep learning capability)	~5% direct to robot OEM - higher when considering vision deployed with robotics
ROK	Motors, Presence Sensing Saftey Devices, PLC / Controllers, Smart Sensors with I/O Link, Proximity Sensors, Encoders, Relays, Drives	Not disclosed
ST	3D and Solid State LiDAR (for autonomous navigation), Position Sensors and Encoders	Low single digits
TEL	Connectors (various iterations - heavy duty, contactless, etc.), Relays, Servo Motors	~5%

Source: IFR – World Robotics 2018, Company reports, Cowen and Company

Core Markets To Drive Mid-Teens Growth Through 2021 With Optionality Around Alternative Supply Chain Buildouts And Reshoring

Investment Consideration #1: Robotics combines well established global markets (industrial – the focus here) with emerging, evolving, fast paced ones (warehouse/logistics, collaborative) that we will dive into in subsequent reports.

The industrial robotics market is highly concentrated geographically, with the 5 largest markets (China, Japan, Korea, the US, and Germany) accounting for 75% of total shipments. We've seen a material shift in terms of shipment destination and installed base over the past 15 years. In 2002, Japan and Germany accounted for over 50% of total shipments and nearly 60% of the global installed base. In 2017, they represented ~20% of shipments and 25% of installed base despite volumes up ~80% and installed base up ~10%. Over that period growth in global demand has accelerated – from a 12% 15-year CAGR to 20% over the past 3 years. The emergence of China and Korea, which combined have moved from ~7% of global demand in 2002 to nearly half last year, has been remarkable and largely attributable to their respective contribution to global automotive and electronics markets – by far the most robot intensive globally.

Global Industrial Robot Shipment Demand Average Growth

3 year	20%
5 year	19%
10 year	13%
15 year	12%

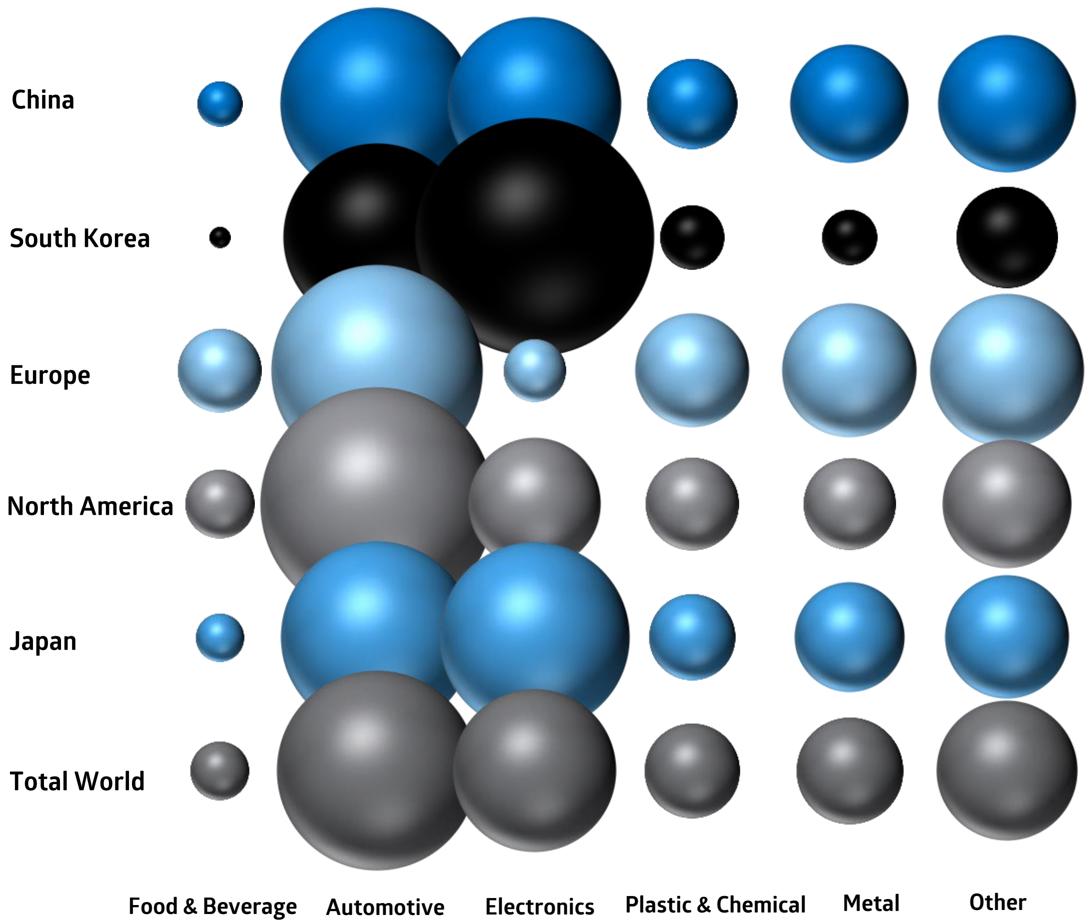
Source: IFR – World Robotics 2018, Cowen and Company

The China story in particular seems supported when considering that it only became the largest demand market in 2013 and the largest installed base market in 2016. In terms of robot density / penetration, it is only slightly above the global average – 2x behind the US and over 7x behind Korea. Chinese robot deployment could also serve as a model for development of the new class of emerging production centers, particularly given global trade rhetoric – an area we examine later in this section.

Figure 2 Operational Stock of Industrial Robots by End Market in units and as a % (bubble chart)

Operating Stock of Industrial Robots by End Market, 2017

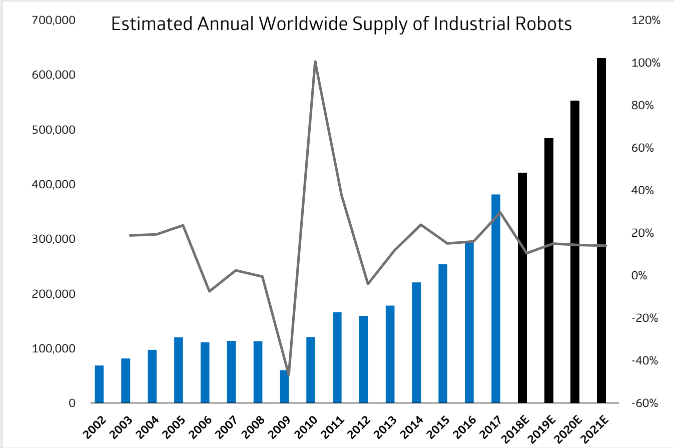
	Food & Beverage	Automotive	Electronics	Plastic & Chemical	Metal
China	8,553	159,787	128,844	34,874	59,921
South Korea	204	11,695	24,011	1,026	495
Europe	31,422	202,527	17,628	58,322	81,590
North America	13,169	152,145	48,262	23,970	23,557
Japan	6,199	99,836	97,694	20,078	32,343
Total World	64,696	763,842	508,629	170,748	216,092



Source: IFR- World Robotics 2018, Cowen and Company

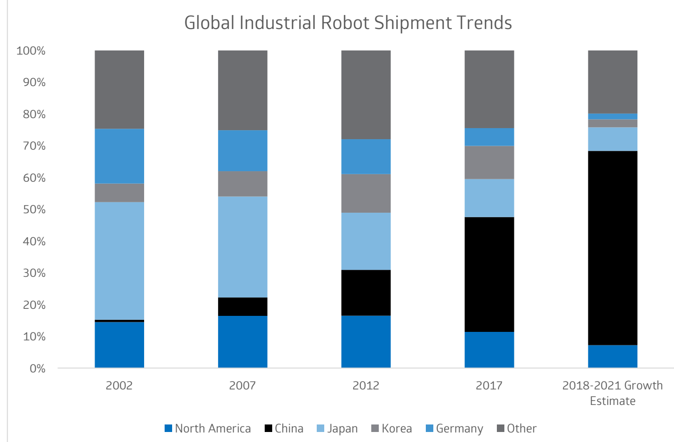
The IFR estimates global robotic shipment volumes to increase at a ~14% CAGR through 2021, with China supplying over 60% of anticipated growth. Rising demand globally for more complex, customized, higher precision products coupled with consistently rising emerging market wages supports the call for incremental robotic deployment to meet demand. Increasingly, rising product volumes and complexity make the human vs. robot decision less an analysis of cost and more one of capability. Further, as rising labor costs incentivize robotic investment, it allows multinational corporations to be more open as to where production facilities are located. We are already seeing evidence of "new Asia" investment in a material way, and wouldn't be surprised to see more regionalized supply chains moving forward. We explore this idea and the major robot markets in more detail below.

Figure 3 IFR sees ~14% Shipment CAGR Over 2017-2021



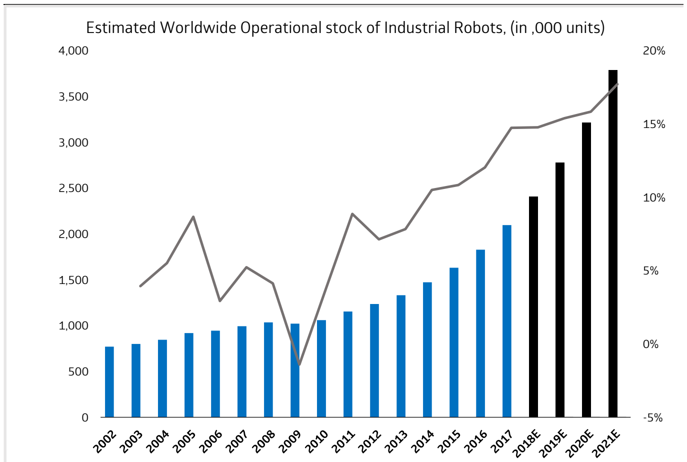
Source: IFR – World Robotics 2018, Cowen and Company

Figure 4 Material Demand Mix Shift Away From Japan and Germany and Towards China and Korea



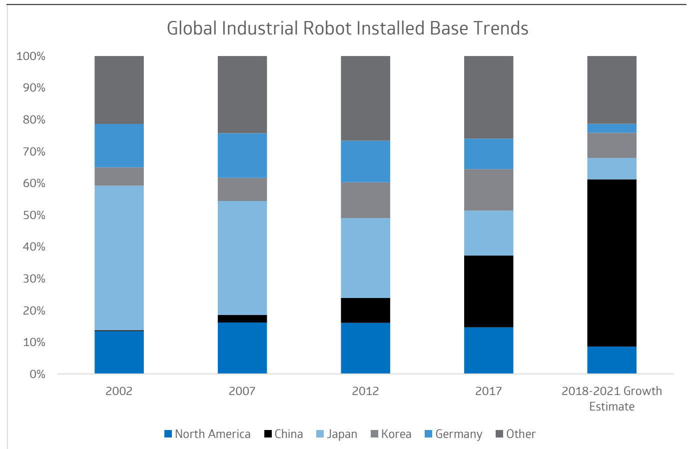
Source: IFR – World Robotics 2018, Cowen and Company

Figure 5 Similar Trends Visible For Global Installed Base...



Source: IFR – World Robotics 2018, Cowen and Company

Figure 6 ...With China Becoming The Largest Base in 2016



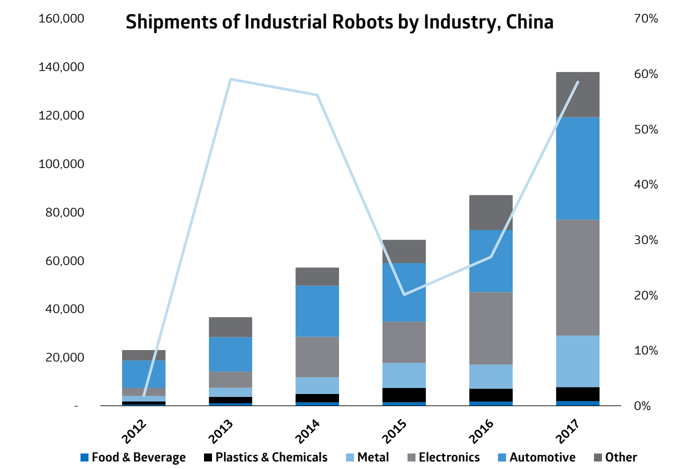
Source: IFR – World Robotics 2018, Cowen and Company

China

Estimated 2018-2021 growth CAGR: 21%

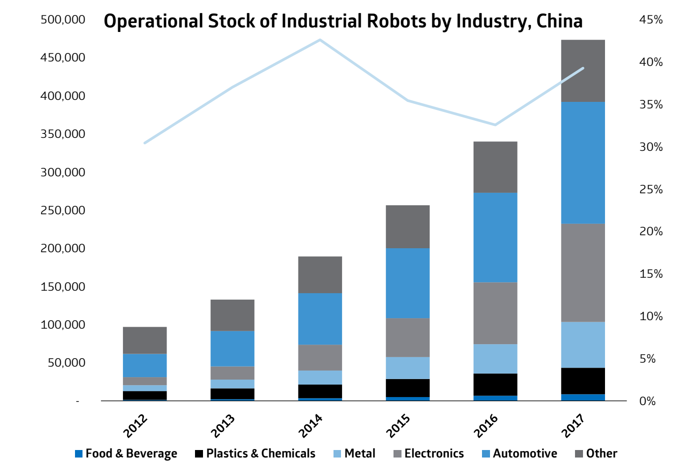
The Chinese market represented approximately 36% of total demand in 2017 and was larger than Europe and the Americas combined for the first time. China is not only the world's largest market, but also the fastest growing: in 2017, 138k robots were sold, 59% more than in 2016, though we note that year-over-year growth, while solidly positive, has shown volatility in the past.

Figure 7 : Shipments Of Industrial Robots To China Continues To Accelerate

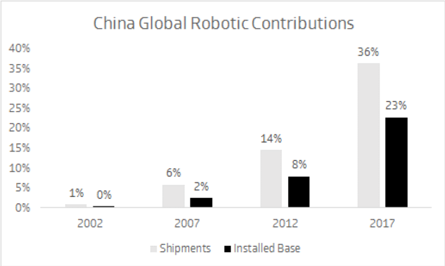


Source: IFR- World Robotics 2018, Cowen and Company

Figure 8 ...As Does The Operational Supply Of Industrial Robots



Source: IFR – World Robotics 2018, Cowen and Company



Source: IFR – World Robotics 2018, Cowen and Company

Asia in general, and China in particular, drive robot demand for three reasons: 1) the electronics industry (where they are a dominant player) has been the fastest growing in terms of robot demand, 2) a large part of manufacturing is still done by humans (see our discussion on robot density here), and 3) there has been consistent upward pressure on local labor rates (covered in our look at potential for reshoring here). The electrical/electronics industry passed the auto industry in terms of shipment units for the first time in 2016, but still lags auto in terms of installed base. These two industries made up almost two-third of total units sold in China in 2017. Although China is still dominant in terms of global demand, there is still a fairly large gap between demand percentage and installed base percentage that should support robust shipment growth.

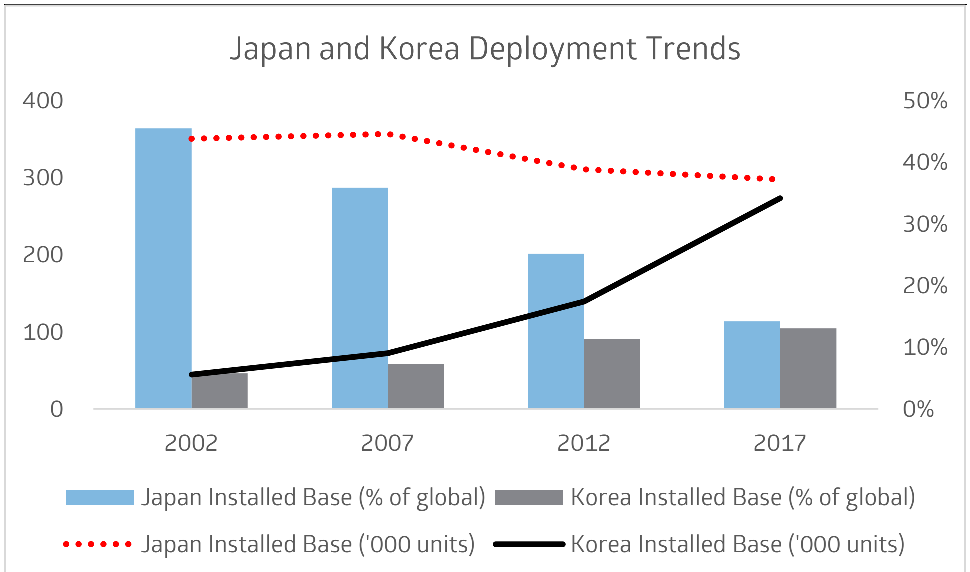
China has also fostered its own production ecosystem, and Chinese manufacturers have accounted for ~25-30% of domestic shipments over the past 4 years.

Japan and Korea

Estimated 2018-2021 growth CAGR: Japan 6%, Korea 4%

Japan and Korea are two of the most heavily penetrated large scale markets in the world, coming in at #4 and #1, respectively, in terms of robots per 10,000 workers. However, they have been on two very distinct journeys over the past 15 years. In 2002, Japan represented over 45% of total global installed base and nearly 40% of total demand vs. Korea at 6% of each. Today, Korea's installed base is 5x higher than it was while Japan's is 15% lower and both countries represent ~10% of global demand. **It's important to note though, that despite Japan's installed base moving from 45% of the global total to 14% over the past 15 years it is still the world's 2nd largest.** That's how much the rest of the world has grown...

Figure 9 Japan Remains The Second Largest Global Robotics Base But Share Has Been Cut By ~70% - Korea Installed Base up 500+% Since 2002



Source: IFR – World Robotics 2018, Cowen and Company

There is an interesting dynamic in Japan. The country is and has been one of the largest industrial robot markets in the world. It is also one of the principal global manufacturers with some of the most iconic and successful industrial robot companies, including Fanuc, Kawasaki, Yaskawa, Denso, Mitsubishi, and Epson. Japanese production accounts for 56% of global manufacturing, up from 52% in 2016, though down from 71% in 2006 following the rising production in Europe, Korea, and more recently China. The country's robot density (308 per 10k people) is one of the highest in the world behind only Korea, Singapore and Germany, however, it is down from 319 in 2012 and 331 in 2009. This is primarily due to the 6% decline in robot density in the automotive industry during the same time frame. Overall, the market in Japan remains extremely healthy and saw an increase of 18% in 2017 driven by strength in electronics while auto was relatively flat year-over-year. We note that industrial robot shipments grew at a 10% CAGR between 2012 and 2017 in Japan.

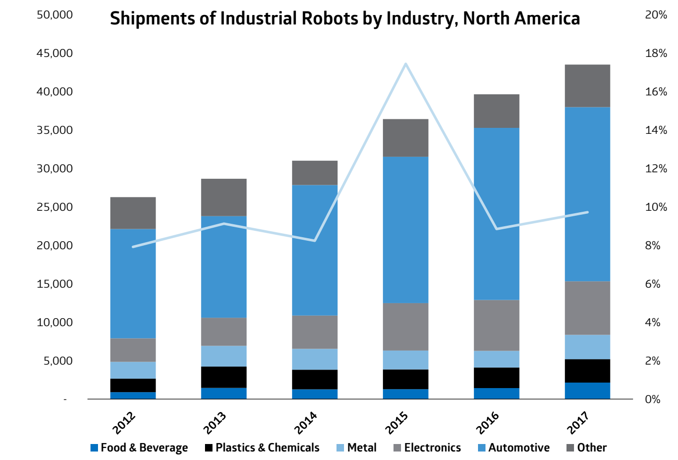
Korea is home of the third largest robot market in the world in terms of supply and installed base, behind only China and Japan. The country also has the highest industrial robot density in the world with 710 per 10,000 employees. It is not that surprising when considering that it is a predominant location for auto, batteries, and electronics manufacturing – the industries with the highest robot density. Annual robot sales for the manufacturing industry grew at a 15% CAGR between 2012 and 2017. In terms of robot production, Korea has been shifting from a specialization in linear and Cartesian robots - low price, short life cycle for limited applications – to articulated robots that are used for operations that requires greater accuracy and precision for more complex applications.

North America

Estimated 2018-2021 growth CAGR: 13%

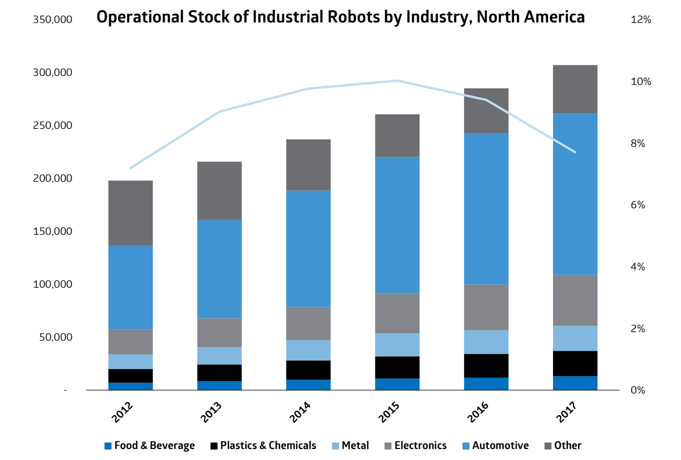
The region represents the second largest installed base of robots behind China. The US, obviously, represents the largest market in North America with 74% of new units sold in 2017.

Figure 10 Shipments To NA Have Been Growing At A Slower Rate Since 2014



Source: IFR- World Robotics 2018, Cowen and Company

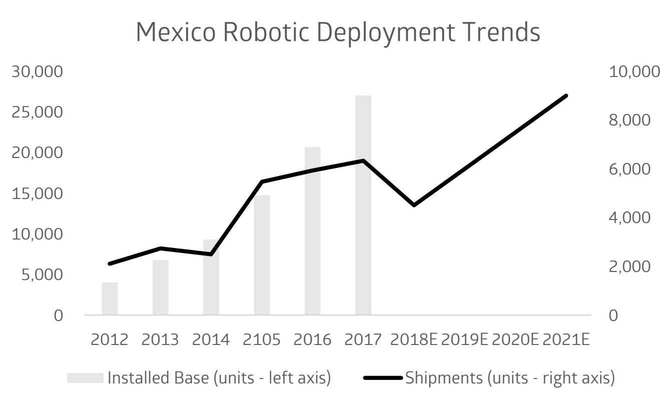
Figure 11 Operating Stock Of Industrial Robots By Industry In NA



Source: IFR – World Robotics 2018, Cowen and Company

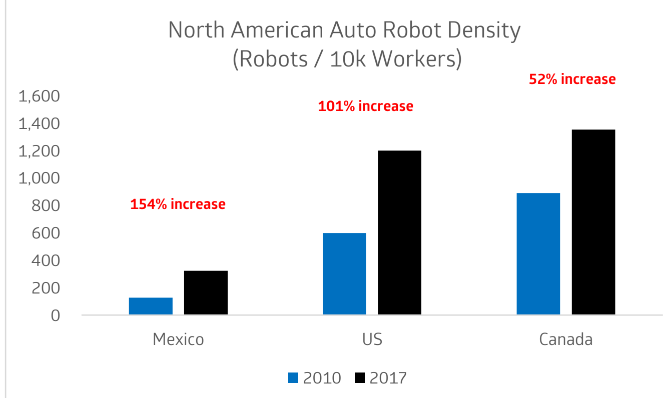
As expected, the auto industry is and has been the driver of new robots in North America. In 2017, 52% of new robot units sold in North America were intended for the auto industry. Between 2011 and 2016, robot investments of car manufacturers in North America increased 14% on average, according to the IFR. In 2017, both the US and Mexico saw robotic investment declines by car manufacturers (-28% and -10%, respectively), which was more than offset by expansion by auto parts suppliers (+18% and +7%). The resurgence in demand after the great recession comes from modernization and expansion of manufacturing facilities in the US. Domestic auto part suppliers have had to invest to keep up with quality control, materials, and demand for efficient energy production, while foreign suppliers have meaningfully relocated to North America to be closer to their customer base. Accordingly, Mexico stands as an exciting opportunity – we've seen a nearly 7x expansion of their installed base since 2012 and note that robotic density in the Mexican auto sector (323 robots per 10k workers) is still a fraction of the US and Canada at ~1200 and 1300, respectively.

Figure 12 Mexican Installed Base Up Nearly 7x Since 2012…



Source: IFR – World Robotics 2018, Cowen and Company

Figure 13 …And Auto Density Still Has Plenty Of Room To Expand



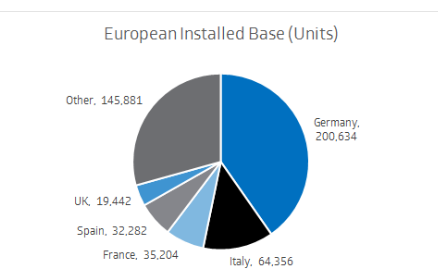
Source: IFR – World Robotics 2018, Cowen and Company

The electronics industry represents the second largest North American market, with most of the volume going to the US. Sales in in North America were up 5% in 2017 and up 18% on average between 2012 and 2017. Sales of robots for the electronics industry in North America represented about 16% of all units shipped in 2017. Foxconn, the Taiwanese contract manufacturer who counts Apple as its largest customer has recently decided to set up an extensive plants in Wisconsin. This is one of the largest catalysts for the growth of robot shipments for the electronics industry and could pressure other manufacturers to build capacity closer to the US market.

The US ranks fourth in terms of annual robot demand behind China, Korea, and Japan. It is important to note that despite the size of its market, the US imports nearly all of its robots from Japan, Korea, and Europe. The US doesn't have any major domestic robot manufacturers, though it has a lot of robot system integrators. In 2015, ABB decided to open a third robotics production facility that will be located in the US. The other locations are in China and Sweden. ABB is the first global automation company to open a robot manufacturing facility in the US, which represents the largest market for the company with $7.5B in sales. ABB noted that it makes economic sense to be as close as possible to its customer base and sees not only growth in the auto industry, but also a substantial opportunity with the electronics light assembly market.

Europe

Estimated 2018-2021 growth CAGR: 10%

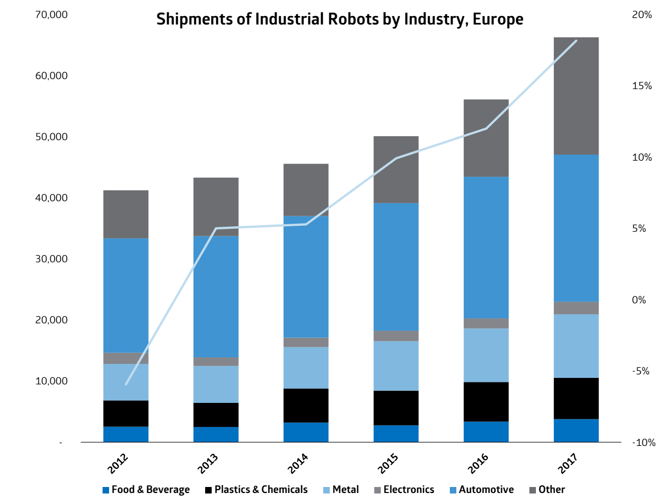


Source: IFR – World Robotics 2018, Cowen and Company

Germany is by far the largest robot market in Europe. It represented 32% of units sold in 2017 and 40% of all European installed base. The country is also one of the most automated in Europe and has the third highest robot density in the world, behind Singapore and Korea. Other significant countries in Europe include Italy with 12% of total European demand and France with 7%.

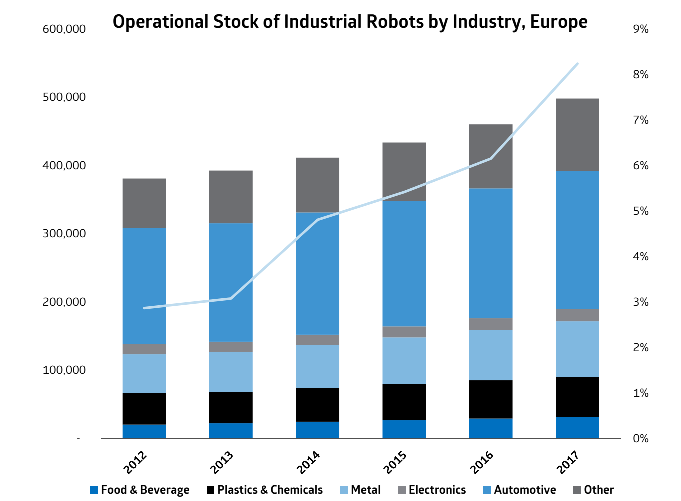
The average annual growth rate between 2012 and 2017 for robot supply in Europe was about 10%. We note that Germany grew 4% during the same period.

Figure 14 Shipments To Europe



Source: : IFR- World Robotics 2018, Cowen and Company

Figure 15 Operating Stock Of Industrial Robots In Europe



Source: : IFR- World Robotics 2018, Cowen and Company

The reason for the relative underperformance of robot sales in Europe has to do with the auto industry. As it is with all the other regions, the auto market is the most important in Europe. IFR notes that between 2012 and 2017 robot installations in the German auto industry barely grew (less than 1%) – the largest auto market in Europe. This was likely due to the fact that robotics are already well penetrated within the German auto market (one of the densest in the world). The IFR expects a CAGR of 5% in Germany over the 2018-2021 time frame, driven by investments in EV and hybrid platforms in the auto market and increasing demand in the general industry.

Trade Tensions Open Up New Emerging Asia Opportunity – Continued Global Deployment Helps Democratize Production Bases

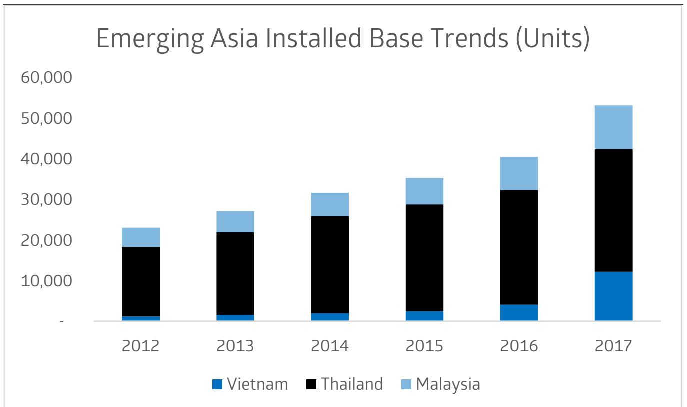
Investment Consideration #2: Provides access to build outs of emerging production centers – potentially critical as supply chains are retooled in response to global trade tensions.

Escalating global trade rhetoric, particularly between the US and China, has led most multinational organizations scrambling to retool supply chains to avoid tariffs and secure alternative sourcing. At the same time, further robot penetration in traditional manufacturing centers combined with escalating low-cost labor wage inflation pushes the production decision point variable incrementally away from labor price and supports calls for reshoring and more regionalized production frameworks. Importantly, growth in emerging Asia is not necessarily a zero sum game with decreased investment in China – despite tremendous growth in China's deployment there is still an outsized opportunity to deepen rather than broaden – increasing density and efficiency. We examine this idea later in this report.

Good Morning, Vietnam

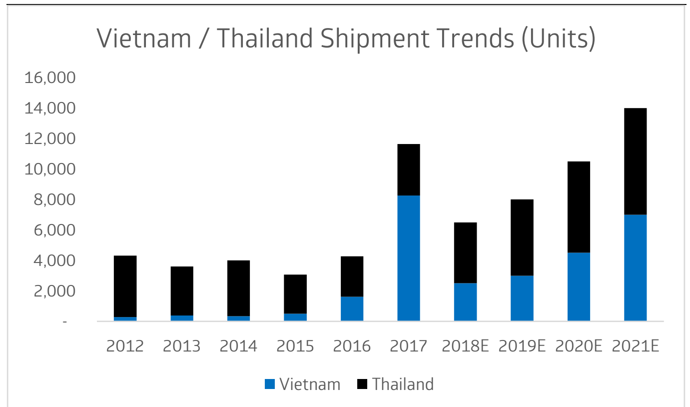
Southeast Asia has become more of a focus as a production base as costs have escalated in traditional manufacturing hubs and trade tensions have intensified. Vietnam, for example, was largely irrelevant in the robotics landscape as recently as 3 years ago before breaking onto the scene as the world's 7th largest demand market in 2017. Although 2018 growth is expected to moderate meaningfully from historic levels last year, we are clearly in a new growth paradigm there – the installed base has grown nearly 28x over the past 5 years and the country's share of global installed base has grown 12x. Thailand (a larger market historically) and Malaysia have seen similar trends and have been identified by many companies we've listened to as areas for incremental focus and investment to diversify supply chains.

Figure 16 Emerging Asia Investment Has Ramped Considerably – 130% Installed Base Increase in 5 Years



Source: IFR – World Robotics 2018, Cowen and Company

Figure 17 Clear Step-change In The Growth Function



Source: IFR – World Robotics 2018, Cowen and Company

Incremental Pendulum Swing Away From Labor Cost Focus

As we've discussed, the robotic landscape in production centers like China has changed considerably over the past several years. Although robotic penetration remains relatively low on a per worker basis (slightly above the global average and well below the leaders) it has increased materially. Rising wages help incentivize incremental deployment and as the trend towards more automated production continues, labor price becomes less of a critical variable in the overall decision process and factors like electricity cost and skilled labor availability (as opposed to lower end labor cost) rise in relative importance.

Figure 18 Consistent Chinese Wage Inflation In CNY and USD Terms

Source: Thomson Reuters, Cowen and Company

Electric costs can represent a substantial part of the operating expense of industrial companies and can be an influential factor in the decision process to determine the location of a new factory. For developed countries, electric prices are generally the highest in Western Europe. Comparing the US to China in order to determine which nation is more attractive for new manufacturing investment, including reshoring, is not straightforward. For example, in China, electricity prices fluctuate based on the region, the type of industry that will consume power, the level of voltage, and obviously when the power is needed during the day (peak, level, or trough). Comparing two nations' average electricity cost can be deceiving due to all these different parameters. In the US, the cost of industrial electricity can range from 5-6c/kWh in Texas, Tennessee, Montana, and Washington to 14-16c/kWh in California, or New England. In China, depending on the province, electricity prices can range from 0.4-0.6 Yuan/kWh or 5.7-8.6c/kWh.

Continued robotic investment supports a view that cost/benefit analyses regarding production location will shift somewhat away from labor cost. Taking into consideration supply chain costs, which include shipping times and fuel and transportation costs, the balance could tip in favor of reshoring to the US. The Reshoring Initiative believes that in 2017 reshoring and foreign direct investment related jobs represented ~90% of the ~190k gross manufacturing jobs added in the US.

The federal minimum hourly wage in the US remains at $7.25 per hour, though we note that some states have introduced a minimum wage floor over $10 per hour. Chinese factory workers are getting paid approximately $3.60 in hourly wages. While still low relative to the US, the current rates are 64% higher than they were in 2011, according to research firm Euromonitor. A continued increase, especially at a pace similar to what has been sustained over the past few years, could lead factory owners to invest outside of China.

As Installed Bases Broaden and Deepen, Robotic Growth Should Outperform Underlying End-Market Trends

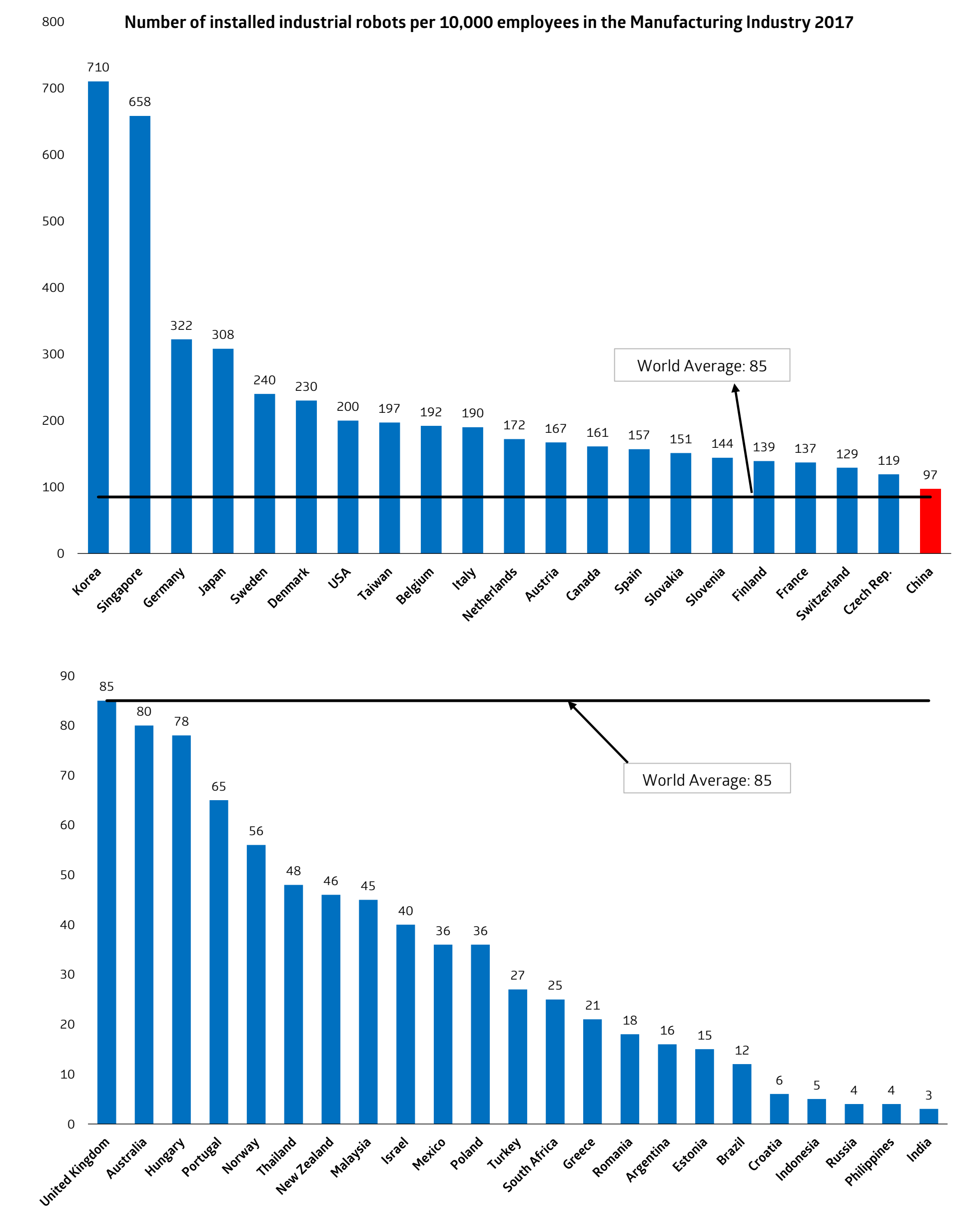
Investment Consideration #3: Robotics investment should grow faster than spending in underlying markets and provide and element of offset as efficiency measures are targeted in down cycles.

With automotive and electronic industries representing ~65% of current robot demand, it's hard to ignore the cyclical implications on the sector. At the same time, many of the fastest growth markets (namely China) remain relatively underpenetrated in terms of robots per worker despite material increases in recent years. The automotive and electronics industries are by far the densest (robotic intensive) and given outsized exposure to those industries, growth above market seems appropriate. For scale, each robot added in China per 10k manufacturing workers adds over 1% to global demand and density in China is 2x below the US and 7x below Korea even after a 4x gain over the past 5 years.

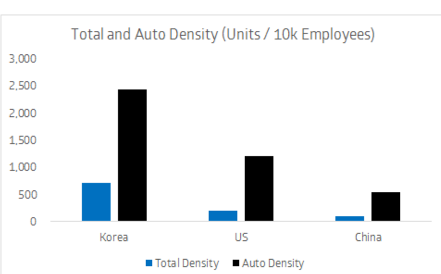
Robot Density Gains Provide Foundation For Cyclical Outperformance

Robot density refers to the number of robots in an industry or country per 10,000 employees and is used to track the level of robotic penetration. The average global robot density for the manufacturing industry is currently 85.

Figure 19 China's Installed Base Is ~5x 2012 Levels Yet Density Remains Barely Above Global Average

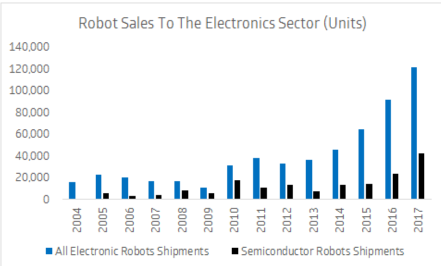


Source: IFR- World Robotics 2018, Cowen and Company



Source: IFR – World Robotics 2018, Cowen and Company

As a means of comparison, Korea has the highest robot density in the manufacturing industry with 710 industrial units per 10,000 employees. Germany and Japan have 322 and 308 industrial robot per 10,000 employees, respectively. The US' robot density is 200 and China's has grown from 25 in 2013 to 97 in 2017. Most of the emerging countries have a robot density below 50. The auto industry is the most automated and its robot density is substantially higher than the average general industry. Korea's robot density in the auto industry is 2,435 and has more than doubled since 2009. The US had the second highest robot density in the auto industry with 1,200 per 10,000 employees in 2017 – well above China's 539. Robot density, already the highest in the auto industry, was pushed further with global investments made to manufacture batteries for hybrids and EVs.

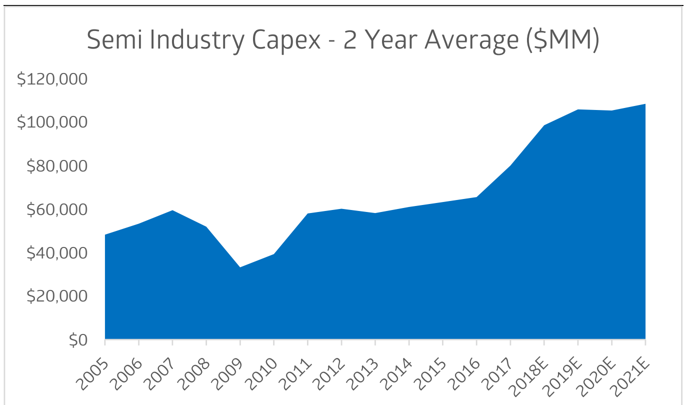


Source: IFR – World Robotics 2018, Cowen and Company

Performance vs. Semiconductor Spending

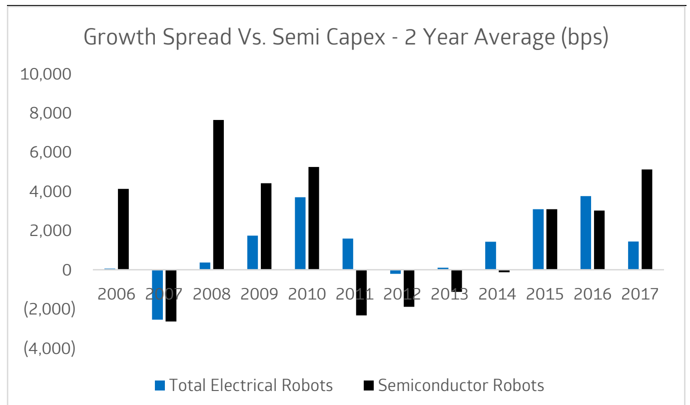
Total capex by semiconductor manufacturers is expected to top $100B in 2018, up over 50% vs. 2016 levels. While not all electronics related robots are sold into semiconductor manufacturers, spending levels there are likely a fair guide post for total electronics related demand. We looked at growth in total electronics directed robots and semiconductor specific robots vs. changes in semi capex spending (using 2 year averages for capex and robot shipments to adjust for timing) and found that total electronic robot shipment growth outperformed in 10 of the 12 periods analyzed and by a comfortable average of over 1700 bps. We note that in each of the periods where we saw capex decline on the 2 year average (2008, 2009, and 2013), total electronics shipments outperformed.

Figure 20 Semi Spending Has Been A Broadly Positive Trend…

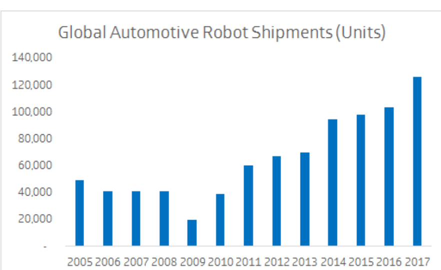


Source: Company reports, Cowen and Company

Figure 21 …With Consistent Outgrowth In Robotic Shipment



Source: IFR – World Robotics 2018, Cowen and Company



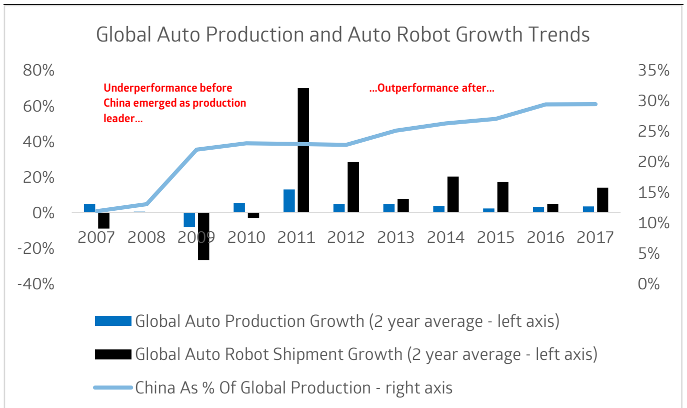
Source: IFR – World Robotics, 2018, Cowen and Company

Performance vs. Auto Production

The analysis here becomes a little more tricky given China's significant change in auto production share and the variance in its robot density vs. the rest of the global auto production leaders (Germany, the US, Japan, Korea, etc.) which are much more penetrated in terms of robotic deployment. Robot shipments to the auto sector have materially exceeded production growth since 2010 (using 2 year averages similar to our semiconductor analysis) – by over 1000 bps in 2017 and an average of over 1800 bps over the period.

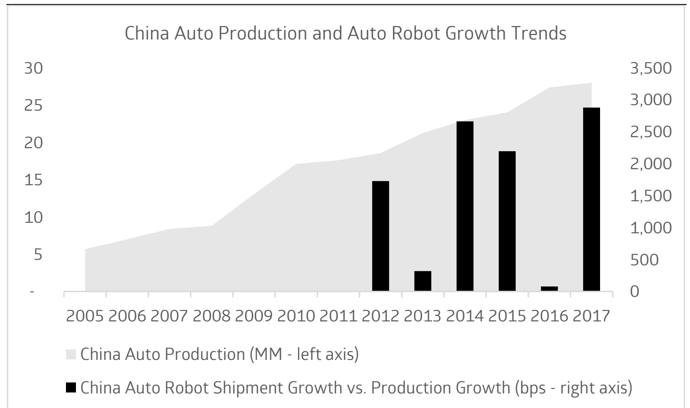
When global auto production declined in 2008/09, Chinese production increased substantially – 56% over the 2 years – but China only represented ~12% of global production heading into the global decline vs. ~30% currently. While we don't have Chinese auto robotics data broken out prior to 2010, we note that shipments in 2017 were nearly 6x what they were in 2010 and that robotic shipment growth has meaningfully outpaced production growth in China (using 2 year averages) over the past 5 years. Given China's auto density (as we mentioned earlier it stands at 539 vs. leaders Korea at over 2400 and the US and Germany at ~1200) and its much larger position in terms of global auto production, we would expect robotics growth to perform differently than in 2008/09 as Chinese deployment continues and the region moves towards density more in line with the established players.

Figure 22 We Believe China's Emergence Will Support Spreads In A Future Downtrend – Meaningful Outperformance Since 2010



Source: IHS, IFR – World Robotics 2018, Cowen and Company

Figure 23 Average Robotic Outgrowth of ~1700bps In China Over Past 5 Years



Source: IHS, IFR – World Robotics 2018, Cowen and Company

Harnessing Powerful Technology To A Common Platform

Investment Consideration #4: Can be viewed as an epicenter of cutting edge investment across multiple powerful themes: electrification, vision, AI, automation, cloud analytics – all of which are deployed in robotic platforms.

Selected Capability Offerings At Leading Robot Manufacturers

	ABB	KUKA	FANUC	Mitsubishi	Omron	Yaskawa
Robots	✓	✓	✓	✓	✓	✓
IoT Platform	✓	✓	✓	✓	✓	✓
Vision		✓	✓		✓	✓
Controllers/Drives	✓	✓	✓	✓	✓	✓
Sensors	✓			✓	✓	✓

Source: Company reports, Cowen and Company

Similar to the transformation of next generation cars, we can think of future robots as somewhat of a blank canvas on which to deploy technology. Progress in advanced vision (both 2D and 3D – see our detailed work here), sensors and connectors (see our sector launch here), broad automation and IIoT / cloud enabled analytics, and AI all contribute to consistent expansion of robotic capability. Continued improvement in peripherals like grippers can be considered at least as important as those on the robot itself – we've come from a place where robots were programmed to grab an object as tightly as possible without crushing to one where the goal is to gab as lightly as possible without dropping…progress. Research continues towards a reality where robots can teach themselves through trial and error and interact with humans in more complex ways. Below we explore some of the areas receiving some of the most attention.

AI-Based Software Algorithms Are Advancing the Capabilities of Machine Automation Technologies (Derrick Wood, CFA)

At a high level, AI is a branch of computer science that focuses on making machines imitate intelligent human behavior. AI has already started to become pervasively applied in consumer tech, such as facial recognition in social media and speech recognition in voice-controlled devices, but this is just the tip of the iceberg and we expect to see AI innovation in commercial markets to ensue. AI is a broad term that encompasses many sub-segments including Machine Learning (ML), Natural Language Processing (NLP), Speech Recognition, Computer Vision, Robotics and more.

Enterprises are increasingly investing in new technologies leveraging various aspects of AI and Automation technologies. As a result, we expect a wide variety of next-generation applications to emerge, resulting in more machine intelligence based services and more business process automation across a variety of verticals. Machine Learning-based Applications and Deep Learning Neural Networks are experiencing the largest and widest amount of investment attention in the enterprise. Computer Vision also promises to be highly transformative in industries like manufacturing, agriculture, healthcare & automotive.

A Massive Technology Shift Is Underway, And Instead Of Humans Adapting To Computers, Computers Are Now Adapting To Humans

AI is the science of making computers emulate human decision-making and learning processes in order to solve various complex tasks. The tenants of AI today give computers human-like abilities related to seeing (Image Recognition / Computer Vision), hearing (Natural Language Understanding), learning (Deep Neural Networks) and reasoning (Reinforcement Learning). AI-powered machines can now learn, reason and interact with humans, while solving problems and recognizing patterns in data that is far too complex and too large in scale for humans or human-written software programs to address.

An ML algorithm first needs to be trained with sample data; then when put into production, it iteratively learns from real-time data, and as more data is fed into the algorithm, the system gets smarter and its predicted outputs become more accurate. Machine Learning can be intertwined with a variety of applications in order to transfer the programming of algorithmic code from developers to computers to help build far more complex and intelligent systems.

The explosion in the amount of data being generated has been a major force in driving down storage costs, driving up computing bandwidth and sparking new investments in Machine Learning. The volume and variety of data being generated comes from sources such as videos, photos, website traffic, social engagements, text communications, sensors, mobile devices, IoT devices, cloud applications, industry data sets, and more. With lower-cost storage, the ability to store this data and keep it for longer periods of time has led to a vast trove of data being generated, collected and mined. Access to large sets of data is necessary to train effective AI algorithms, and Amazon's market-changing S3 and ECC cloud-based storage services have been a major contributor to lowering the cost barriers and making AI development far more economical than before.

Deep Learning (DL) Is Where The Most Cutting-Edge Advancements Are Now Taking Place

Deep Neural Networks, a sub-segment of ML, are trained to recognize patterns from massive amounts of data and involve layering many sets of algorithms within a neural network. A neural network detects relationships in data that humans could never identify, let alone code. DNNs require large amounts of training data and highly iterative data processing. These attributes demand huge computational processing power that CPUs cannot provide. Until just a few years ago, DNN development was relegated to research labs that could afford expensive super computers, but the newfound use of GPU chips (particularly from Nvidia) in DNN models has unleashed massive new commercial development. DL models have led to major advancements in areas like Image Recognition, Speech Recognition and Computer Vision.

In November 2015, Google open-sourced its Tensorflow Deep Learning platform. This was the first time there was a developed and widely available Machine Learning technology that could be used by the public to build and train Neural Networks. Google has used TensorFlow for deploying ML algorithms in production for several use-cases including speech recognition, computer vision, robotics, natural language processing and computational drug discovery. It used the Tensorflow platform for its DeepMind program, including the AlphGo application that beat a world champion human player in the highly complex board game Go, and Tensorflow is also used to optimize Google's data center operations, amongst other applications.

GPUs and other advanced processing technologies have helped democratize the development of Deep Learning models, and new applications embedding Computer Vision and Natural Language Understanding should drive growing demand. Break-through capabilities around image recognition, speech recognition, drug discovery and autonomous driving/drones have come from developments in Deep Learning. Deep Neural Networks (DNNs) are used to decide if a car is going to hit a pedestrian; detect suspicious behavior in a security video, or determine if social posts represent abusive behavior. Many claim that if a person can do a mental task with less than one second of thought, it can be automated with DNNs.

AI In Manufacturing

Supply Chain Management is one area where manufacturers are increasingly leveraging AI and related technologies for a variety of use-cases including 1) production plan optimization; 2) supply chain risk mitigation; 3) defect inspection; 4) bill of material optimization; and 5) demand forecasting for optimizing production workflows and inventory levels. For example, GE is using Machine Learning and predictive analytics for smart manufacturing systems. Using several process improvements leveraging ML, it saw 10% improvement in machine reliability, 5% decrease in batch cycle time and 5% reduction in energy costs. Similarly, an automotive OEM was able to improve equipment effectiveness from 65% to 85% by embedding condition monitoring processes with integrated sensor data on several operating parameters (oil pressure, oil temperature, leakage and other data). Industrial Robots is another promising area where AI/ML can provide tremendous benefits. Fanuc, the world's largest makers of industrial robots, is working with Nvidia to incorporate Machine Learning capabilities in industrial robots. Machine Learning will enable robots to reprogram themselves by learning how to perform tasks through practice.

AI In Agriculture

There is an exciting opportunity to use AI and Data/Analytics in agriculture to increase crop yield, optimize resource utilization and improve efficiency. Data generated from sensors, agricultural equipment or agricultural drones collected at farms or during transportation offers a wealth of information about soil, seeds, livestock, crops, costs, farm equipment, irrigation and fertilizer. Agricultural drones or Unmanned Aerial Vehicles (UAVs) can help in a variety of ways including soil and field analysis, planting, crop spraying, crop monitoring, irrigation and health assessment. For example, researchers at Chile's Universidad Católica de la Santísima Concepción (UCSC) have developed an Artificial Intelligence irrigation system that aims to increase water efficiency significantly. In a pilot test on blueberry cultivation, the system is expected to save 70% more water than other irrigation methods through the use of measuring instruments equipped with wireless sensors. Prospera, an Israeli company, is using Machine Learning to detect pests and diseases, optimize water and nutrients, predict and monitor yields, and analyze plant development.

End-Of-Arm Tool Improvements

Innovation of end-of-arm-tools, or end effectors, is the next logical advancement that will expand robot applications and functionality. End effectors are becoming increasingly "smarter" due to improvements in vision and sensor technologies. Future innovation will enable end effectors to recognize materials and apply the correct level of force to manipulate the item they are interacting with and become more dexterous.

Dexterity of robots, particularly end effectors, is a limiting obstacle for robot utilization in untapped applications. One new end effector which doesn't involve machine vision was displayed at Automatica this year, the Gecko Gripper – which allows robotic arms to pick up oddly shaped and delicate items without the use of significant gripping force or pressure. The Gecko Gripper, developed by NASA Jet Propulsion Laboratory and Perception Robotics (now OnRobot), mimics the method and performance of the adhesive system found on geckos' feet. In figures below, the gecko gripper technology is mounted to a modified Kuka robot arm at JPL, and is shown lifting a 45lb dumbbell and is also shown delicately grasping a tomato. At recent trade shows such as PackExpo we saw deployment of (and heard a lot of positive commentary about) gripping technology from SoftRobotics in many food & beverage applications and note that Robotiq is also considered a leader in terms of end-effector technology.

Figure 24 Showing The Force Needed To Lift A 45lb Dumbbell…

Source: JPL

Figure 25 …And The Delicacy To Handle A Tomato

Source: JPL, UC San Diego, Bioinspired Robotics and Design Lab

Improved Sorting Capabilities

As machine vision and learning capabilities expand, improved robotic sorting capabilities will be available. The Danish Technological Institute, Refined Technologies and STENA have developed the AAWSBE 1 Robot which extracts discarded batteries from electrical waste. The robot can detect different items and sort them according to value or classification for more efficient recycling. This link shows the robot in action (https://www.dti.dk/new-robot-system-extracts-dangerous-and-valuable-items-from-waste-using-artificial-intelligence/39554). Continued innovation in such tasks has clearly dramatic implications on logistics and fulfillment industries – an area we will dig into more deeply in Part II of our robot series.

Ease Of Integration and Setup

Further adoption of robotic automation will increase the need for standardized automation architecture to enable seamless integration of robots and end effectors manufactured by different companies. We will likely see large industrial companies work alongside industry organizations to produce standards and universal platforms which will make robotic integration easier and improve product compatibility.

Not long ago, sensors and actuators had to be individually linked to robot controllers through dedicated wiring through terminal racks and connectors. There has been a rise in technology which utilizes plug-and-play interfaces enabling components to be connected to robot systems using more simplistic network wiring. Some of the newest end effectors no longer need to be hard-wired to robot controllers and contain self-identifying software which allows the component to automatically identify itself to the control system, thus simplifying setup and saving time.

As end-effectors become more interchangeable, it will help manufacturers become increasingly nimble, particularly with higher customization and short run manufacturing on the rise. For example, one study of mass customization in the German automotive industry found that the number of option combinations for the BMW 6 series was 33x greater in 2015 than 2008.

Easier Programming

Robot manufacturers are also working to make robots easier to program. Demonstration programming, when a worker guides a robot through the desired motions and then finalizes force-torque measurements in a programming interface, is becoming more widely used. As programming interfaces become more intuitive, it will enable workers with little to no programming experience to select and adjust actions to be performed by robots through natural movement. We'd note that a considerable amount of academic research is currently focused on enabling programming via voice and through the application of machine learning and trial-and-error learning.

Drag & Bot is a company focused on simplifying robot programming. The company's web-based software can be utilized for easy setup, programming and operation of industrial robots. The graphical user interface allows inexperienced users to generate program sequences by guiding them through reusable function blocks. Ease of programming is a selling point for collaborative robot manufacturers like Teradyne's Universal Robots (and more traditional manufacturers are taking notice and moving in similar directions) – a market that will be a focus in Part III of our series.

Self-Optimization, Cloud Robotics, And Cybersecurity

Further advancement in sensors and vision systems will enable robots to adjust parameters in real-time to changes in conditions. For example, sensors and vision systems enable a robot to recognize if a part is out of alignment or misplaced. As the Industrial Internet of Things gains wider adoption and more data is collected and stored on the cloud, it can be analyzed in real-time allowing the manufacturing process to be adjusted to optimize performance. As IIoT evolves, data from multiple robots, or the entire system, can be analyzed, adjusted and improve the optimization of the entire process. <u>We are of the belief that the value of the robotic / automation system will continue to gravitate towards data application and plant efficiency solutions and away from hardware.</u>

According to research from IDC, by 2020 approximately 75% of all manufacturers will utilize industry clouds, but only a third will monetize their data. Robot manufactures can utilize cloud storage data of robot performance for applications such as predictive maintenance, which would save manufacturing companies money by curtailing or even avoiding unexpected machine downtime. The automotive industry has already begun adopting data usage for predictive maintenance, which isn't a surprise given unplanned downtime for automotive part manufacturers is estimated to be ~$1.3MM per hour.

Robots of the future will be deployed with more smart sensors that can be placed at the edge of production and will collect data previously inaccessible to manufacturers. This trend is currently underway, and as data collection from industrial robots expands, it will lead to higher levels of productivity and efficiency through machine learning. As robots become more connected to internal systems for data collection, the risk of cybersecurity increases. The increased risk will force manufacturers to invest heavily in cybersecurity to ensure safe and reliable production. We have already begun to see partnerships across automation, robotics, and IIoT companies – at ROK's recent Automation Fair their robot partner (Fanuc), IIoT partner (PTC), and cybersecurity partner (Claroty) were all on display.

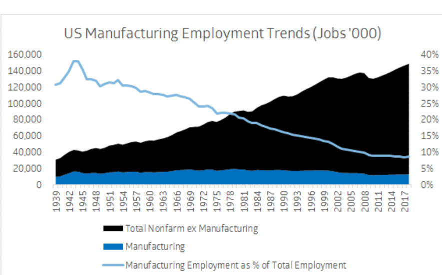
Rage Against The Machine – Examining The Human Element Of Robot Deployment

Investment Consideration #5: Large scale transition from labor to robotics generally comes with negative near-term job implications and requires re-training to fill skills gaps.

There is no getting around the fact that the very near-term impact of robot deployment on jobs is negative – simply put, certain human tasks are immediately replaced the minute the power is turned on. Tractors have replaced farmers in the field, assembly lines re-imagined the auto plant, and computers perform tasks more quickly and more correctly than any human workers. In the manufacturing industry in particular, the introduction of industrial robots in the late 1980s led to the automation of labor-intensive tasks, including machining, welding, painting, palletizing, assembly, material handling, and quality control. Further advancement in AI could lead to ultimately replacement of more cognitive based tasks as well, whereas historically this was limited to the "Three D's" – dirty, dull, and dangerous tasks.

In the absence of an accurate framework – to be fair, this is a very complicated subject – we have found quite polarizing opinions from economists, engineers, CEOs, heads of tech and labor unions. At one end of the spectrum, some argue that automation will spell doom for the fate of human workers, and on the other, some claim that new technologies will ultimately increase the demand for labor, as it has been in the past. The truth is likely somewhere in the middle. In their paper (here) David Autor and Anna Salomons used nearly four decades of data from 28 industries in 19 OECD countries. They have found that technological progress is broadly employment augmenting in the aggregate, though relatively small – 6% from 1970 to 2007. The net positive effect comes from the productivity spillovers that one industry's automation has on its customers and suppliers.

US Data Shows Improving Manufacturing Labor Data Despite Robotic Deployment

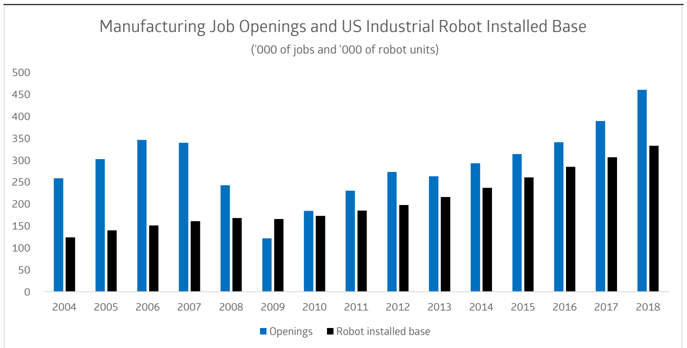


Source: Bureau of Labor Statistics, Cowen and Company

Manufacturing employment in the US as a % of total employment has been in a consistent decline since the 1940s – a combination of the emergence of new, faster growth markets, a steady offshoring of production jobs to low cost countries, and elements of robotics/automation. Manufacturing share of employment peaked at nearly 40% and today stands at just ~8.5%.

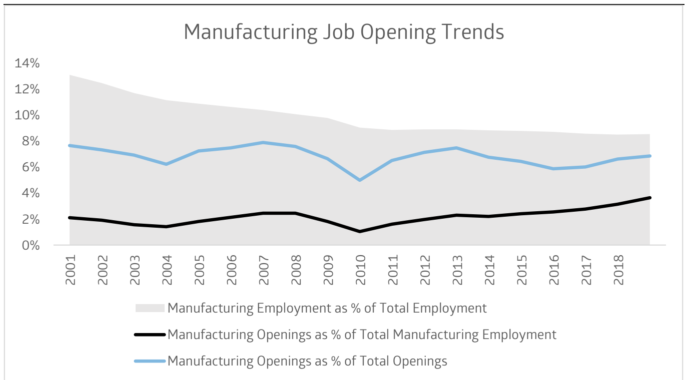
Over the past 10 years, however, manufacturing job openings have grown on pace with robotic installed base growth. According to the IFR, we've seen a near tripling of the robotic installed base in the US since 2004, but over that same span manufacturing openings as a % of total manufacturing jobs has doubled – and it currently sits at the highest level we've seen over the past nearly 20 years. Manufacturing openings have also held steady as a % of total job openings despite manufacturing as a % of total employment declining 300 bps over the same period.

Figure 26 Manufacturing Job Openings Growth Has Kept Pace With Robot Installed Base Expansion Over The Past Decade…



Source: Bureau of Labor Statistics, Cowen and Company

Figure 27 …And Openings As a % of Total Manufacturing Jobs Has Increased To Highest Level In Nearly 20 Years

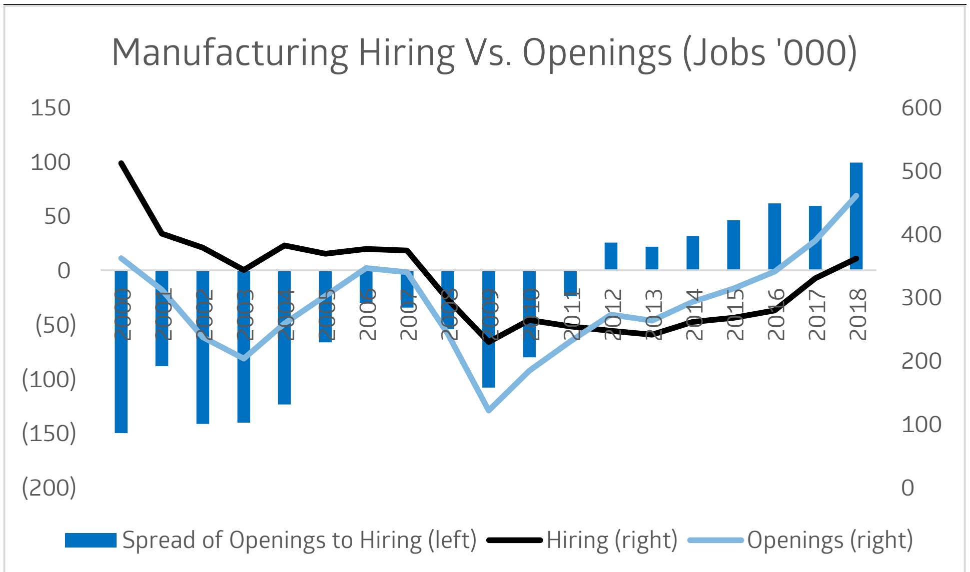


Source: Bureau of Labor Statistics, Cowen and Company

Given the idea that robotic deployment closes some doors (the repetitive tasks) while opening others (both lower level, non-repetitive jobs and higher level oversight/management jobs) – a concept which we discuss in more detail shortly – it's important to look at hiring and wage trends in addition to openings. Creating job opportunities (openings) with no one to fill them (weak hiring) doesn't accomplish much.

Over the past 5 years, manufacturing hiring has averaged ~8.5%, outpacing the broader private market at <5%. 2018 manufacturing hiring is on track to be the highest level (in gross terms) since 2007 – and at the same time the spread of job openings to total hiring is at its widest point in nearly 20 years, suggesting that jobs are being both opened and filled.

Figure 28 Spread Of Manufacturing Openings Vs. Hiring At Widest Since 2000 Despite Most Hiring Since 2007



Source: Bureau of Labor Statistics, Cowen and Company

Wages would be the other variable to consider to support the view that, in aggregate, "better" jobs are being created. Over the past 10 and 20 years, manufacturing wage growth has lagged the private sector by ~40bps per year. However, over the past 5 years that spread narrows to 20bps and over the past 3 manufacturing wage growth has narrowly outpaced private sector growth by 10bps.

Figure 29 Steady Improvement In Relative Wage Performance Despite Consistent Robot Deployment

Average Annual Wage Growth				
	3 Year	**5 Year**	**10 Year**	**20 Year**
Manufacturing	0.7%	0.8%	0.4%	0.2%
Total Private Sector	0.6%	1.0%	0.8%	0.6%
Manufacturing Spread (bps)	8	(18)	(35)	(43)

Source: Bureau of Labor Statistics, Cowen and Company

Compression Of The Middle – A Bifurcation Of The Manufacturing Labor Market

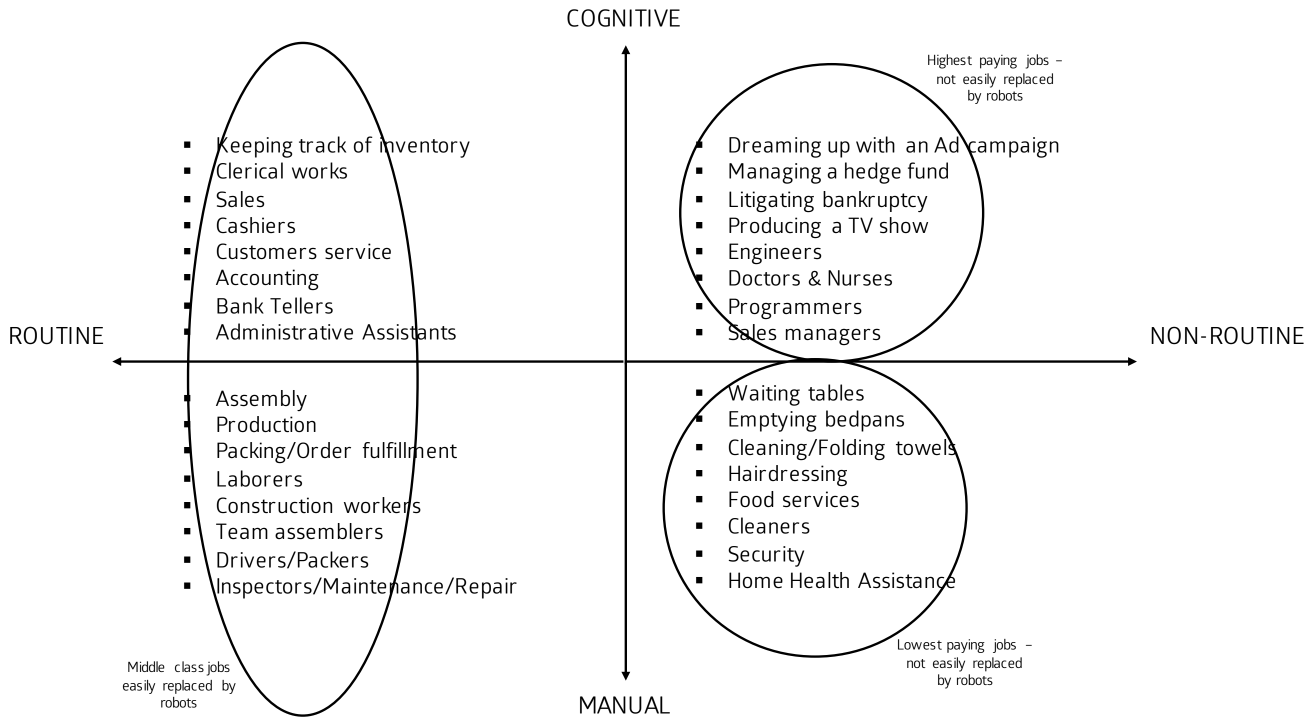
The recent developments and technological breakthrough in artificial intelligence and adaptive robotics are leaving an increasingly small set of activities in which labor can add significant value. Below we explore the types of labor that is more likely to be replaced my machines.

Historically, factory automation and robotics have replaced lower-skilled workers on factory floors. As robots added capabilities, the type of jobs that they started displacing required higher skills and education. In their NBER working paper (here), Daron

Acemoglu and David Autor argue that instead of thinking of jobs being only either manual or cognitive in nature, they should also be classified as routine and non-routine.

The common misconception about robots replacing workers is that it applies only to manual jobs and that all manual labor will ultimately be replaced. This is inaccurate for two reasons: 1) Not all manual labor can currently be replaced by robots, and it will likely never be. Food services, cleaning, security, hairdressing, and home health aide are some example of very difficult manual tasks to be automated. 2) With the advent of computerization and greater robotics dexterity, cognitive jobs that are routine – have well-understood rules and procedures that can easily be codified – are at risk of being replaced. These include all operative production tasks, clerical work, keeping track of inventory, and some sales positions. By replacing routine jobs, rather than only manual ones, the pool of occupations that remains available are either non-routine and cognitive – engineers, doctors and nurses, programmers, lawyers, etc. or non-routine and manual (the ones described above).

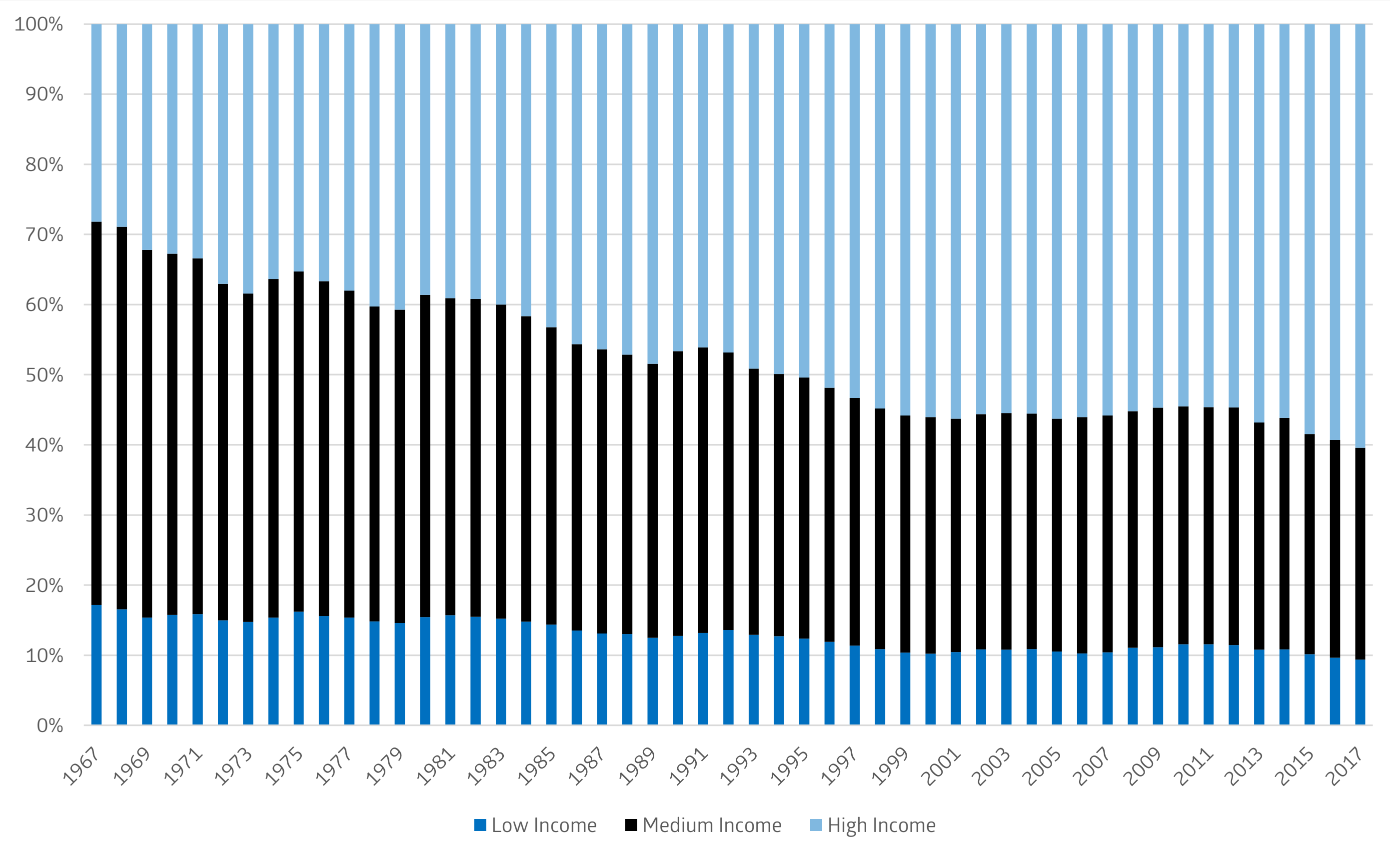
Figure 30 Types Of Jobs Potentially Impacted By Robots



Source: David Autor and Daron Acemoglu, 2010, Cowen and Company

These two sets of jobs, which lie at the two extremes of the pay scale, become the only types of occupations available if we extrapolate the exercise out. The problem with the current workforce is that no one wants the low-skill jobs and most don't have the necessary knowledge for the high-skill ones. This analysis appears consistent with longer-term trends we have seen in US median income, where we have seen material compression of the "middle income category" over time.

Figure 31 Medium Income % Has Fallen From Over 40% to ~30% With High Income Taking Share – Clear Compression Of The Middle



Source: US Census Bureau, Cowen and Company

Some Potential Socio-Economic Responses

Because of the impact on labor displacement and the relative increase of capital-intensive over labor-intensive factories, it is very likely that new policies will have to be implemented to protect worker's wages.

One proposal calls for a universal basic income, which is a sort of social safety net that guarantees a paycheck for workers who have been displaced by automation. The backlash of this proposal is the risk of creating a large pool of permanent unskilled workers that will rely on this income for life. We see this proposal as very difficult to implement in a country as capitalist as the US. A similar initiative was put to the vote in 2016 in Switzerland – a country that lies left of the US on social issues – and the results were an overwhelming rejection with 77% opposing the plan. We note that Switzerland was the first country to hold such a vote.

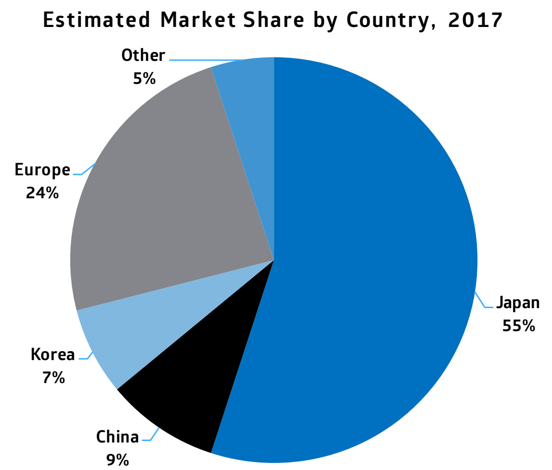
Some other models of compensation propose that government entities tax wealthy capital owners and redistribute income to workers (which sounds like the plot of *Atlas Shrugged*), though that is not the direction most countries are currently taking. Workers are likely better off owning capital than relying on governments' income redistribution policies. A model that incorporates employee ownership of stock, options, profit sharing, etc. might more sense, though would clearly be very challenging to implement in mass scale.

Competitive Landscape And Major Robot Manufacturers

Investment Consideration #6: From the US standpoint, we are almost strictly importers of robotic content – with domestic production immaterial on the global scale.

Though the total robot market is very global, the production base is quite concentrated to Japan, Western Europe, and increasingly China. The top companies include Mitsubishi, Omron, Fanuc, ABB, Yaskawa, and KUKA Robotics. All these companies are publicly traded and we note that there are no material pure-play US manufacturers of traditional industrial robots despite the fact that the US is the 3rd largest market in the world in terms of annual demand and the 4th largest in terms of installed base.

Figure 32 Global Production Concentrated Towards Japan and Europe



Major Players

China
- Saisun
- Efort
- GSK
- Estun
- STS
- Greatoo

Japan
- Mitsubishi Electric
- Omron
- Fanuc
- Kawasaki Heavy Industries
- Yaskawa

Europe
- Kuka
- ABB

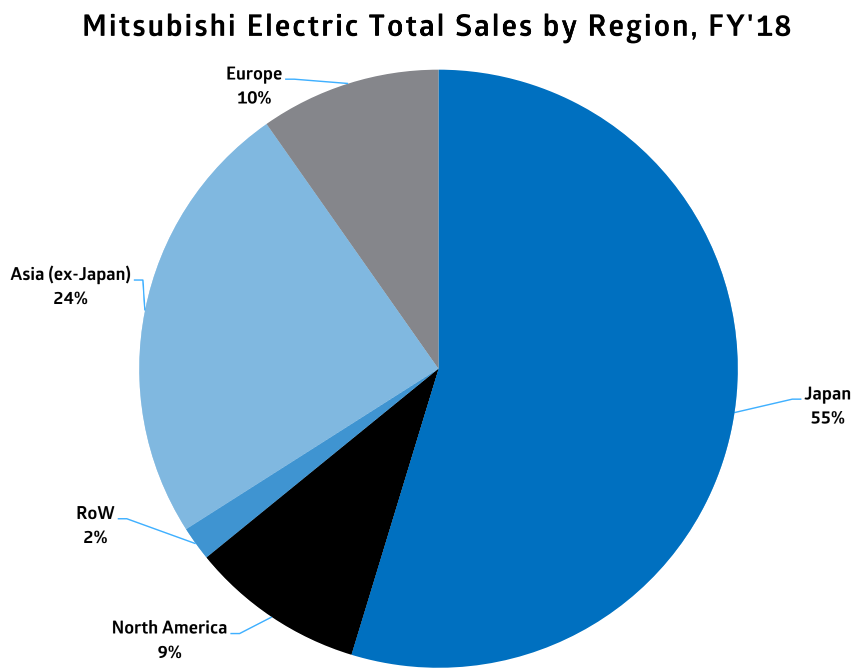
Source: IFR- World Robotics 2018, Cowen and Company

Mitsubishi Electric (6503.T – Japan)

Sales of Mitsubishi's Industrial Automation Systems (includes robotics) in FY'18 was ~$12.8B, while operating income was ~$1.7B (operating margin of 13.2%) and accounted for roughly a third of total revenue and ~60% of total operating income. Total company operating margin for 2018 was 7.2%.

IAS segment sales have been outpacing total company sales growth – IAS segment sales have grown at a 4-year CAGR of 7.1% vs total company sales growth of 2.3%. Operating income has expanded at a 4-year CAGR of 18% vs total company operating income growth of ~7.9% over the same time period.

Figure 33 Sales Levered To Japan / Asia

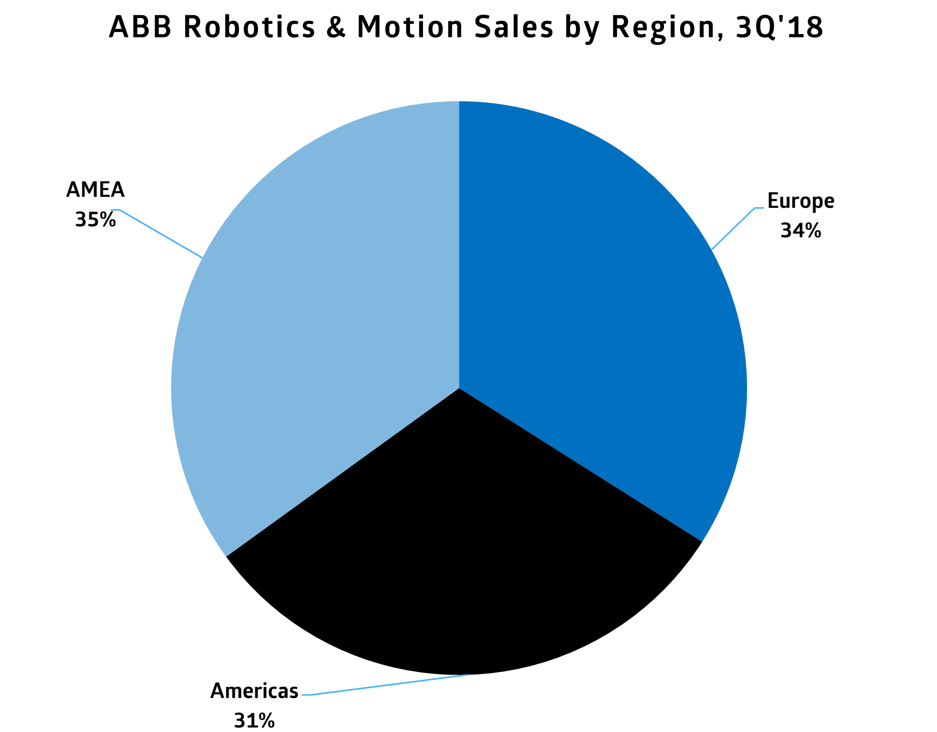


Source: Mitsubishi Electric, Cowen and Company

ABB (ABB – Switzerland)

ABB considers itself the #2 supplier of industrial robots globally. ABB's Robotics and Motion segment generated Revenue of $8.4B in FY 2017, up 6.1% y/y, and accounted for 24.5% of total company sales ($34.3B). In 2017, Robotic and Motion segment operating EBITA was ~$1.18B (operating EBITA margin of 14%) and accounted for ~28% of total company operating EBITA of ~$4.15B (total company operating EBITA margin of 12.1%).

Figure 34 ABB Sales Balanced Globally



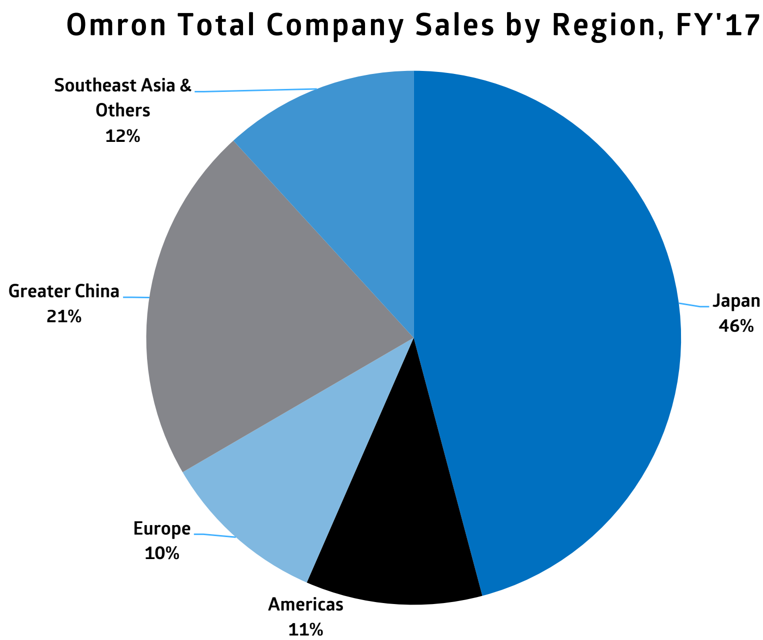
Source: ABB, Cowen and Company

Omron (6645.T – Japan)

The company's Industrial Automation segment, which includes robotics, generated ~$3.5B in revenue FY 2017 and accounted for ~46% of total company revenue. Operating income for the IAB segment was ~$657MM for FY 2017, for an operating margin of 18.7%. Total company operating income for FY 2017 was ~$763MM in 2017, for an operating margin of 10.0%.

The Industrial Automation business has been outpacing overall company growth on both Sales and operating profit over the last five years. The 5-year CAGR for IAB segment Sales was 8.5% vs 5.7% for the total company. The 5-year CAGR for IAB's operating income was 18.8% vs 13.7% for the total company.

Figure 35 Nearly 80% Of Sales To Asia Pacific Region

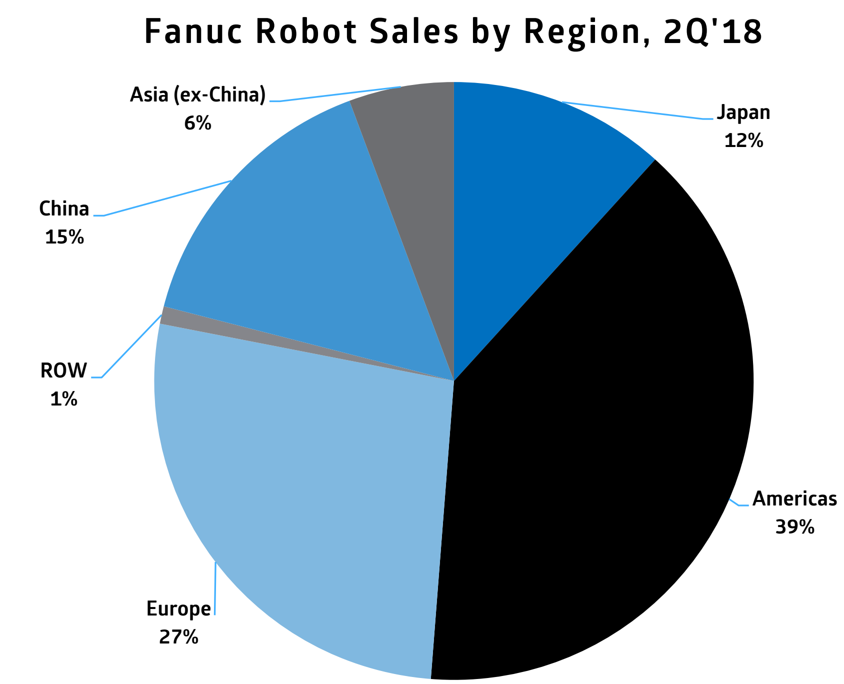


Source: Omron, Cowen and Company

Fanuc (6954.T – Japan)

In FY 2017, Fanuc Robot segment Sales totaled ~$2.0B and accounted for 31% of total company sales. Sales within the Robot division grew at a 3-year CAGR of 13.3% vs -0.1% for total company Sales.

Figure 36 2Q18 Sales Balanced Geographically



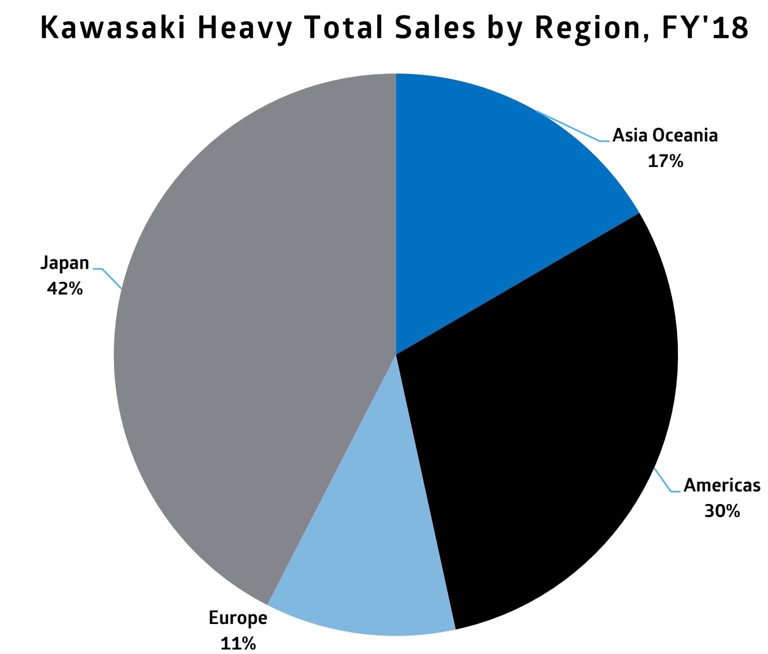
Source: Fanuc, Cowen and Company

Kawasaki Heavy Industries (7012.T - Japan)

In fiscal 2018, the Precision Machinery and Robot segment generated net Sales of ~$1.79B which was 12.6% of total company net Sales. The segment reported operating income of ~$195MM for an operating margin of 10.9% (vs overall company operating margin of 3.6%).

The Precision Machinery and Robot segment net Sales have expanded at a 4-year CAGR of 12.7%, outpacing total company net Sales growth of 3.2% over the same time. Margins have been steadily improving for the segment, operating margin expanded from 6.4% in FY 2016 to 10.9% in FY 2018.

Figure 37 Sales Weighted Towards Asia-Pacific Region In Fiscal 2018



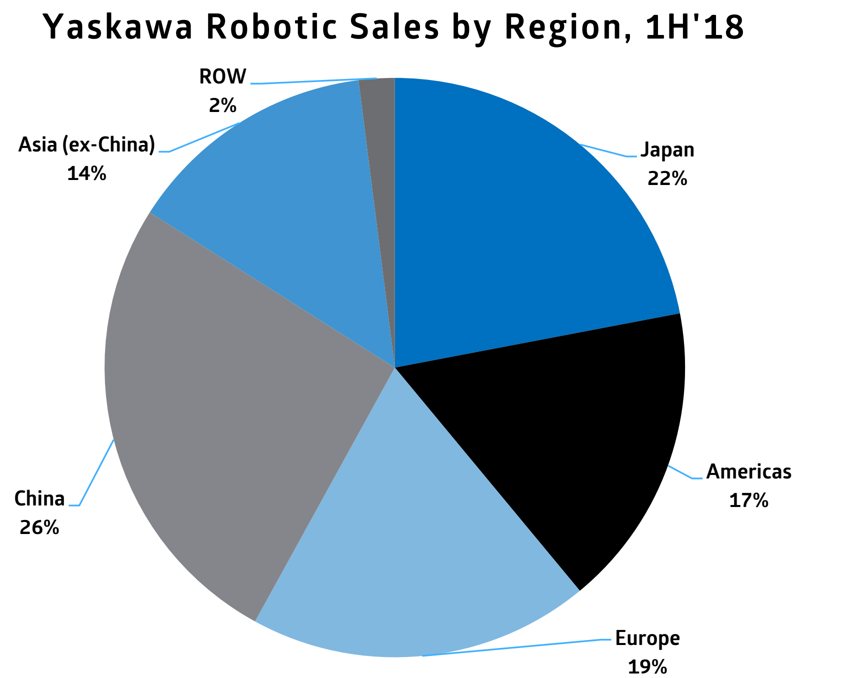
Source: Kawaski Heavy, Cowen and Company

Yaskawa (6506.T – Japan)

In 2017, the sales of Yaskawa's Robot division was ~$1.48B and accounted for 36% of total company Sales. Operating income for the segment was ~$164MM (11.1% margin) and accounted for ~32.4% of total company operating income.

Sales within the Robot division have been growing in line with total company sales over the last 5-years. The 5-year CAGR for the Robot Division Sales was 8.7% vs 8.4% for the total company.

Figure 38 Over 60% Of Sales To Asia Pacific



Source: Yaskawa, Cowen and Company

Kuka (KU2G.DE – Germany)

Kuka's Robotics division generated Sales of ~$1.05B in 2017 and accounted for ~34.5% of total company sales. The Robotics division EBIT was ~$117MM, margin of 11.1% (improved from 10.1% in FY 2016). Sales for the total company grew at a 5-year CAGR of 14.9% vs 10.1% of the Robotics division.

Kuka total sales in 2017 were split North America 39%, Europe 38% and Rest of the World at 23%, while Robotic segment orders by industry for 2017 were split, Service 18%, Automotive 35% and General Industry 47%.

Figure 39 Kuka Sales Fairly Balanced Geographically

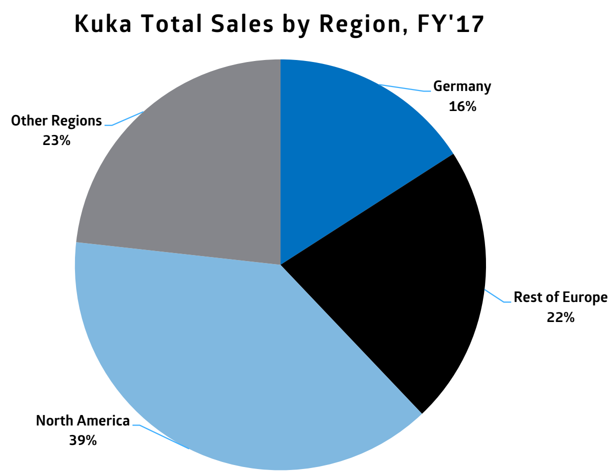
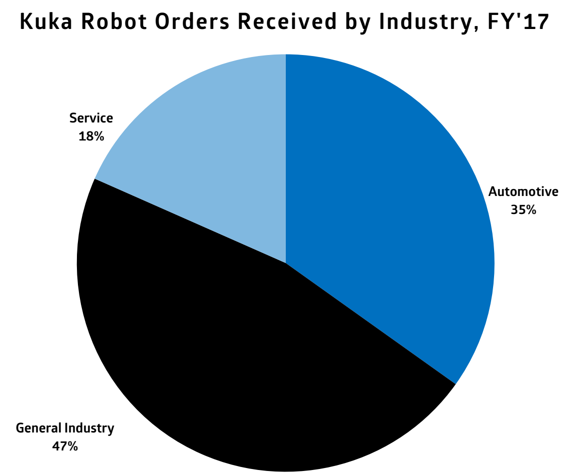


Figure 40 Automotive and General Industry Account For Over 80% Of Kuka's Robot Orders



Source: Kuka, Cowen and Company

Primer – A Brief History Of Robotic Development And Capability

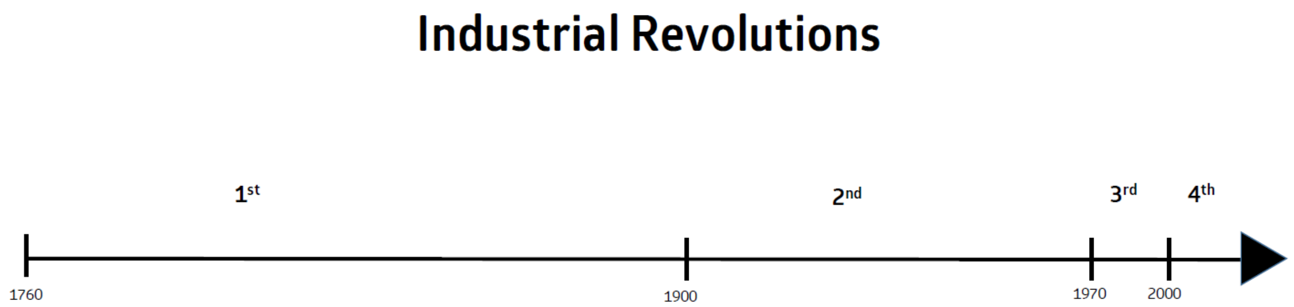
Machine vision coupled with the Industrial Internet of Things, will enable machines to process images and understand what they are "seeing" on a more complex level than ever before. As this technology evolves, the next step is to give robots the ability to learn on their own. Currently, a robot can be programmed to pick and place items, but are evolving towards the ability to program itself through trial and error. Academic research is currently focused on expanding the ways humans can interact with robots, including voice, gestures and recognizing intent from human motion.

Below we explore deployment timelines, capability evolution, and the types of robots available in the market today.

Automation And Robotics Through Time

From a handicraft economy to one that involves machines manufacturing machines, the world went through what is commonly known as four industrial revolutions.

Figure 41 Industrial Revolution Timeline



The first industrial revolution began in the late 18th Century
- Improved steam engine
- Steam powered mechanical production
- Development of machine tools

The second industrial revolution began at the turn of the 20th Century
- Electrical Energy
- Oil & Gas
- Mass production
- Assembly lines
- Telegraph & Telephone
- Elevator
- Motion Pictures
- Refrigerators
- Automobile

The third industrial revolution Began in the early 1970s and is still ongoing
- First commercially available Robots
- Nuclear Energy
- Electronics
- Computers
- Internet
- Mobile Phones

Term Fourth Industrial Revolution coined in 2016
- Wide spread adoption of robotics and automation
- Cloud Computing
- IIoT
- Cognitive computing
- Mass customization
- Artificial intelligence

Source: Cowen and Company

The 1st Industrial Revolution – End Of The 18th Century

It all started in Britain when the country's economic development was led by the introduction of mechanical production facilities powered by steam. Some of the first machines, such as the spinning jenny – used for spinning more than one spindle at a time for the weaving industry – allowed increased production with less human capital. The division of labor and the specialization in some sub-functions led to new organizational schemes on the factory floor and increased productivity. The steam engine and other technological changes permitted industries to use a greater array of natural resources and the beginning of mass production of manufactured goods. The British had a monopoly on manufacturing techniques early on, though some entrepreneurs saw the opportunity to export that know how to continental Europe. That transition first took place in Belgium and France before coming into Germany in the second half of the 1800s. It took only about 30 years for the German economy to outpace Britain in steel production and become the world leader in chemical industries. The US and Japan joined the industrial revolution later in the 19th and 20th century at a pace that was far greater than their European counterparts. Eastern Europe, and especially the Soviet Union invested heavily in the early 20th century to become a major industrial power. Finally, the mid-20th century saw the rise of the industrial revolution in non-industrialized nations such as China and India.

The 2nd Industrial Revolution – Start Of The 20th Century

The second industrial revolution largely overlapped the first one. The evidence of a new "revolution" took place with the introduction of electrical energy that led to wide adoption of a mass production business model that was based on the division of labor. More modern factories were able to use new alloys of lighter metals and synthetic products, including plastics. Products were increasingly manufactured using assembly lines, which simplified work flow and made repetitious procedure more cost-effective. However, this sort of automated manufacturing was still relatively expensive and only made economic sense if the products were manufactured with a high level of output.

The 3rd Industrial Revolution – Start Of The 1970s

The late 20th century saw the introduction of the use of electronics and information technology for further automatization of production. In the early 1970s, both ABB and KUKA offered the first industrial robots that were commercially available.

Figure 42 The IRb-6 Robot From ABB (Formerly ASEA)

Source: ABB

Figure 43 The KUKA Famulus – One Of The First Industrial Robots Commercially Available

Source: KUKA

In the late 70s and early 80s, when robots where becoming very popular, several large US industrial companies that included GE and GM entered the field of robotics and where joined by several startups. However, none of them survived the rise of Japanese companies such as FANUC and Yaskawa.

The 4th Industrial Revolution - Today

Commonly referred to as industry 4.0, the fourth industrial revolution is the one taking place today. It involves not only physical robots and systems, but also the internet of things and cognitive computing, such as machine learning. Automation and robotics have been embraced largely because the sort of products that are manufactured could not be effectively done so with humans any longer. Components are too small, production lines are too fast, and the level of accuracy required in most processes can only be achieved with machines. The newest technology has also given rise to mass customization where investing in robotics becomes cost effective even at lower production volumes. However, there are several challenges that need to be addressed to fully embrace this next generation of fully automated assembly operation – such as economic benefit, the lack of a qualified workforce, and the geolocation of the supply chain, to name a few.

Robot Precision

We have come a long way from the first Industrial Robot, the Unimate, which was installed on the General Motors assembly line at the Inland Fisher Guide Plant in Ewing Township, New Jersey in 1961. According to McKinsey & Company, today's general-purpose robots are accurate to within 0.10 millimeters, while some robots have repeatable accuracy of 0.02 millimeters. In applications outside of industrial robotics (specifically robot assisted surgeries), the movements can become as precise as 1 micron, or 1/50 the diameter of a human hair.

As robots have evolved, the number of axes in industrial robot arms has increased, which has made the challenge of improving accuracy all the more difficult. No robot is 100% accurate, all have some margin of error. As the number of axes increase, compounding of minute errors at each axis is an issue that robot manufacturers continue to face. For example, on a six axis robot arm, the error of each axis will contribute to the overall positioning error – if there is a small error at the first axis (near the base), this will be compounded by other errors at the remaining five axis, by the time we get to the end-effector, the error can be significant.

There are numerous factors which impact accuracy - weight of the end-effector or payload, foundation the robot is fixed upon, proximity to other machines, velocity, acceleration and deceleration. Nonetheless, technological advancements, including sophisticated encoders and extremely precise gearboxes, have enabled robots to become more coordinated and accurate overtime. Further advancements in accuracy will likely come from continued improvements in sensors, further integration of machine vision and AI driven machine learning.

Types Of Robots

There are five main types of industrial robots: Linear, SCARA, articulated, delta, and cylindrical. Each has its pros and cons and favored industrial applications.

Linear Robots

These robots are also defined as Cartesian or gantry. They usually have two or three linear joints whose axes are correlated with a Cartesian coordinate system. As their name implies, the robots' motion takes place on a straight line rather than a rotational plane. 3D printing and CNC machining use linear robots. Pick and place machines as well as plotters use this type of robots.

Figure 44 Example Of A Linear Robot

Source: Yamaha

SCARA Robots

The SCARA acronym stands for Selective Compliance Articulated (or Assembly) Robot Arm. The robot's arms are fixed in the Z-axis but can rotate around the X and Y axes. Because the robot's arm can extend and retract in confined area, it is often used to transfer parts from one station to another, making it ideal for loading/unloading solutions. SCARA robots are usually faster than linear robots, though more expensive.

Figure 45 Example Of A SCARA Robot

Source: FANUC America

Articulated Robots

Probably the most common in the mind of people when thinking about "industrial robots". Articulated robots have at least three rotary joints but can easily have up to 10 or even more interacting joints. Because of all their axes, articulated robots have more degrees of freedom than the other types of robots, which makes them more versatile than other options to perform in a wide array of industrial applications, including welding, material handling, dispensing, assembling, and processing.

Figure 46 Example Of An Articulated Robot

Source: ABB

Parallel/Delta Robots

Delta robots are types of parallel robots that use three arms that are connected at the base. The movement only takes place in the X, Y, and Z directions with no rotation, essentially restricting the base to a pure translation. These types of robots are ideal for picking and packaging due to their quickness. Some 3D printers also use delta robots.

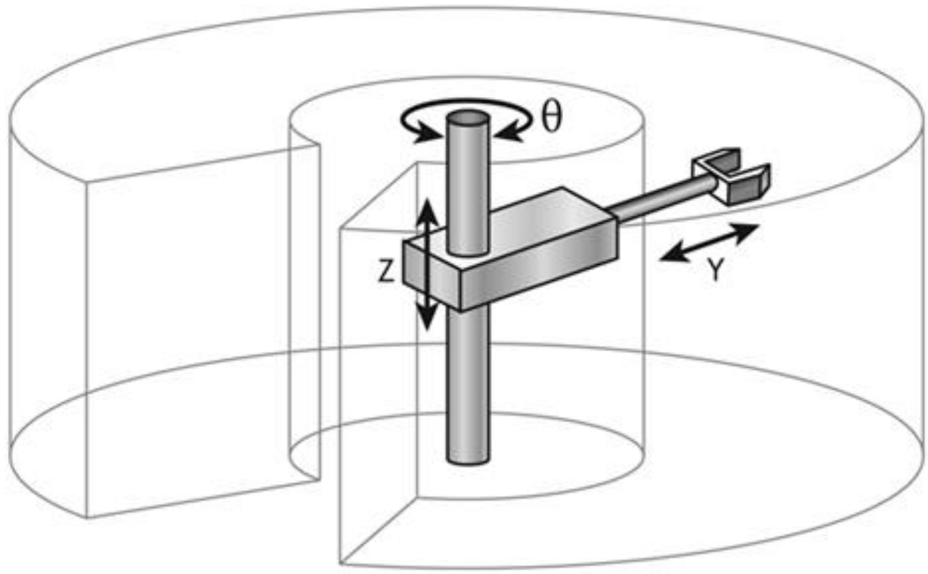
Figure 47 Example Of A Delta Robot

Source: Omron

Cylindrical Robots

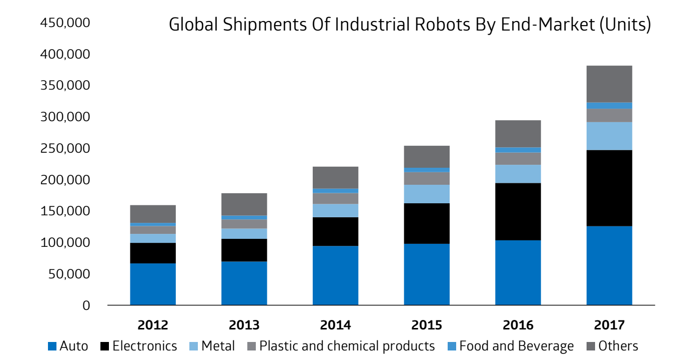
Cylindrical robots have three axes of movement: two are linear and one circular. They are called cylindrical due to the form of the work envelop in which they can perform. Cylindrical robots usually move linearly in the X and Z axes, and rotate around the Y axis. They are used in an industrial setting for assembly operations, handling, and welding.

Figure 48 Example of a cylindrical robot



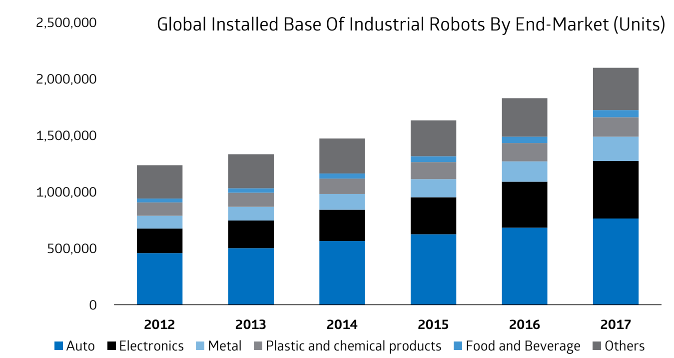
Source: Machine Design

Figure 49 Global Shipments By End-Market



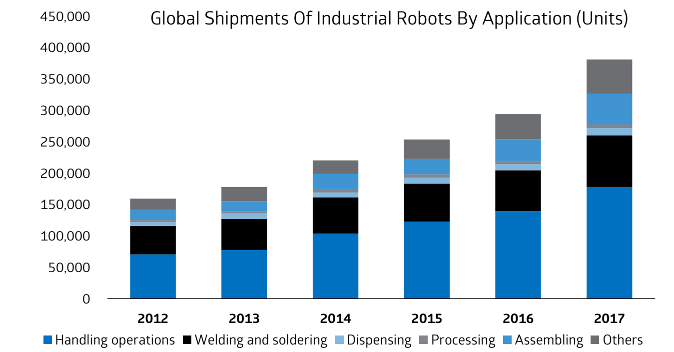
Source: IFR – World Robotics 2018, Cowen and Company

Figure 50 Global Installed Base By End-Market



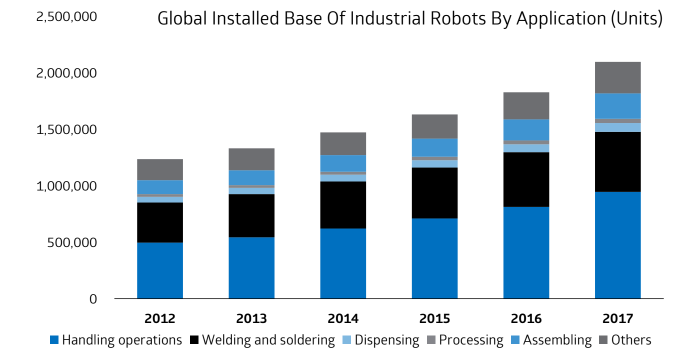
Source: IFR – World Robotics 2018, Cowen and Company

Figure 51 Global Shipments By Application



Source: IFR – World Robotics 2018, Cowen and Company

Figure 52 Global Installed Base By Application



Source: IFR – World Robotics 2018, Cowen and Company

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Ticker	Rating	Price*	Price Target	Ticker	Rating	Price*	Price Target
AME	Outperform	$72.08	$85.00	**CGNX**	Outperform	$45.01	$45.00
APH	Outperform	$85.65	$110.00	**ROK**	Underperform	$171.46	$150.00
ST	Market Perform	$45.66	$55.00	**TEL**	Outperform	$74.17	$100.00

**As of 12/04/2018*

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A general decline in the industrial production index, coupled with a global decrease in automation spending as a percentage of total capex could negatively impact the sector and the implied industry growth rate.

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ADDENDUM

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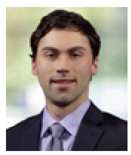

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