BERNSTEIN

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THE ROBOT RENAISSANCE – CHINA INVESTMENT, GLOBAL IMPLICATIONS

Investing for technology super cycles, policy certainty, and future champions

China is 30-50% of global automation, where the changing tech regulatory environment and demographic trends are sector tailwinds. Its expeditions impact global players profoundly.

In four interwoven super cycles — the robot renaissance, the ubiquitous use of vision, the proliferation of collaborative robots, and the commercialization of AI — China is where high-end, innovative solutions emerge.

Local substitution continues with inflections. Embrace changing pace, migration of battlefields, "duel risks," and shuffling of local winners. In-depth understanding of technology is important for stock picking.

Investing beyond the cycles, investors are advised to focus on accelerating share gain (Estun), robotic/vision super cycle (Estun, FANUC, and Keyence), and the takeoff of AI in manufacturing (Hikvision). In the last field there are also several successful startups.

PORTFOLIO MANAGER'S SUMMARY

It is the best of times, it is the worst of times; it is an exciting time to invest in Chinese automation despite an expected economic downturn, seemingly tightening tech regulation, a war elsewhere, and global supply chain disruptions. China is already 30-50% of global automation. Investing in Chinese automation today is to invest for the certainty of policy and demographic tailwinds, for adoption super cycles, and for future global champions.

Reversing a decade-long trend, China's 14th Five Year Plan (FYP) (2021-25) and 2035 Long-Range Objectives decisively raised the strategic importance of the manufacturing sector. Advanced manufacturing, for which automation is a key enabler, is arguably the leading beneficiary of China's changing tech regulatory environment.

Policy support, aggravating manufacturing labor shortage, technology progress, and improving user economics drive four interwoven technology adoption super cycles, globally and in China: the robot renaissance ("rob-aissance"), the ubiquitous use of vision, the proliferation of collaborative robots, and the successful commercialization of AI in manufacturing. The first two are established technologies lending themselves to quickly diversifying industries, processes, and SMEs; their markets will likely expand at a 15%+ CAGR over the next decade. The latter two have just entered the steep climbing section of the adoption S-curve. For them, 2022 is like 2012 for robotics in China or 1982 in Japan. In these newer areas, unlike mature technologies, China is where the high-end demand and most innovative solutions are first emerging.

In the last few years, the competitive landscape in China has been very dynamic, bearing profound global implications. Local substitution is fastest in fiber laser, AC servos, SW reducers, collaborative robots; but there is surprising resilience in others. One should expect multiple inflections. Be prepared for acceleration (e.g., RV reducers), deceleration (e.g., motion control), migration of battlefields (e.g., from fiber lasers to laser diodes), and most important, the "duel risks" associated with over-profitable local champions. In-depth understanding of technology is important for stock picking.

Facing an economic down cycle in 2022, we advise investors to focus on accelerating market share gain (Estun), robotic/vision super cycle (Estun, FANUC, and Keyence), and the takeoff of AI in manufacturing (Hikvision). The last field saw the rise of successful startups such as AInnovation, Mech Mind, and Aqrose. Foreign automation companies will face stronger competition, but China continues to need advanced industrial tech, and decoupling is not part of its policy goal. At least two global leaders, Keyence and FANUC, will continue to do well in China, we believe.

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EXHIBIT 1: **Financial overview**

5/Apr/22	FANUC	Harmonic Drive	Keyence	Cognex	IPG Photonics	Estun	Han's Laser	Hikvision	Inovance	Hollysys
Ticker	6954 JP	6324 JP	6861 JP	CGNX	IPGP	002747 CH	002008 CH	002415 CH	300124 CH	HOLI
Rating	**O**	**U**	**O**	**M**	**M**	**O**	**O**	**O**	**M**	**O**
LC	*JPY*	*JPY*	*JPY*	*USD*	*USD*	*CNY*	*CNY*	*CNY*	*CNY*	*USD*
Share Price (LC)	21,915	4,275	58,770	77.80	105.17	19.89	37.32	40.72	56.23	16.32
Target Price (LC)	**29,000**	**3,500**	**75,000**	**75.00**	**154.00**	**39.00**	**66.00**	**75.00**	**75.00**	**24.00**
Up(Down)side potential	32.3%	(18.1%)	27.6%	(3.6%)	46.4%	96.1%	76.8%	84.2%	33.4%	47.1%
TP implied P/E (2022E)	41.1x	39.9x	53.6x	45.3x	30.0x	112.4x	32.5x	31.0x	54.7x	10.7x
Market Cap (LC Mil)	4,203,644	411,525	14,253,277	13,951	5,606	48,864	21,224	348,696	104,331	1,007
Market Cap (USD Mil)	34,010	3,329	115,318	13,951	5,606	7,672	3,332	54,745	16,380	1,007
EV/EBITDA (x) *										
FY2021E/A	18.0	25.5	31.2	39.1	8.9	151.2	7.0	16.8	26.1	23.4
FY2022E	16.8	21.8	29.2	37.1	8.7	92.3	6.4	12.9	22.7	18.0
FY2023E	15.2	19.9	26.1	34.1	7.7	61.1	5.6	10.5	19.9	16.0
P/E (x)										
FY2021E/A	26.6	69.7	50.0	49.9	20.4	110.9	19.9	22.8	46.8	10.0
FY2022E	31.1	48.8	47.2	47.0	20.5	57.3	18.4	16.8	41.0	7.3
FY2023E	28.0	41.0	42.0	41.6	18.0	34.2	15.9	13.7	36.1	6.5
EPS										
FY2021E/A	822	61	1,176	1.56	5.16	0.18	1.88	1.79	1.20	1.63
FY2022E	706	88	1,245	1.65	5.13	0.35	2.03	2.42	1.37	2.24
FY2023E	784	104	1,398	1.87	5.86	0.58	2.35	2.97	1.56	2.51

Note: Share prices are as of April 6, 2022 for Estun, Han's Laser, Hikvision, and Inovance; and April 5, 2022 for the remaining companies. FY2021 numbers are actual for Cognex, IPG, and Han's Laser, and estimates for the remaining companies. The stocks are benchmarked against the MXAPJ that closed at 591.32, the MXJP that closed at 1,199.30, and the SPX that closed at 4545.86 as of April 6, 2022.

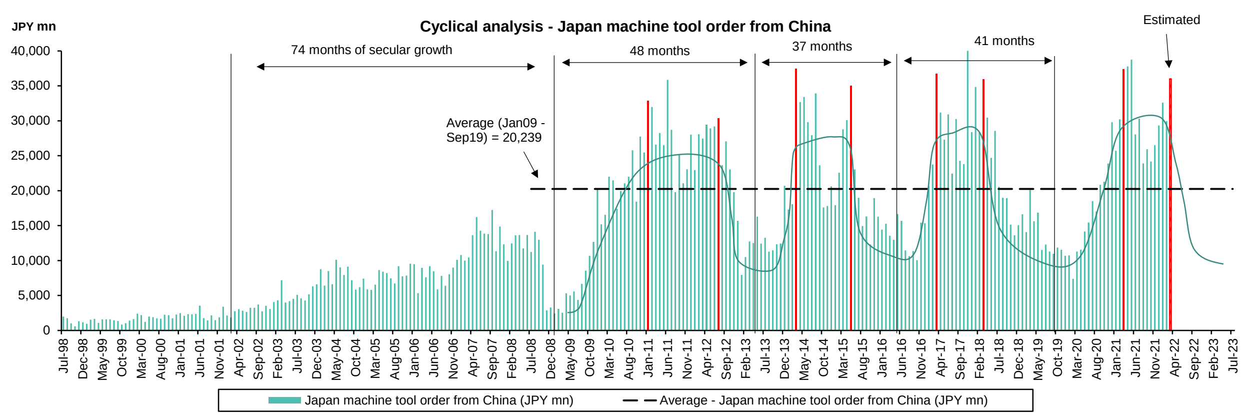
Source: Bloomberg, company reports, and Bernstein estimates and analysis

SIGNIFICANT RESEARCH CONCLUSIONS

Cycles come and go (see Exhibit 2), but for the years to come there are genuine super cycles in robots/cobots, industrial vision, and AI, thanks to China's policy support, demographic trends, and technology progress.[1] All the while, the ongoing local substitution trend shuffles winners every few years. It is these super cycles and structural shifts that make this an exciting time to invest in the sector, and in-depth understanding of technology is important for stock picking.

We advise investors to focus on idiosyncratic opportunities from accelerating market share gain (Estun), robotic/vision super cycle (Estun, Hikvision, Keyence, and FANUC), and the takeoff of AI in manufacturing (Hikvision). The last field saw the rise of successful startups such as AInnovation, Mech Mind, and Aqrose. We also advise a cautious stance toward "over-profitable" local champions that previously dominated their fields but are suddenly seeing strong competition from below. A "duel risk" will press their margins and shares.

EXHIBIT 2: **China automation is now approaching the second twin peak and will likely hit the downcycle after 1Q22**



Source: Japan Machine Tool Builders' Association (JMTBA), Bloomberg, and Bernstein estimates and analysis

FINDING TRUE SUPER CYCLES

Every cycle has its unique drivers — iPhone X and automotive capacity expansion in 2017, and EV/battery in 2021 are just part of the cycles. Battery makers, e.g., emerged as important customers of automation in 2021, but like all other industries, the investment there will be cyclical and its overall contribution is just 10-15% of automation demand (see Exhibit 3 and Exhibit 4) — this does not lead to a super cycle by itself. Instead, we identify true super cycles in the automation technologies discussed later in this *Blackbook*, where

[1] See The Playfield chapter of this *Blackbook*.

adoption is quickly proliferating to diversified industries, processes, and SMEs, driven by better technologies and labor shortages.

Amplifying these technology super cycles is China's policy inflection. Reversing a decade-long trend, China's 14th FYP (2021-25) and 2035 Long-Range Objectives decisively raised the strategic importance of the manufacturing sector. The government's new directive of stabilizing the manufacturing share of GDP will meaningfully reaccelerate investment growth in the automation sector.

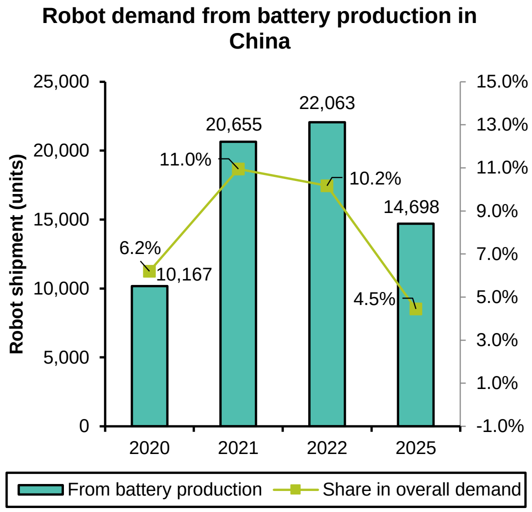
THE "ROB-AISSANCE"

In retrospect, 2016-17 marked an inflection point. Even in well-"robotized" economies, industrial robot adoption has reaccelerated since then. This phenomenon is the most profound in Japan, where robot density had remained stagnant for two decades but has increased 25% since 2017 (see Exhibit 5). This robot renaissance ("rob-aissance") is helped by advancements in robotic technology, which ushered robotic applications into diversified industries, processes, and SMEs (see Exhibit 6). Among the enablers are expanding robot SKUs, autonomous robotic path planning (vision and machine learning being critical to this), more process software packages, and improving user economics (see Exhibit 7).

Worsening labor shortages further fuel this rob-aissance (see Exhibit 8). Our analysis shows that China will need 3.4-4.2 million robots by 2030 to offset the manufacturing labor shrinkage, corresponding to an annual robot shipment CAGR of 12-16% in 2020-30, and a decent 5-8% yoy even in the downcycle in 2022-23 (see Exhibit 9).

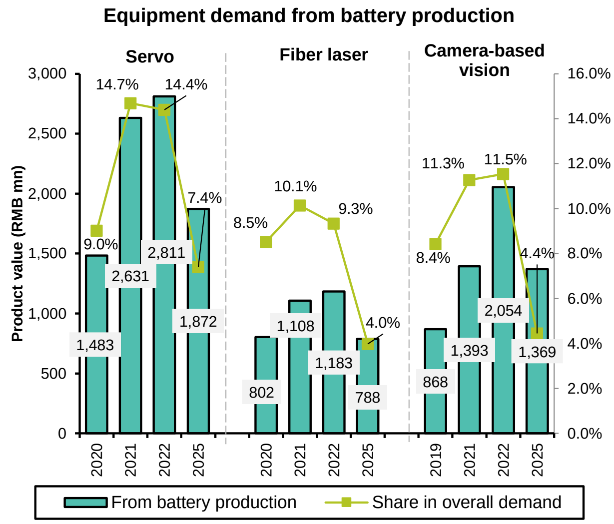
China's robot industry 14th FYP target is even more aggressive — to double robot density by 2025 from the current level, at an industry CAGR of 20%. The FYP also indicates additional supporting measures on both the demand (incentivizing broad-based robotic and smart manufacturing upgrade) and supply (supporting supply chain debottlenecking and the emergence of world-class robotic companies from China) sides.

EXHIBIT 3: **Battery industry accounts for ~10% of robot demand in China...**



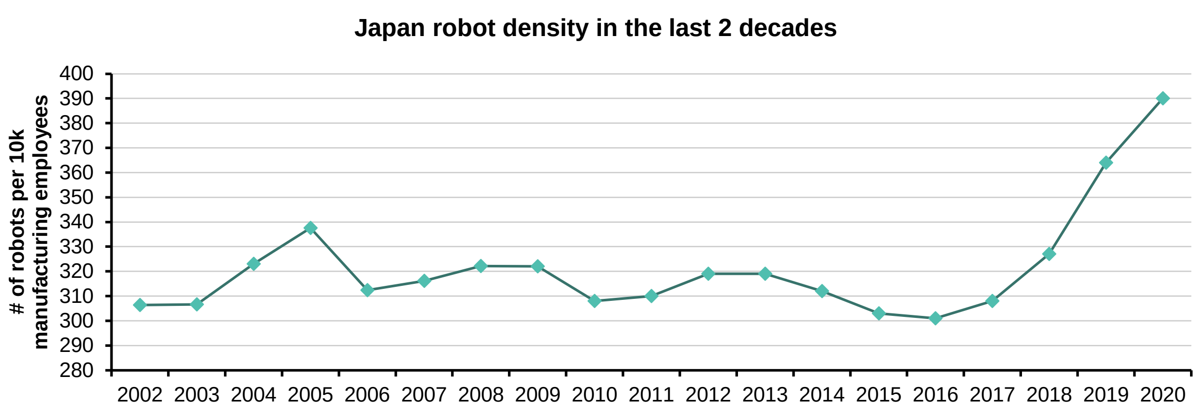
Source: MIR Databank, Bernstein Global Energy Storage team, and Bernstein estimates (2022+) and analysis

EXHIBIT 4: **...and 10-15% of servo motor, fiber laser, and machine vision demand**



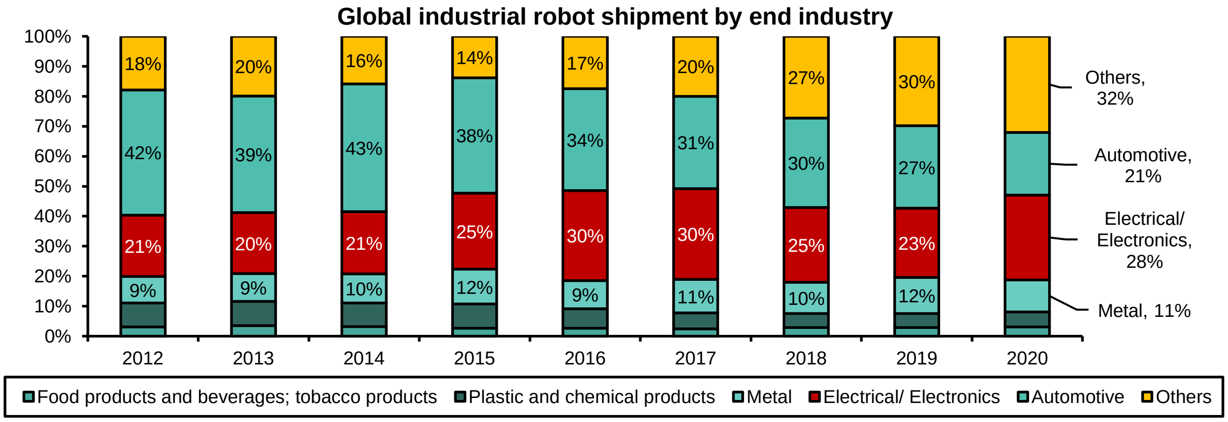
Source: MIR Databank, annual report on Chinese laser industry by Wuhan Library, Chinese Academy of Sciences, China Machine Vision Industry Union (CMVU), Bernstein Global Energy Storage team, and Bernstein estimates (2022+) and analysis

EXHIBIT 5: **Technology advances have significantly expanded the scope of industrial robot applications since 2017, resulting in a stunning re-acceleration of robot adoption in Japan**



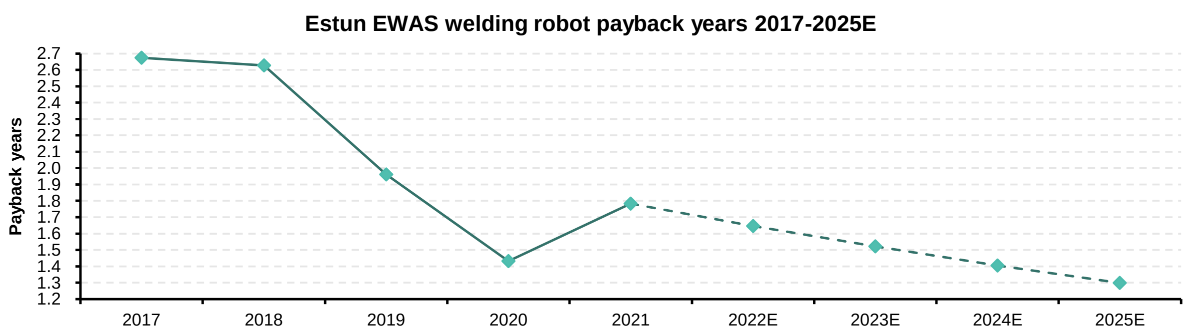
Source: International Federation of Robotics (IFR), Wind, China NBS, and Bernstein analysis

EXHIBIT 6: **Since 2017, robot adoption has meaningfully broadened**



Source: IFR and Bernstein analysis

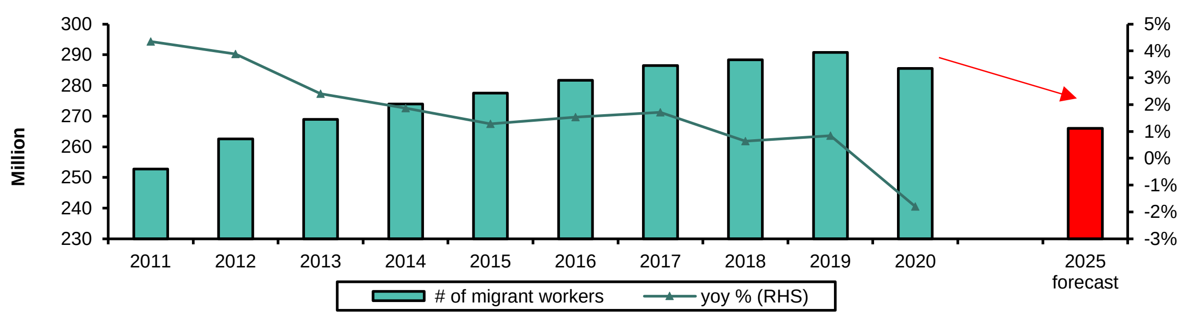
EXHIBIT 7: **Robot economics are improving fast, with payback well under two years now**



Note: We assume 5% p.a. wage inflation 2022 onward; 3% p.a. robot and integration cost deflation going forward, compared to 6% p.a. 2017-19.

Source: Jobui, various industry experts, and Bernstein estimates and analysis

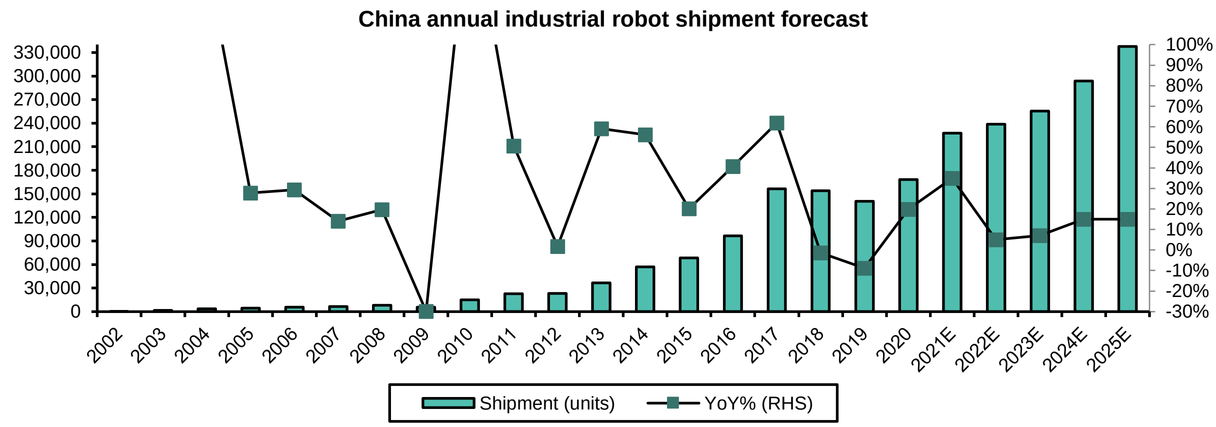
EXHIBIT 8: **2020 marked an inflection, i.e., the start of chronic shrinking of migrant worker population in China**



Note: The 2025 forecast is by Caiyi Lin, Deputy Director of the China Chief Economist Forum research institute.

Source: China National Bureau of Statistics (NBS), Wind, China Chief Economist Forum, and Bernstein analysis

EXHIBIT 9: **We forecast industrial robot shipment to maintain at least mid-single-digit growth in 2022-23, outperforming overall FA downcycle**



Source: IFR, and Bernstein estimates and analysis

THE UBIQUITOUS USE OF VISION

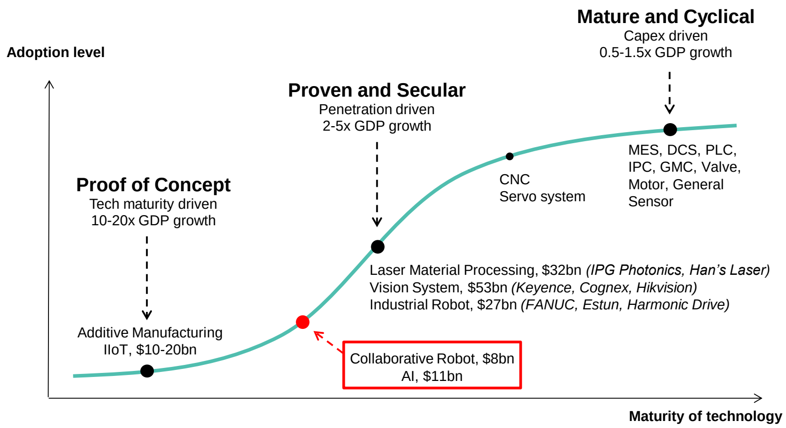
We estimate the global vision market size will reach USD53bn in 2030, implying a CAGR of 16% from the 2020 trough.[2] The overall penetration of vision technologies, averaging around 20% today across various applications, will increase to ~55% in 2030 — more mature but not quite saturating by then. Camera-based machine vision systems in China is an RMB10bn+ market today.

The adoption of vision proliferates in multiple dimensions. Its roles are expanding from presence and simple defect inspection to appearance and complex defect inspection, and from quality control to robot guiding, and other more integrated functions. Within each role, vision penetration increases naturally with the overall automation level; as human hands are replaced by machines (robots, CNC, laser tools, packaging equipment, etc.), human vision (for identification, alignment, coordination, and verification) needs to be replaced by vision sensors, critical but often unnoticed by inexperienced observers.

Two other automation technologies are in the much earlier phase of a super cycle. They have just entered the steep climbing section of the adoption S-curve (see Exhibit 10). 2022 is to cobots and AI in manufacturing what 1982 and 2012 were to robotics in Japan and in China, respectively. We expect a 30-50% CAGR in the coming decade.

[2] Within this, about one-third, or USD18bn, will likely be camera-based vision systems, and the rest based on laser and other non-camera technologies.

EXHIBIT 10: **Cobot and AI for manufacturing have reached the inflection point of accelerated adoption**



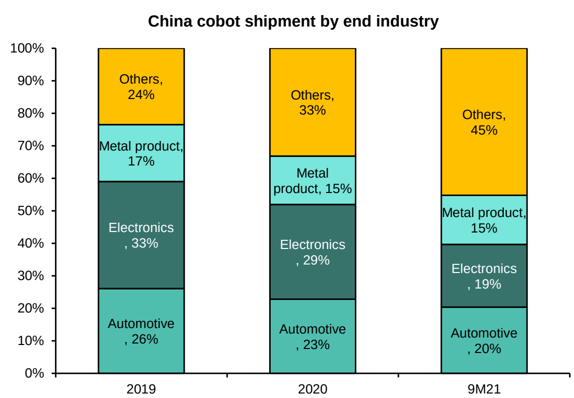
Note: Estimated market sizes are for 2025 global.

Source: Bernstein analysis

THE PROLIFERATION OF COLLABORATIVE ROBOTS

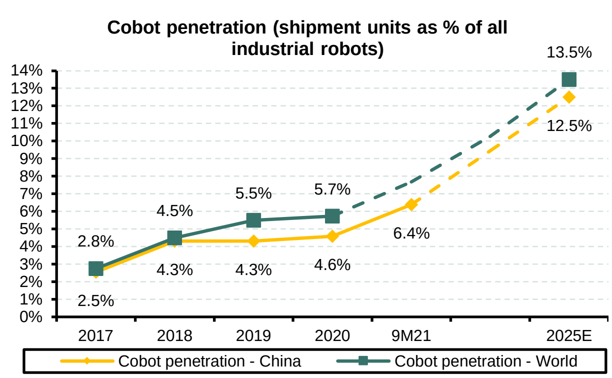
Cobots enable automation at the granular, single-worker level, so that manufacturers that cannot or do not wish to adopt fully automated lines are able to choose where and how much to automate.[3] In the last two years, cobots saw very fast expansion of use cases and customer base into diversified industries, processes, and SMEs (see Exhibit 11). This was enabled by expanding SKUs, integration/accessory ecosystem, process software packages, and shortening payback period — Chinese local cobot brands now claim one-to-two-year payback for customers (see Exhibit 13). Cobots are currently around 7% of all industrial robots both in China and globally, and we forecast this ratio to increase to the mid-teens by 2025 (see Exhibit 12).

EXHIBIT 11: **Cobot adoption is taking place in a broad range of end-industries**



Source: MIR Databank and Bernstein analysis

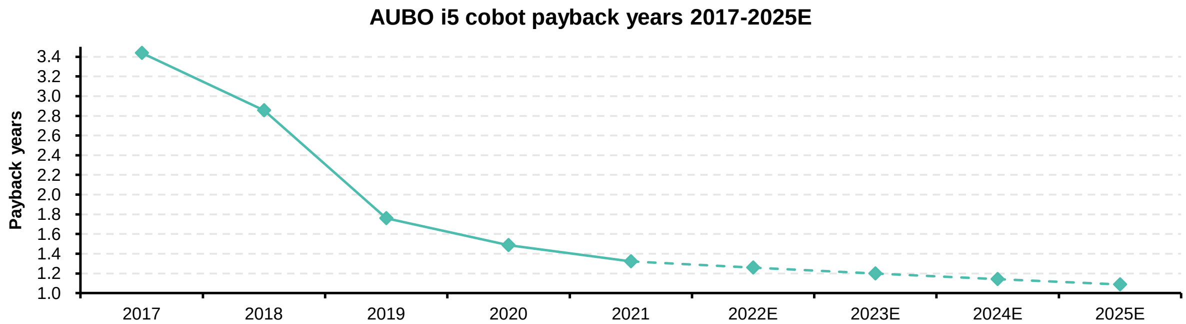
EXHIBIT 12: **Cobot penetration at ~7% of all industrial robots; forecasted to reach mid-teens % by 2025**



Source: MIR Databank, IFR, and Bernstein estimates and analysis

[3] See Collaborative Robot: Bin picking - latest progress and enabling technologies for a multi-billion-dollar opportunity, Automation: The Day After... Structural shifts post-Covid-19 & the case for unmanned factories and human-robot collaboration, The Long View: A moving boundary of automation, and The Long View: Collaborative robots, driving automation at the granular level.

EXHIBIT 13: **Cobot machine tending payback has shortened drastically since 2017, and is now well under two years**



Note: We assume 5% p.a. wage inflation 2022 onward; we assume cobot and integration cost to stay flat.

Source: AUBO Robotics, Universal Robots, MIR Databank, Jobui, various industry experts, and Bernstein estimates and analysis

THE SUCCESSFUL COMMERCIALIZATION OF AI IN MANUFACTURING

In manufacturing, AI adoption mostly takes place in three areas (see Exhibit 14): industrial machine vision, robot guiding, and industrial software, accounting for 54%, 18%, and 28% of 2025 TAM, respectively. AI strengthens, rather than substitutes for, the underlying technology and expands the boundary of their applications. For example, AI enables complex defect inspection by machine vision and robot adoption in unstructured environments that require autonomous trajectory planning.

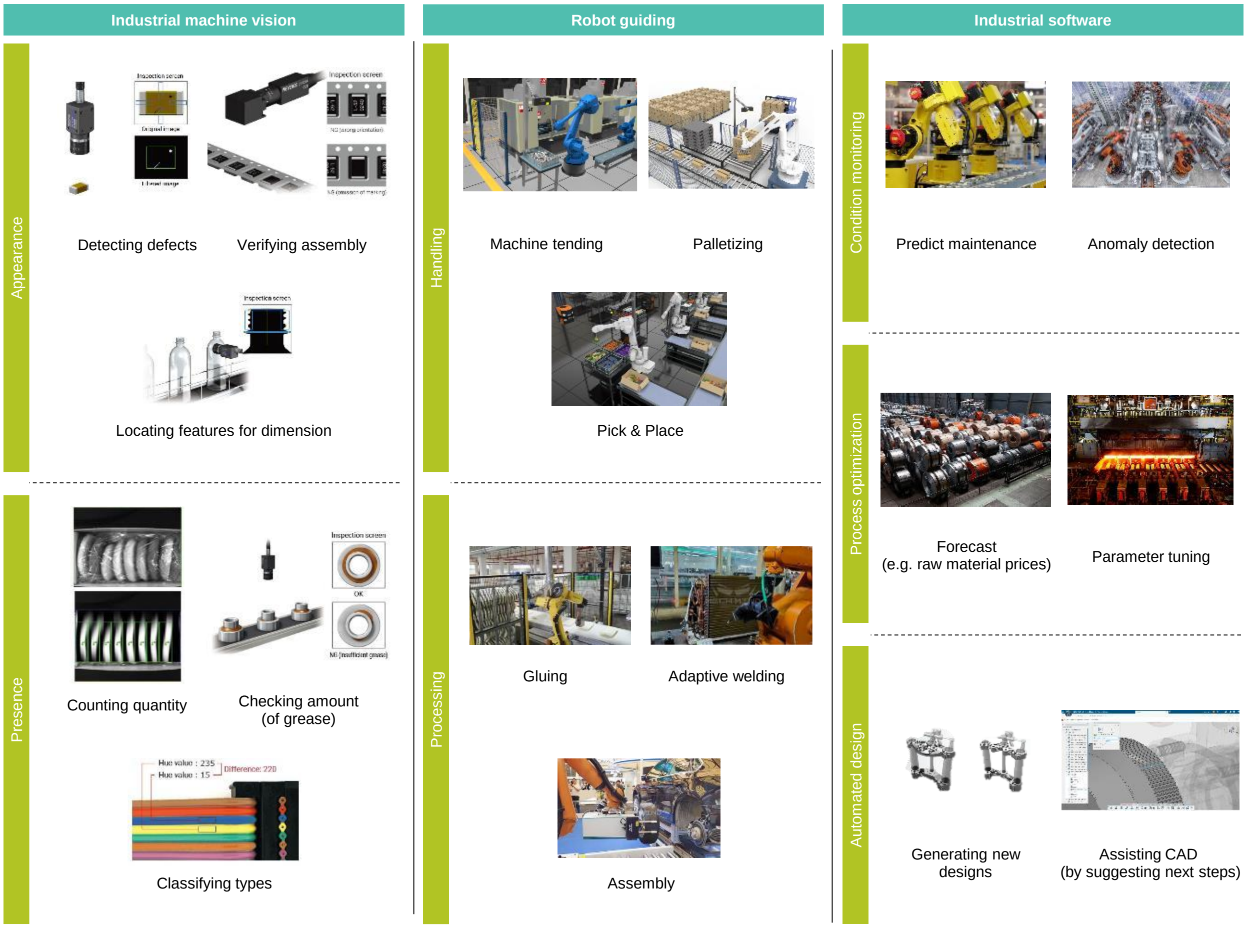
AI adoption in manufacturing is still in the very early stage, and we estimate the China market size in 2025 will reach RMB20bn, representing 28% of the global opportunity.

Only in the last two to three years have AI technologies progressed to square off the unique challenges in manufacturing. These challenges include small and unlabeled datasets, large variety of objects and tasks, manufacturing domain know-how, and labor-intensive, difficult-to-scale deployment. We believe that for a decade or longer, the AI needs in manufacturing will be diversified enough to offer distinct sweet spots to each of these three cohorts of players: manufacturing incumbents (Keyence, Cognex, FANUC, etc.), software giants as AI architects (such as Google and Amazon), and startups as AI product developers.

In China, among global and local players (see Exhibit 15), we find four successful names: Mech Mind in robot guiding; AInnovation (a recent IPO), Aqrose, and Smartmore in machine vision.[4]

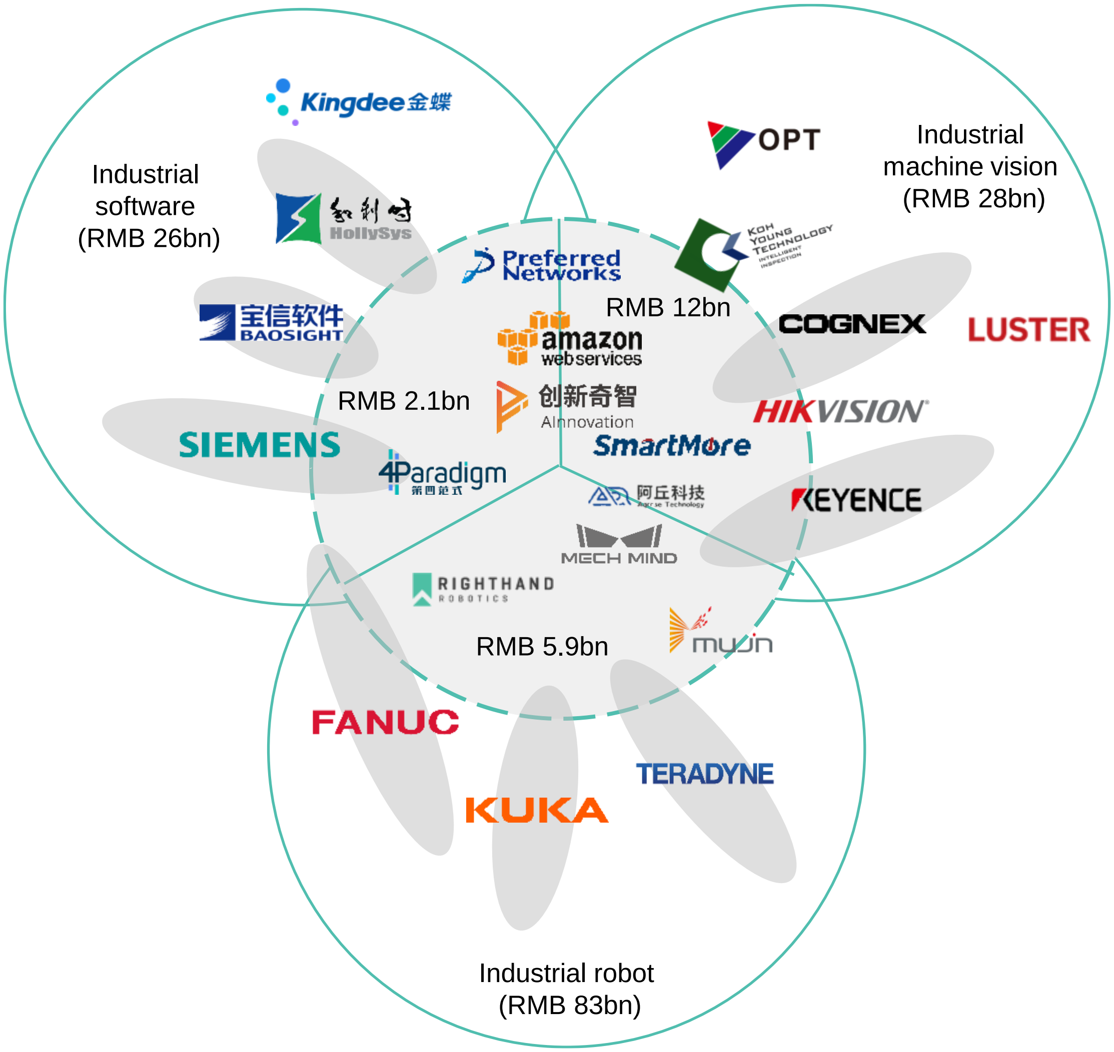
[4] Video technology, an adjacency of industrial machine vision, is also seeing increasing AI adoption in the digitalization of manufacturing enterprises and presents a great opportunity for Hikvision. See Hikvision: Full speed and five platforms toward AIoT and digital enterprise.

EXHIBIT 14: **Three major application areas of AI in manufacturing**



Source: BMW, Mech Mind, Autodesk, Keyence, Getty Images, and Bernstein analysis

EXHIBIT 15: **AI in manufacturing TAM (circle in the middle) consists of three key underlying markets and many local and global players in China**



Note: Siemens and Amazon are covered by other Bernstein teams. KUKA, Teradyne, Baosight, Kingdee, Koh Young, and OPT are not covered by Bernstein.

Source: MIR Databank, IRF, McKinsey, Cognex, Keyence, AutoDesk, and Bernstein estimates and analysis

CHINA SUBSTITUTION IN 2022 AND BEYOND: INFLECTIONS AND DUELS

Over the last few years, the competitive landscape in China has been very dynamic (see Exhibit 16). We saw the fastest local substitution in fiber laser, AC servos, SW reducers, small PLCs, and collaborative robots, but also surprising resilience of foreign players' shares in medium/large PLC, heavy-payload six-axis robots, CNCs, linear guides, sensors, etc. We do not expect a linear extrapolation of historical trends, but instead some important shifts in substitution trends going forward with profound global implications.

EXHIBIT 16: **Automation product market share trends and 2022-23 outlook in China**

Layer	Product	Market share in China																			
		Chinese major players						Local leading player							Foreign leading player						
		2017	2018	2019	2020	2021	2022E-2023E?	Name	2017	2018	2019	2020	2021	2022E-2023E?	Name	2017	2018	2019	2020	2021	2022E-2023E?
Industrial software	ERP	56%	57%	58%	59%	59%	→	Yonyou	33%	33%	34%	34%	32%	→	SAP	23%	23%	22%	22%	21%	→
Industrial software	PLM	19%	20%	20%	20%	21%	→	CAXA	18%	18%	18%	18%	19%	→	Siemens	27%	28%	29%	29%	28%	→
Industrial software	MES	24%	26%	27%	29%	32%	→	Baosight	6%	6%	7%	7%	8%	→	Siemens	9%	9%	10%	10%	10%	→
Control instrument	Small PLC	7%	8%	9%	13%	13%	↑	Inovance	3%	3%	3%	5%	7%	↑	Siemens	35%	38%	38%	36%	37%	→
Control instrument	Medium/Large PLC	0%	0%	0%	0%	0%	→	-	-	-	-	-	-	→	Siemens	50%	53%	50%	49%	49%	→
Control instrument	DCS	-	43%	35%	40%	45%	→	SUPCON	-	25%	19%	22%	28%	→	Emerson	-	16%	18%	15%	14%	→
Control instrument	CNC	21%	21%	22%	23%	25%	→	GSK	11%	11%	13%	14%	14%	→	FANUC	26%	29%	33%	32%	34%	→
Control instrument	PC-based motion controller	-	31%	31%	31%	31%	→	Googol Tech	-	15%	10%	11%	11%	→	Beckhoff	-	17%	19%	17%	18%	→
Control instrument	Low-to-mid power laser equipment controller	~90%					→	Friendess	62%	53%	62%	70%	-	→	Beckhoff	No info					→
Control instrument	High power laser equipment controller	0%	>3%	>9%	>15%	-	↑	Friendess	0%	3%	9%	15%	-	↑	Beckhoff	No info					↘
Automation Equipment	Industrial robots																				
Automation Equipment	6-aixs robot - Heavy	21%	20%	21%	22%	18%	→	ESTUN	3%	3%	4%	7%	7%	↗	FANUC	21%	23%	20%	25%	29%	→
Automation Equipment	6-aixs robot - Light	18%	26%	32%	29%	34%	↗	ESTUN (incl. Cloos)	1%	2%	2%	2%	4%	↗	FANUC	15%	14%	13%	18%	14%	→
Automation Equipment	SCARA	25%	27%	25%	20%	27%	↗	Inovance	3%	6%	7%	7%	13%	↗	Epson	28%	26%	25%	31%	27%	→
Automation Equipment	- SW reducer*	>70%					→	Leader Drive	69%	69%	52%	55%	-	↘	Harmonic Drive	~20%					→
Automation Equipment	- RV reducer*	-	-	-	~30%		↗	Shuanghuan	-	-	-	26%	-	↗	Nabtesco	~60%					↘
Automation Equipment	Collaborative robot	-	62%	56%	64%	72%	→	Aubo	20%	21%	23%	33%	29%	↘	Universal Robots	46%	28%	33%	30%	16%	→
Automation Equipment	5-axis machine tool	-	-	11%	16%	-	↗	Kede	-	-	2%	5%	-	↑	DMG MORI	-	-	12%	12%	-	→
Automation Equipment	Fiber laser	29%	35%	45%	54%	65%	↗	Raycus	12%	17%	24%	24%	27%	↗	IPG	53%	49%	42%	35%	28%	↘
Automation Equipment	- Single emitter diode chip	-	8%	11%	15%	-	↑	Everbright	-	6%	7%	9%	-	↑	II-VI	No info					↘
Automation Equipment	AGV	97%	98%	98%	98%	-	→	Geek+	11%	12%	13%	14%	-	→	-	-	-	-	-	-	→
Motor and drive	AC Servo	11%	13%	13%	19%	25%	↗	Inovance	5%	6%	6%	11%	16%	↗	Yaskawa	14%	12%	11%	11%	11%	↘
Motor and drive	Low-voltage VFD	20%	22%	23%	24%	26%	↗	Inovance	9%	11%	11%	12%	13%	↗	ABB	13%	14%	14%	14%	14%	→
Motor and drive	Middle/High-voltage VFD	47%	48%	39%	37%	40%	→	Hiconics	14%	12%	12%	10%	10%	→	ABB	9%	9%	8%	8%	9%	→
Sensor	Rotary encoder	7%	8%	8%	9%	10%	→	Yu-Heng	7%	8%	8%	9%	10%	→	TAMAGAWA SEIKI	18%	18%	18%	19%	21%	→
Sensor	Optical linear encoder	0%	0%	0%	0%	0%	→	-	-	-	-	-	-	→	HEIDENHAIN	53%	55%	54%	53%	51%	→
Sensor	Camera-based vision system	19%	20%	24%	24%	23%	↗	Hikvision	6%	9%	13%	14%	13%	↗	Cognex	22%	20%	19%	19%	18%	↘
Sensor	Displacement sensor	0%	0%	0%	0%	0%	→	-	-	-	-	-	-	→	Keyence	36%	35%	34%	34%	34%	→
Sensor	Photoelectric switch	1%	1%	1%	1%	1%	→	Controlway	1%	1%	1%	1%	1%	→	Keyence	27%	27%	26%	25%	28%	→
Sensor	Proximity switch	4%	4%	4%	5%	5%	→	Controlway	4%	4%	4%	5%	5%	→	Omron	22%	23%	22%	21%	23%	→

Note: SW reducer* — SW reducer market share in Chinese brands robots; RV reducer* — RV reducer market share in Chinese brands robots; EPR — Enterprise Resource Planning; PLM — Product Lifecycle Management; MES — Manufacturing Execution Systems; PLC — Programmable Logic Controller; Small PLC: I/O ≤ 256; Medium/Large PLC: I/O > 256; DCS — Distributed Control System; CNC — Computer Numerical Control; AGV — Automated Guided Vehicle; VFD — Variable Frequency Drive; Low-voltage VFD: Voltage ≤ 690V; Middle/High-voltage VFD: Voltage > 690V.

Besides the names our team covers, other Bernstein teams cover Emerson, Siemens, ABB, and SAP. The rest are not listed or not covered by Bernstein

Source: MIR Databank, "Annual report on Chinese Laser Industry 2020", company reports, and Bernstein analysis

We believe the following categories will see acceleration of collective market share gain by Chinese players, driven by diminishing technology gaps, concerns on access to foreign technology, and Chinese industry policies and supply chain "self-help" cohorts. These areas present the best opportunities to invest in local rising stars and the most risks to global players in China.

- **RV reducer:** RV reducers have long been dominated by Nabtesco. Chinese player Shuanghuan was suddenly on the rise from 2020, and now is being tested with major Chinese robot makers such as Estun and Effort, which hope to get dual supply and negotiate better pricing from Nabtesco in the future.

- **Laser diode chip:** This is the core component in fiber and semiconductor lasers. As a semiconductor product, it is at the center of China's supply chain security concerns. In the last few years, Everbright, the leading Chinese laser chip maker, has largely closed the technology gap vs. global leaders, but partly due to its capacity constraints, China's current level of localization in laser chips is still much lower than in fiber and semiconductor lasers. Many potential customers are queuing up for Everbright.[5]

- **Multi-axis machine control:** The motion controller needs to manage 10s to 100+ motors (integrated in various machines) simultaneously. It requires solution capability, a natural strength of Chinese companies in the local market. Multi-axis control further benefits from the rise of specialty equipment in emerging industries such as battery and solar. Inovance and Estun/Trio are among the key beneficiaries.

- **High-power laser equipment control:** Friendess is making solid progress here.

- **Camera-based vision systems:** Hikvision progressed from low-end to mainstream in both hardware and software in the last three years.[6] Other local players are also able to compete in applications that require a high degree of customization. Thus, the market share battle between foreign and local players is expanding from logistics and low-end 3C to part of the battery and Apple supply chain.

- **Robotic arc welding:** Estun/Cloos's newly launched products now cover the entire range of thin/medium/thick plate welding, with world-leading technology at attractive pricing, and have gained quick customer traction. A local robotic welding expert Kaierda, a key customer for Yaskawa in China, also recently introduced its own robots to partly replace Yaskawa's. This will further accelerate the share shift in this segment.

On the other hand, in AC servos, fiber lasers, and strain wave (SW) reducers, Chinese players' shares are already high. We expect the substitution to continue but meaningfully slow down.

In two areas, the average foreign-local technology gap remains largely stable, but local leaders have carved out a sweet spot in the middle level. The collective local share may not increase much, but the leaders will likely continue to consolidate shares and benefit disproportionately:

- **Six-axis robots:** Estun,[7] especially driven by arc welding and battery industry demand.

- **Five-axis CNC machine tools:** Kede.

In a few areas, we see "duel risks" outweigh opportunities for Chinese local champions. This happens when local champions that previously dominated their field suddenly see strong competition from below, pressing their market share, margin, or both. One such example was the rise of Raycus — while it was gaining share from IPG, the duel between Raycus and Maxphotonics, which have very close technologies and highly overlapping customer base, resulted in continued price wars and margin contraction even in the demand upcycle (see Exhibit 17). The risk is highest to over-profitable market dominators in areas where the technology barrier is ambiguous.

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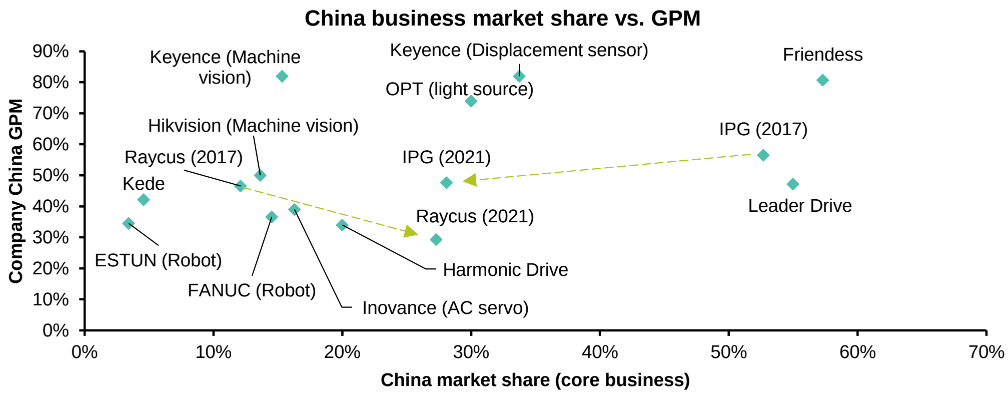
[5] See Lasers chapter of this *Blackbook*.
[6] See Industrial Vision chapter of this *Blackbook*.
[7] See Robotics chapter of this *Blackbook*.

- **Low-to-mid-power laser equipment control:** Local champion Friendess vs. challenger Weihong;
- **Strain wave reducer:** Local champion Leader Drive vs. challengers CTKM and, most dangerous in our view, Shuanghuan's planned new product launch in 2022;
- **High-power fiber laser:** Local champion Raycus vs. challenger Maxphotonics;
- **Collaborative robot:** Local champion AUBO vs. challengers JAKA and ELITE;
- **Machine vision light source:** Local champion OPT machine vision vs. challengers Jiali, Wordop, V-Light, Grand Unified Optics, and KST.

EXHIBIT 17: **"Overly profitable" market dominators are facing "duel risks" on their margin and share**



Source: Bloomberg, and Bernstein estimates and analysis

VALUATION METHODOLOGY

We use EV/EBITDA multiple as the primary valuation method. We set the target multiple referencing previous cycles but adjust for secular or competitive trends that we believe are moving multiples higher or lower across multiple cycles. We use discounted cash flow (DCF) as reference for the company's long-term intrinsic value. As we move along the different stages of a cycle, the time-dependent target price may deviate from the DCF-implied value.

RISKS

The risks to our coverage names are mainly associated with the global macroeconomy, including industrial capex cycles, trade frictions, and currency.

INVESTMENT IMPLICATIONS

It's an exciting time to invest in Chinese automation. The sector is undergoing favorable structural shifts driven by government policy, demographic trends, and technology progress. Adoption of industrial robots, cobots, vision, and AI will likely continue to accelerate despite industrial cycles. All the while, the ongoing local substitution trend shuffles winners every few years, bringing idiosyncratic opportunities to investors.

THE PLAYFIELD

Policy, "decoupling," and the making of global champions

CHINESE MANUFACTURING POLICY — AN INFLECTION, TWO GOALS, AND MANY TOOLS

Reversing a decade-long trend, China's 14th FYP (2021-25) and 2035 Long-Range Objectives decisively raised the strategic importance of the manufacturing sector (see Exhibit 18). We believe China's new directive of stabilizing manufacturing's share in GDP will meaningfully reaccelerate investment growth in the sector (see Exhibit 19). China has a rich policy toolkit that is far more than just government subsidies (see Exhibit 21 and Exhibit 22).

Besides growth, China's manufacturing policy has another clear objective of targeted technology upgrades, covering three priority areas (see Exhibit 23): (1) Industry X.0 (e.g., green and smart manufacturing) that drives modernization of a wide range of manufacturing verticals; (2) where China is already in the lead and hopes to incubate global champions (e.g., high-speed rail, certain heavy equipment, and AI); and (3) supply chain bottlenecks where self-sufficiency in the long run is deemed necessary (e.g., high-end CNC, semiconductor manufacturing, and special materials).

Although many policy tools have been in place for years, recently China's support for upgrade has become far more sophisticated and targeted, concentrating resources to help companies that are making real R&D efforts, have met certain technology bars, and show high potential to succeed, instead of giving broad-based subsidies to anyone whose company name happens to contain certain key words in the policy documents.

For Chinese industrial tech companies, it is the best of times. Capital access is made easier with newly established stock exchanges and the central government's push to drive a bigger portion of total debt to manufacturing (see Exhibit 27); serious R&D and upgrade investment are rewarded with more subsidies and tax deductions; industrial IP is better protected; supply-chain "self-help" consortiums and investment funds are formed to reduce foreign technology dependence; downstream customers are more willing than ever to use domestic products and help them improve, even before their technologies become strictly "good enough." Our coverage names in China (Estun, Inovance, Han's Laser, Hikvision, and Hollysys) and many other STAR board listed names (see Exhibit 29) are beneficiaries of these recent trends.

Foreign industrial tech companies will inevitably face stronger competition in China, but it's not all bad news. "Decoupling" is not part of China's policy goal. In order to move to high-value-add segments, i.e., shifting away from making shoes and cement to making electric vehicles, high-speed trains, large aircraft, smartphones, fuel cells, innovative drugs, etc., China is fully aware of the need for advanced industrial technologies, domestic or foreign, such as robotics, CNC, laser, and industrial software; and it knows better than to close the market to "protect" local players. Quite the contrary, the country has been encouraging the import of advanced technologies with its tariff scheme. Upgrade is the dominant goal; local substitution is a by-product.

POLICY INFLECTION

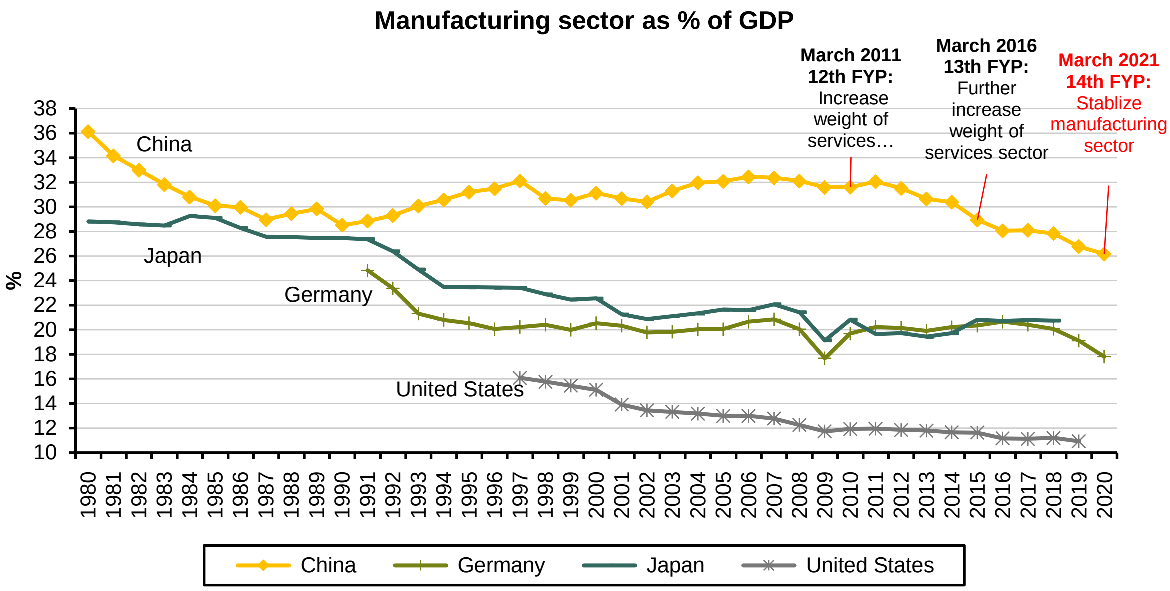
Between 2011 and 2020, China's manufacturing sector value add in the overall economy decreased ~600bps (see Exhibit 18). This was the outcome of the policy focus of the 12th and 13th FYPs to expand the service sector in the Chinese economy. The 14th FYP announced in 2021, however, vowed to "stabilize the manufacturing sector" — a major top-down policy shift compared to the last decade. Several key local governments (in the Yangtze River Delta and the Pearl River Delta, where manufacturing activities are concentrated) have since announced their own goals to reaccelerate the growth of the manufacturing sector in the next decade (see Exhibit 20).

The FYP's top-down target had a direct impact on manufacturing investment. When the manufacturing sector's share in GDP declined in the 2010s, investment in the sector slowed down drastically. A stabilized manufacturing sector is expected to drive a meaningful rebound of related investment (see Exhibit 19).

Promoting the manufacturing industry to the next level fits the new China policy paradigm in multiple dimensions. The aspiration of becoming a major industrial powerhouse is core to not only the next phase of economic development, but also the country's strategic goal of "common prosperity." The manufacturing sector employs 13% of the total labor force in China, and close to 30% of all migrant workers, with an even bigger indirect employment impact on related service sectors such as logistics. A stronger manufacturing industry will contribute substantially to a wealthier working population and a broadening middle class. Experience in the developed world and related research show that a declining manufacturing industry exacerbates income inequality.[8] China is acting to avoid that.

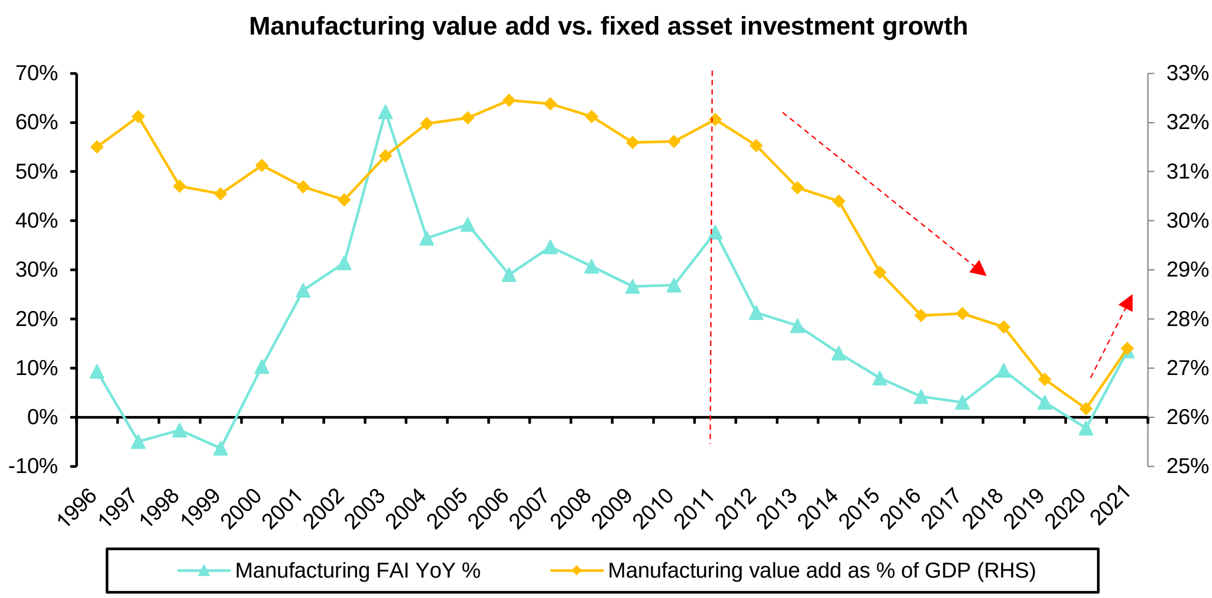
[8] See Gould, Eric D. "Explaining the unexplained: Residual wage inequality, manufacturing decline and low-skilled immigration." *The Economic Journal* 129.619 (2019): 1281-1326.

EXHIBIT 18: **China's latest FYP marks an inflection: it aims to reverse a decade-long trend of the declining importance of the manufacturing sector**



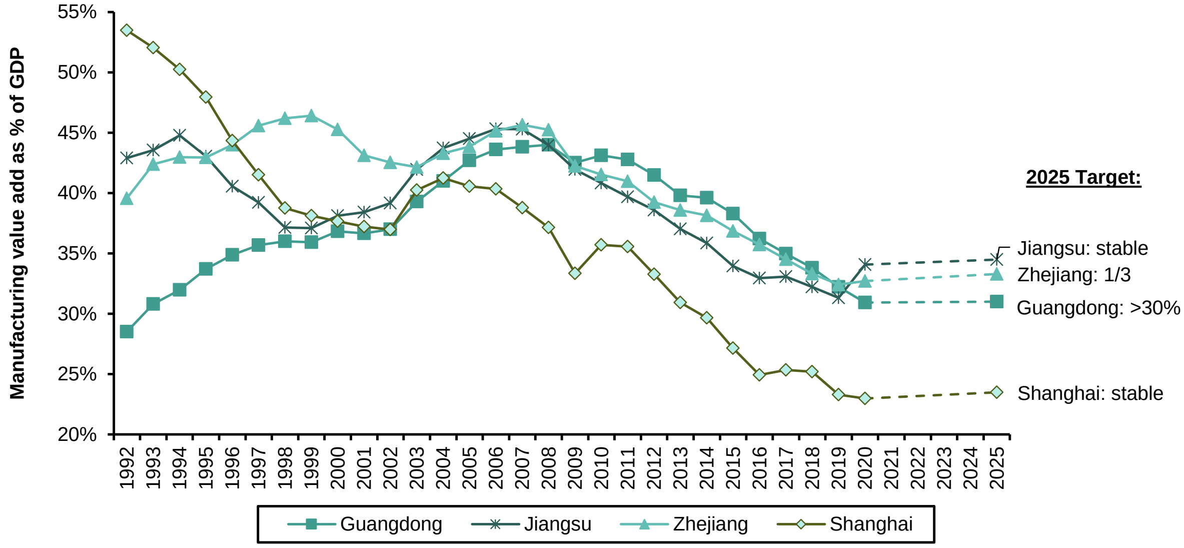
Source: World Bank, Haver, Chinese government, China NBS, and Bernstein analysis

EXHIBIT 19: **In the last decade, as manufacturing sector's share in GDP declined, investment in the sector decelerated; the trend is now reversing with the 14th FYP directive**



Source: China NBS, China Ministry of Industry and Information Technology, and Bernstein analysis

EXHIBIT 20: **In accordance with the central government plan, local governments in China's key manufacturing areas all aim to strengthen the manufacturing sector**



Note: 2025 targets are set by various provincial governments in China.

Source: Chinese government, China NBS, and Bernstein analysis

TWO GOALS AND MANY TOOLS

China has two primary policy goals regarding the manufacturing sector. First, to drive steady **growth** of the sector, a critical element of overall economic growth, employment, and common prosperity. Second, to **upgrade** the technology level of the sector. With this upgrade, China manufacturing can continue to shift to higher value-add output, mitigate the risk of capacity migration to other low-cost countries, and eliminate critical dependence on foreign technologies in the supply chain.

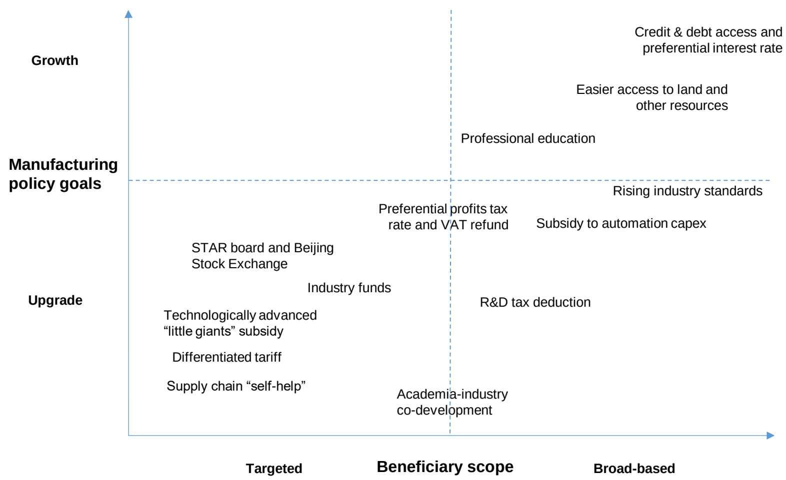
We note that "decoupling" is not part of the policy goal. In order to move to high-value-add segments, i.e., shifting away from making shoes and cement to making electric vehicles, high-speed trains, large aircraft, smartphones, fuel cells, innovative drugs, etc., China is fully aware of the need for advanced industrial technologies, domestic or foreign. Upgrade is the dominant goal; local substitution is a by-product, except in specific areas where foreign technology dependence is seen as a major supply chain risk in the context of a US-China tech war.[9]

China identifies a list of priority areas to upgrade (see Exhibit 23). It covers three sets of industries: (1) Industry X.0 (e.g., green and smart manufacturing) [10] that drives modernization of a wide range of manufacturing verticals; (2) where China is already in the lead and hopes to incubate more/stronger global champions (e.g., high-speed rail, certain heavy equipment, and AI); and (3) supply chain bottlenecks where self-sufficiency is desired (e.g., high-end CNC, semiconductor chip manufacturing, and special materials).

[9] See Will China and U.S. decouple in industrial tech, and where to invest?.
[10] See Global Automation: The Two Pillars of Industry 4.0 - A Primer.

To support the two policy goals, "growth" and "upgrade," the Chinese government has put in place a variety of policy tools, including direct subsidies, preferential tax and tariff regimes, capital/credit support, industry standards, and collaborative R&D schemes (see Exhibit 22). Although some of these policy tools have been in place for years, we have recently observed a clear trend of China's industry policies becoming more sophisticated and effective (see Exhibit 21). Its "growth" policies are generally broad based, but "upgrade" policies are increasingly targeted, concentrating resources to help companies that are making real R&D efforts, have met certain technology bars, and have high potential to succeed, instead of giving broad-based subsidies to anyone whose company name happens to match certain key words in the policy documents.

EXHIBIT 21: **China's manufacturing policy is becoming more sophisticated and targeted — two goals, many tools**



Source: China National Development and Reform Commission, Ministry of Finance, State Tax Administration, Ministry of Industry and Information Technology, multiple company reports, and Bernstein analysis

EXHIBIT 22: **Key manufacturing policy tools in China**

Category	Policy	Details
Subsidies	Subsidy to automation capex	Direct subsidy as % of automation equipment purchase
	"Little Giants"(Zhuan Jing Te Xin) subsidy	Flagship program to support technologically advanced manufacturing SMEs
Preferential tax and tariff	Preferential VAT and profits tax rate	Qualified high tech enterprises enjoy lower (or zero) VAT and profits tax rates
	R&D tax deduction	Extra 100% R&D expense tax deduction for manufacturing enterprises
	Differentiated tariff	Lower tariff for import of advanced technology (esp. when no domestic capability)
Capital/credit	Credit & debt market access	Easier access to debt market & lower interest rate for manufacturing enterprises
	Beijing Stock Exchange	New stock exchange to list technologically advanced manufacturing enterprises
	Shanghai STAR board	To promote the listing of smaller high technology-focused enterprises
	Industry funds & investments	Incl. gov't big fund and various private enterprise funds
Industry standards	Rising industry standards	New requirements on environmental protection, energy saving & safety standards
Collaborative R&D schemes	Supply chain "self-help"	Industrial clusters cooperate across the supply chain (e.g. R&D consortium)
	Academia-industry cooperation	To marry state and academic R&D resources with private sector needs and commercial opportunities
	Military-civilian integration	

Source: China National Development and Reform Commission, Ministry of Finance, State Tax Administration, Ministry of Industry and Information Technology, multiple company reports, and Bernstein analysis

EXHIBIT 23: **China is driving upgrades in three priority areas**

Technology	Industry X.0	Global champion	Supply chain bottleneck
High-end CNC machine tool	√		√
Industrial robot (incl. advanced controller, high precision servo system, high performance reducer, etc)	√		√
Laser manufacturing	√		
Core industrial software	√		√
Smart manufacturing (incl. DCS, PLC, data analysis, industrial IoT, high precision servo system, etc)	√		√
Green manufacturing	√		
Additive manufacturing (3D printing)	√		
Artificial intelligence	√	√	
Scientific key instruments & equipment			√
Advanced railway, transportation, and power equipment		√	
Advanced construction and agriculture equipment		√	
Semiconductor equipment incl. mask aligner			√
Optoelectronic device & integration			√
Integrated circuits and microwave components			√
Key basic materials			√
Advanced electronics materials			√
Structural and functional material			√

Source: China Ministry of Science and Technology, National Development and Reform Commission, Science and Technology Daily, and Bernstein analysis

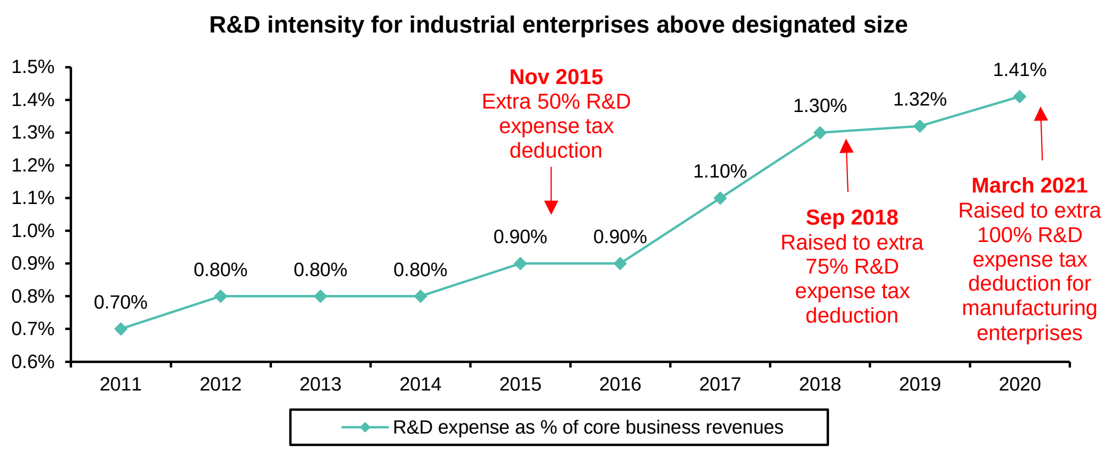
We take a closer look at five key policy tools and their impact.

R&D for tax deduction

To encourage innovation, the Chinese tax authority started to allow an extra 50% of R&D expenses to be deducted from corporate taxable income in 2015. This ratio was raised to 75% in 2018. As a result, R&D intensity of Chinese industrial enterprises increased by more than 50% in the past five years (see Exhibit 24). The positive impact was direct and substantial. In March 2021, this ratio was further raised to an extra 100% of R&D expenses for manufacturing enterprises.

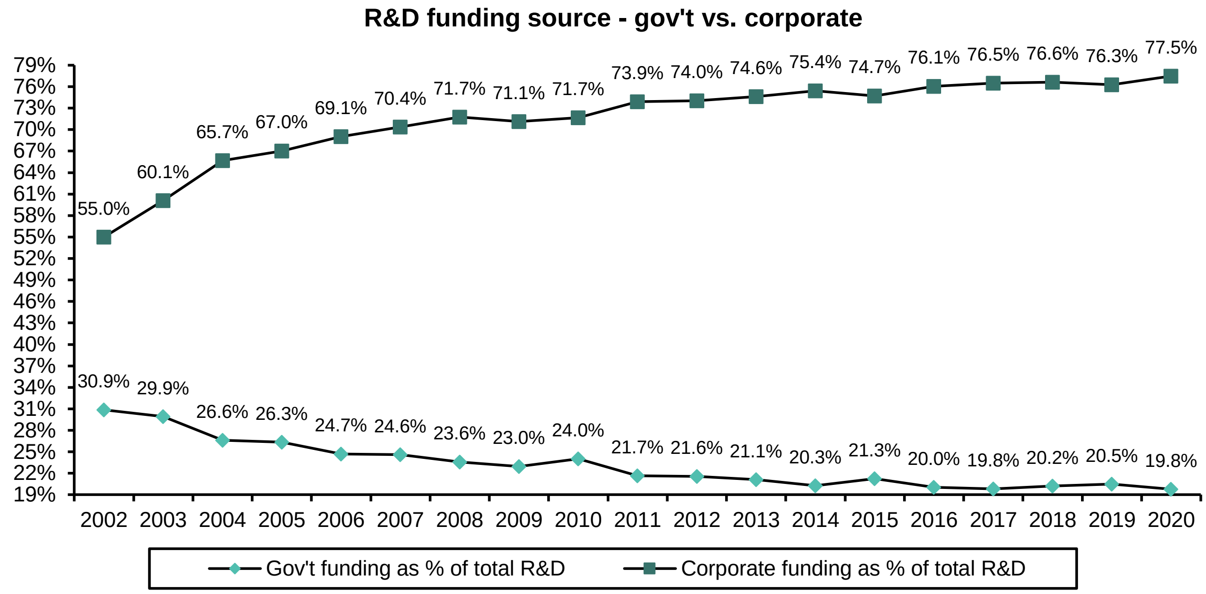
In the last two decades, encouraged by the Chinese government, the role of corporates in R&D has become increasingly important (see Exhibit 25). This is in part helped by the better protection of intellectual property by Chinese laws and courts.

EXHIBIT 24: **With increasing incentives, industrial sector R&D intensity has been on the rise**



Source: China NBS, Ministry of Finance, and Bernstein analysis

EXHIBIT 25: **Corporate innovation now accounts for close to 80% of national R&D**



Source: China NBS and Bernstein analysis

Evolving subsidy regime

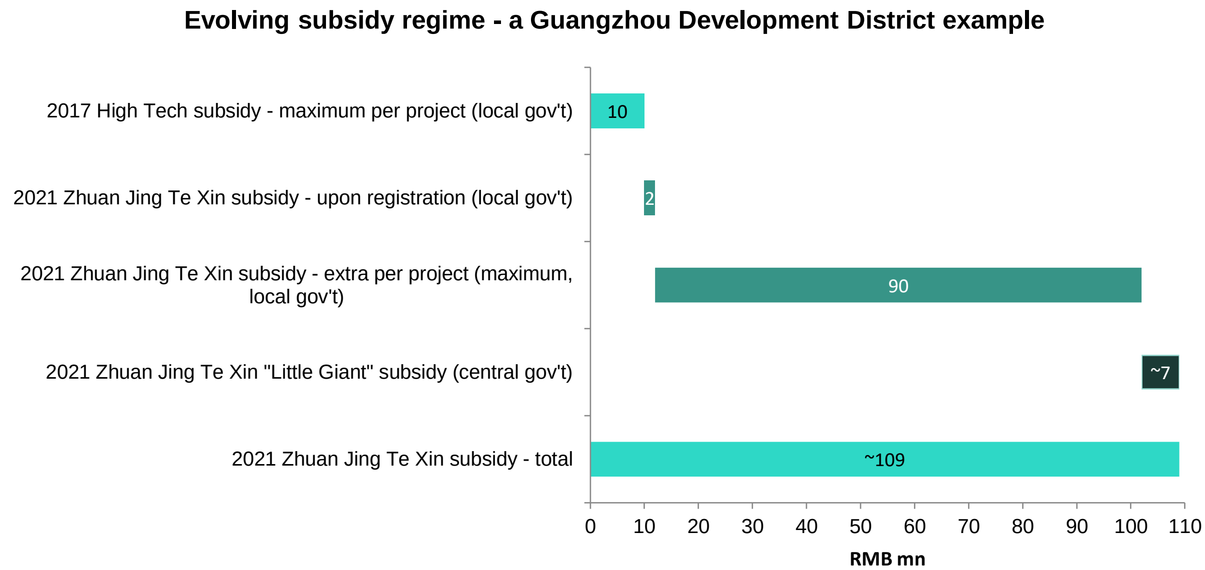
To encourage upgrades, subsidies are given to users in proportion to qualified automation capex (with certain caps). In most cases, this type of demand-side subsidy is indiscriminative of equipment origin. It's broad-based, serving both the "growth" and the "upgrade" goals.

Another type of subsidy focuses on the supply side and goes directly to automation companies. In the past, there was almost no threshold — numerous "robotic" companies even without real products were able to get subsidies from their respective local government. The tool proved highly ineffective and a huge waste. In recent years, however, supply-side subsidies have become much more targeted. The schemes are redesigned to focus on removing supply chain bottlenecks and helping companies that already meet some technological bars.

One such scheme is dubbed "Zhuan Jing Te Xin Little Giant" (meaning "technologically advanced SMEs"). Since 2019, the Ministry of Industry and Information Technology (MITT) has certified ~1,400 national-level "Zhuan Jing Te Xin Little Giants" — each of them still small but already leading in technology and product in a specific field. These national "Little Giants" are allotted a total of RMB10bn in subsidies, averaging ~RMB7mn per company. While the national subsidy amount does not seem substantial, the scheme is also a lever to mobilize local government subsidies, which, for any given "Little Giant," could be 10-15x as much as the national subsidy. We illustrate in Exhibit 26, taking Guangzhou Development District as an example, how a typical national "Little Giant" is eligible for 10x more subsidies than before.

"Zhuan Jing Te Xin" and other similar policies aim to accelerate the development of domestic capabilities in key components and technology.

EXHIBIT 26: **Under the "Zhuan Jing Te Xin" (Little Giant) scheme, government subsidy could potentially increase significantly for qualified high-potential companies**



Note: The central government subsidy amount is our estimated average for a typical certified "Little Giant" enterprise.

Source: China Ministry of Industry and Information Technology, Guangzhou government, and Bernstein estimates and analysis

Value chain "self-help"

Apart from "Zhuan Jing Te Xin" subsidies, key component makers in China are being blessed with unprecedented endorsement from downstream users. The post-Covid-19 supply chain tightness has become an overwhelming pressure on cost and delivery globally. Upstream component localization proved a great help this year. Cost as well as supply chain security considerations have accelerated testing and adoption of domestic branded components — e.g., Shuanghuan RV reducers are tested by several Chinese robot brands, including Estun, even before their product quality becomes "good enough" relative to Nabtesco's. In industrial laser, upstream diode maker Everbright also benefits from supply chain localization.

Systematically, self-sufficiency across the value chain is now a central investment theme in China. The Chinese government has largely taken an indirect approach and facilitated players along the value chain to help each other. One of the "self-help" mechanisms is industry investment funds at multiple levels: (1) National funds such as the Advanced Manufacturing Industry Investment Fund, the National Manufacturing Transformation and Upgrade Fund, and China Integrated Circuit Industry Investment Fund. (2) Provincial/municipal and corporate funds — often led and facilitated by the local government, and participated by and intended for an iconic corporate. Hikvision, Estun, and Xiaomi all have set up such industry funds to support and take stake in their respective supply chain. (3) Private equity and venture capital funds that focus on the industrial sector.

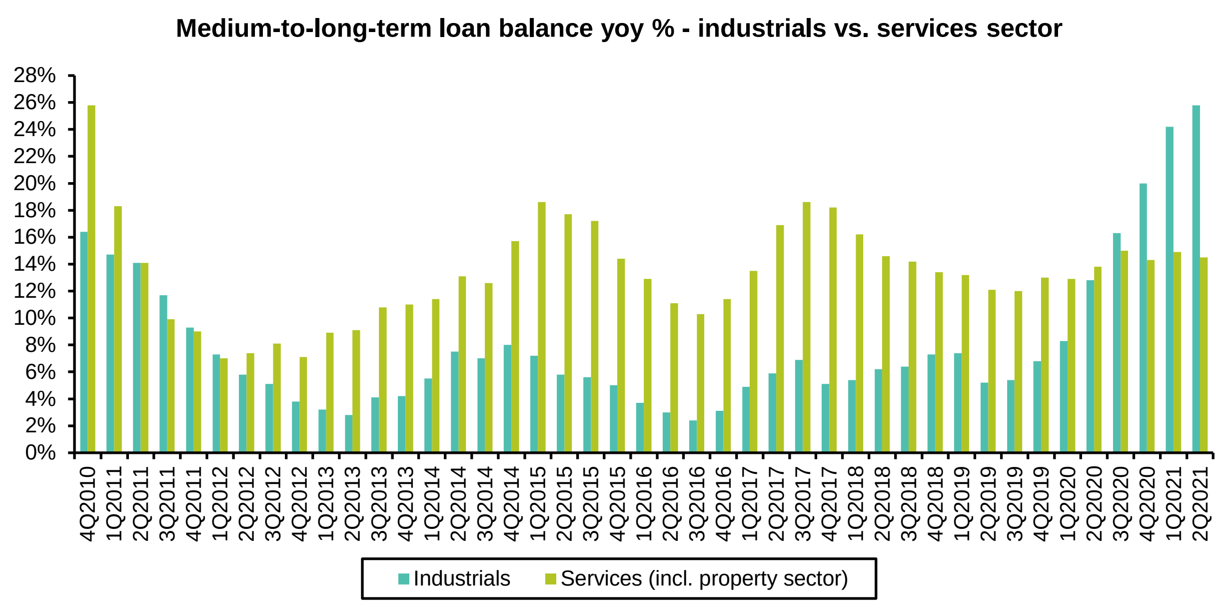
Differentiated tariffs

In order to pursue manufacturing upgrades, China knows better than to close the market to "protect" local players. Quite the contrary, the country has been encouraging the import of advanced technologies with its tariff scheme. MIIT issues an official list of designated high-tech equipment categories that are exempted from import tariffs and VAT. The list is revised regularly, and categories with newly developed domestic capabilities are removed from tariff-exempted status. For example, high-power (above 20kW) fiber lasers were added to the tariff exempt list in 2019, but removed in the May 2021 release, as multiple Chinese companies have already developed this technology. Another example is CNC equipment, where many models were gradually removed from the tariff exempt list over 2010-21 as domestic capability caught up.

Capital access

China is putting its money where its mouth is. The system-wide medium-to-long-term loan balance to the industrials sector has recently started outgrowing that of the services sector (the latter includes the property industry) (see Exhibit 27). This is in contrast to the preceding decade, and consistent with the new FYP goal we discussed at the beginning of this chapter (see Exhibit 18). As a result, even when China tries to fight its high debt ratio and will at times be "tight" on credit, it clearly aims to direct more credit to manufacturing.

EXHIBIT 27: **While carefully managing the country's total debt level, the Chinese government wants manufacturing companies to get a bigger portion of the total debt**

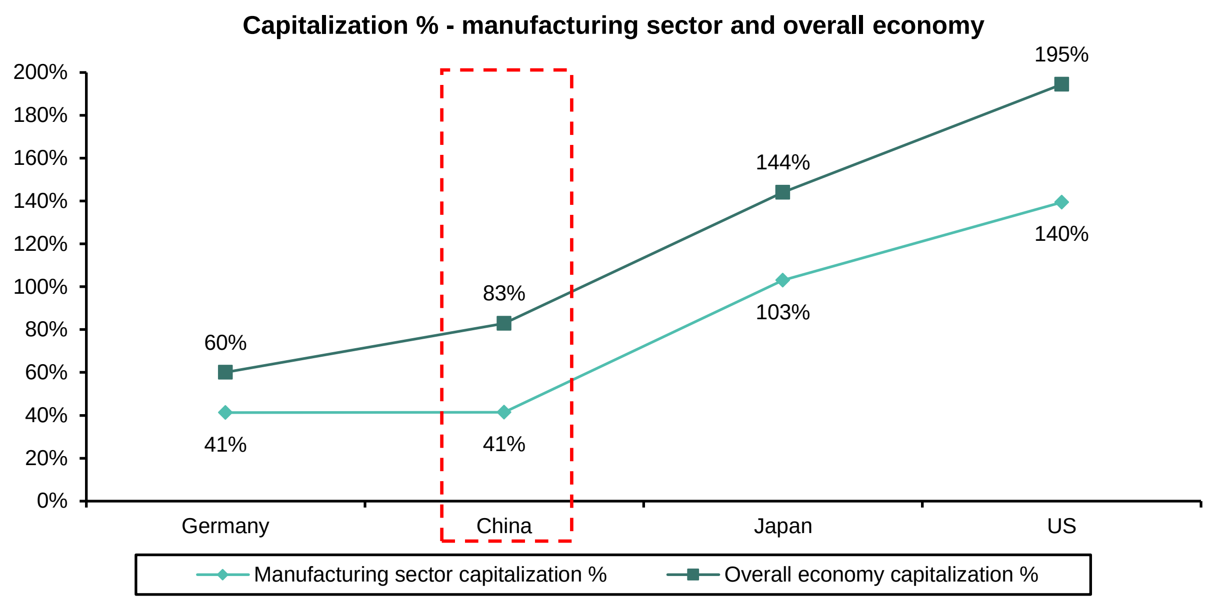


Source: People's Bank of China (PBoC), Wind, and Bernstein analysis

Besides monetary policy, China is also helping manufacturing enterprises access more capital in the equity market. President Xi personally endorsed the launch of the Shanghai STAR Board (the Science and Technology Innovation Board) in November 2018. Since then, more than 140 industrial companies have been listed on the STAR Board. In September 2021, Xi announced plans to set up the Beijing Stock Exchange, dedicated to

SMEs and in particular the aforementioned "Little Giant" enterprises. These facilitative infrastructure and policies will help drive higher levels of capitalization and fuel the development of the manufacturing industry (see Exhibit 28). Similar to the evolving subsidy scheme, the equity market help is clearly targeting companies that are making real effort and have demonstrated success in manufacturing technology advancement.

EXHIBIT 28: **Higher capitalization ratio goes hand in hand with more developed manufacturing industry**



Note: The sector capitalization ratios are calculated with 2019 manufacturing value-add statistics and current sector market capitalization (as of November 2021); overall economy capitalization ratios are based on 2020 World Bank statistics and Bernstein estimates.

Source: Bloomberg, World Bank, and Bernstein estimates and analysis

EXHIBIT 29: **STAR board listed industrial companies: machinery and machine tool subsectors**

Stock code	Company name	Chinese name	Sector	Sub-sector
688028 CH	Beijing Worldia Diamond Tools Co Ltd	北京沃尔德金刚石工具股份有限公司	Industrial	Hand/Machine Tools
688059 CH	Zhuzhou Huarui Precision Cutting Tools Co Ltd	株洲华锐精密工具股份有限公司	Industrial	Hand/Machine Tools
688305 CH	KEDE Numerical Control Co Ltd	科德数控股份有限公司	Industrial	Hand/Machine Tools
688308 CH	OKE Precision Cutting Tools Co Ltd	株洲欧科亿数控精密刀具股份有限公司	Industrial	Hand/Machine Tools
688518 CH	Shenzhen United Winners Laser Co Ltd	深圳市联赢激光股份有限公司	Industrial	Hand/Machine Tools
688556 CH	Qingdao Gaoce Technology Co Ltd	青岛高测科技股份有限公司	Industrial	Hand/Machine Tools
688558 CH	Nantong Guosheng Intelligence Technology Group Co Ltd	南通国盛智能科技集团股份有限公司	Industrial	Hand/Machine Tools
688577 CH	Zhe Jiang Headman Machinery Co Ltd	浙江海德曼智能装备股份有限公司	Industrial	Hand/Machine Tools
688697 CH	Neway CNC Equipment Suzhou Co Ltd	纽威数控装备（苏州）股份有限公司	Industrial	Hand/Machine Tools
688113 CH	Jiangsu Liance Electromechanical Technology Co Ltd	江苏联测机电科技股份有限公司	Industrial	Machinery-Constr&Mining
688191 CH	Zhiyang Innovation Technology Co Ltd	智洋创新科技股份有限公司	Industrial	Machinery-Constr&Mining
688330 CH	Shanghai Holystar Information Technology Co Ltd	上海宏力达信息技术股份有限公司	Industrial	Machinery-Constr&Mining
688390 CH	Jiangsu GoodWe Power Supply Technology Co Ltd	固德威技术股份有限公司	Industrial	Machinery-Constr&Mining
688425 CH	China Railway Construction Heavy Industry Corp Ltd	中国铁建重工集团股份有限公司	Industrial	Machinery-Constr&Mining
688551 CH	Hefei Kewell Power System Co Ltd	合肥科威尔电源系统股份有限公司	Industrial	Machinery-Constr&Mining
688611 CH	Hangzhou Kelin Electric Co Ltd	杭州柯林电气股份有限公司	Industrial	Machinery-Constr&Mining
688017 CH	Leader Harmonious Drive Systems Co Ltd	苏州绿的谐波传动科技股份有限公司	Industrial	Machinery-Diversified
688022 CH	Suzhou Harmontronics Automation Technology Co Ltd	苏州瀚川智能科技股份有限公司	Industrial	Machinery-Diversified
688025 CH	Shenzhen JPT Opto-Electronics Co Ltd	深圳市杰普特光电股份有限公司	Industrial	Machinery-Diversified
688090 CH	Guangzhou Risong Intelligent Technology Holding Co Ltd	广州瑞松智能科技股份有限公司	Industrial	Machinery-Diversified
688097 CH	Bozhon Precision Industry Technology Co Ltd	博众精工科技股份有限公司	Industrial	Machinery-Diversified
688155 CH	Shanghai SK Automation Technology Co Ltd	上海先惠自动化技术股份有限公司	Industrial	Machinery-Diversified
688165 CH	Efort Intelligent Equipment Co Ltd	埃夫特智能装备股份有限公司	Industrial	Machinery-Diversified
688188 CH	Shanghai Friendess Electronic Technology Corp Ltd	上海柏楚电子科技股份有限公司	Industrial	Machinery-Diversified
688218 CH	Jiangsu Beiren Smart Manufacturing Technology Co Ltd	江苏北人智能制造科技股份有限公司	Industrial	Machinery-Diversified
688333 CH	Xi'an Bright Laser Technologies Co Ltd	西安铂力特增材技术股份有限公司	Industrial	Machinery-Diversified
688360 CH	Zhejiang Damon Technology Co Ltd	浙江德马科技股份有限公司	Industrial	Machinery-Diversified
688378 CH	Jilin OLED Material Tech Co Ltd	吉林奥来德光电材料股份有限公司	Industrial	Machinery-Diversified
688395 CH	Shenzhen Sine Electric Co Ltd	深圳市正弦电气股份有限公司	Industrial	Machinery-Diversified
688499 CH	Guangdong Lyric Robot Automation Co Ltd	广东利元亨智能装备股份有限公司	Industrial	Machinery-Diversified
688529 CH	Dalian Haosen Equipment Manufacturing Co Ltd	大连豪森设备制造股份有限公司	Industrial	Machinery-Diversified
688596 CH	Shanghai Gentech Co Ltd	上海正帆科技股份有限公司	Industrial	Machinery-Diversified
688633 CH	Nantong Xingqiu Graphite Co Ltd	南通星球石墨股份有限公司	Industrial	Machinery-Diversified
688686 CH	OPT Machine Vision Tech Co Ltd	广东奥普特科技股份有限公司	Industrial	Machinery-Diversified
688700 CH	Kunshan Dongwei Technology Co Ltd	昆山东威科技股份有限公司	Industrial	Machinery-Diversified
688718 CH	Wave Cyber Shanghai Co Ltd	上海唯赛勃环保科技股份有限公司	Industrial	Machinery-Diversified
688789 CH	Hangzhou Honghua Digital Technology Stock Co Ltd	杭州宏华数码科技股份有限公司	Industrial	Machinery-Diversified

Note: As of November 2021. Bernstein does not cover these companies.

Source: Shanghai Stock Exchange, Bloomberg, and Bernstein analysis

EXHIBIT 30: **"Zhuan Jing Te Xin" (Little Giant) upcoming IPOs**

Company name	Chinese name	Sector	Sub-sector
Beijing Navigation Control Technology Co Ltd	北京理工导航控制科技股份有限公司	Industrial	Aerospace/Defense
Suzhou Delphi Laser Co Ltd	苏州德龙激光股份有限公司	Technology	Computers
Tongling KingKong Electronics Technology Co Ltd	铜陵兢强电子科技股份有限公司	Industrial	Electrical Compo&Equip
Zhejiang Extek Technology Co Ltd	浙江英特科技股份有限公司	Industrial	Electronics
Zhejiang Meishuo Electric Technology Co Ltd	浙江美硕电气科技股份有限公司	Industrial	Electronics
Luoyang Jianguang Special Equipment Co Ltd	洛阳涧光特种装备股份有限公司	Industrial	Electronics
Shandong Senter Electronic Co Ltd	山东信通电子股份有限公司	Industrial	Electronics
Dalian Youopto Technology Co Ltd	大连优迅科技股份有限公司	Industrial	Electronics
Hefei Jingsong Intelligent Technology Co Ltd	合肥井松智能科技股份有限公司	Industrial	Electronics
Beijing Integrity Technology Co Ltd	北京永信至诚科技股份有限公司	Industrial	Electronics
HKY Technology Co Ltd	北京华科仪科技股份有限公司	Industrial	Electronics
Zenner Metering Technology Shanghai Ltd	上海真兰仪表科技股份有限公司	Industrial	Electronics
Qingdao Spring Water-treatment Co Ltd	青岛思普润水处理股份有限公司	Industrial	Environmental Control
MayAir Technology China Co Ltd	美埃（中国）环境科技股份有限公司	Industrial	Environmental Control
Qingyan Environmental Technology Co Ltd	清研环境科技股份有限公司	Industrial	Environmental Control
Xiamen Jiarong Technology Co Ltd	厦门嘉戎技术股份有限公司	Industrial	Environmental Control
Smartgen Zhengzhou Technology Co Ltd	郑州众智科技股份有限公司	Industrial	Hand/Machine Tools
Keystone Electrical Zhejiang Co Ltd	浙江开创电气股份有限公司	Industrial	Hand/Machine Tools
Henan Hozel Electronics Co Ltd	河南皓泽电子股份有限公司	Industrial	Hand/Machine Tools
Nanjing Toua Hardware & Tools Co Ltd	南京腾亚精工科技股份有限公司	Industrial	Hand/Machine Tools
Ningbo Physis Technology Co Ltd	宁波菲仕技术股份有限公司	Industrial	Hand/Machine Tools
Chongqing Wangbian Electric Group Corp Ltd	重庆望变电气（集团）股份有限公司	Industrial	Machinery-Constr&Mining
Shenyang Tian An Technology Co Ltd	沈阳天安科技股份有限公司	Industrial	Machinery-Constr&Mining
Jiangxi Zhongtian Intelligent Equipment Co Ltd	江西中天智能装备股份有限公司	Industrial	Machinery-Constr&Mining
Anhui Tuoshan Heavy Industries Co Ltd	安徽拓山重工股份有限公司	Industrial	Machinery-Constr&Mining
State Power Rixin Technology Co Ltd	国能日新科技股份有限公司	Industrial	Machinery-Constr&Mining
SKS Hydraulic Technology Co Ltd	赛克思液压科技股份有限公司	Industrial	Machinery-Diversified
Suzhou Invotech Scroll Technologies Co Ltd	苏州英华特涡旋技术股份有限公司	Industrial	Machinery-Diversified
Shenzhen Sinvo Automation Co Ltd	深圳市兴禾自动化股份有限公司	Industrial	Machinery-Diversified
Zhejiang Weigang Technology Co Ltd	浙江炜冈科技股份有限公司	Industrial	Machinery-Diversified
Jiangsu Jinyuan Advanced Equipment Co Ltd	江苏金源高端装备股份有限公司	Industrial	Machinery-Diversified
OK Science & Technology Co Ltd	欧克科技股份有限公司	Industrial	Machinery-Diversified
Focusight Technology Jiangsu Co Ltd	征图新视（江苏）科技股份有限公司	Industrial	Machinery-Diversified
Guangdong Anda Automation Solutions Co Ltd	广东安达智能装备股份有限公司	Industrial	Machinery-Diversified
Changzhou Mingseal Robot Technology Co Ltd	常州铭赛机器人科技股份有限公司	Industrial	Machinery-Diversified
Shandong Auyan New Energy Technology Co Ltd	山东奥扬新能源科技股份有限公司	Industrial	Machinery-Diversified
Tianjin Meiteng Technology Co Ltd	天津美腾科技股份有限公司	Industrial	Machinery-Diversified
GKG Precision Machine Co Ltd	东莞市凯格精机股份有限公司	Industrial	Machinery-Diversified
Shanghai Sinpa Intelligent Technology Co Ltd	上海辛帕智能科技股份有限公司	Industrial	Machinery-Diversified
Shanghai Rychen Technologies Co Ltd	上海瑞晨环保科技股份有限公司	Industrial	Machinery-Diversified
Chengdu Yitong Seal Co Ltd	成都一通密封股份有限公司	Industrial	Machinery-Diversified
Chongqing Yuxin Pingrui Electrical Co Ltd	重庆瑜欣平瑞电子股份有限公司	Industrial	Machinery-Diversified
Jintuo Technology Co Ltd	晋拓科技股份有限公司	Industrial	Metal Fabricate/Hardware
Finework Hunan New Energy Technology Co Ltd	湖南飞沃新能源科技股份有限公司	Industrial	Metal Fabricate/Hardware
Hengbo Holdings Co Ltd	恒勃控股股份有限公司	Industrial	Miscellaneous Manufacturing
Super-Dragon Engineering Plastics Co Ltd	广州市聚赛龙工程塑料股份有限公司	Industrial	Miscellaneous Manufacturing
Beijing Jiuzhouyigui Environmental Technology Co Ltd	北京九州一轨环境科技股份有限公司	Industrial	Miscellaneous Manufacturing

Note: As of November 2021, these companies were private awaiting IPO.

Source: Bloomberg and Bernstein analysis

WILL CHINA AND THE US DECOUPLE IN INDUSTRIAL TECH?

The short answer is no, and there are three reasons why — the relatively low threat from the US, China's policy goal for manufacturing upgrade, and Chinese factories' practical need for imported technologies.

WHO LEADS WHERE IN INDUSTRIAL TECH

We don't think today's decoupling in semiconductor heralds the industrial sector tomorrow. What's unique about the semiconductor industry is that the US not only dominates certain equipment and software segments, US technologies are the "basis" of the global supply chain. This allows the US to effectively control what China has access to and, in turn, China feels the pressure to become self-sufficient in the long term — hence, an irreversible decoupling.

By contrast, these premises are not true in industrial tech. We have reviewed a comprehensive set of manufacturing technologies (see Exhibit 31 and Exhibit 32) and found that in most segments, industry leaders are not US companies. For example, in 2019, the top five countries and regions accounted for 82% of import machine tool value, and the US was not among them (see Exhibit 33). The same is true for robotics, servo motors, and most other automation products and components.

In the few segments where the US leads, e.g., lasers, certain industrial software, and instruments, there are many alternatives. For example, in automotive industry, computer-aided engineering (CAE) tools are widely used in the design/analysis phase (see Exhibit 34). Although US companies lead in almost every category of CAE, it's not difficult to find non-US alternatives.

The US Commerce Control List (CCL) lists controlled technologies and products in 10 categories. Most categories are related to semiconductors. Only Category 2 and Category 6 are relevant to industrial tech, covering materials processing and sensors/lasers. Within the two categories, only 38% of items are directly related to industrial tech. That the US control list is disproportionately semiconductor rather than industrial speaks about, and is the result of, the country's chosen path of migration from manufacturing to "high tech" since the 1980s.

China is not driving an industrial tech decoupling either. China's policy goal is to upgrade the manufacturing sector to produce higher value-add output, and it is fully aware that imported, advanced industrial tech is indispensable for that goal. Investors are often misled by the press — slogans like "national champions" and "Made in China 2025" are over-interpreted when they remain aspirations without mandatory targets or concrete measures. Meanwhile, concrete initiatives that incentivize the import of foreign tech are rarely noticed. Most government subsidies incentivize the use of advanced industrial tech and are agnostic of suppliers' origin. This has not changed since the start of the trade/tech war.

EXHIBIT 31: **Who leads where in industrial tech in China (US companies in dashed boxes) (1/2)**

Layer	Product	Brand / Market share											
Industrial software	ERP	Yonyou	SAP	Kingdee	Inspur	Digiwin	Oracle	Others					
		30-35%	20-25%	10-15%	5-10%	15-25%							
	CAD	Dassault Systèmes	Siemens	PTC	Autodesk	CAXA	ZWSOFT	Hoteam Software	Others				
		>90%				<10%							
	CAE	ANSYS	Siemens	ALTAIR	MSC Software	Dassault Systèmes	ZRIME	Dalian SiPESC	LiToSIM	INTESIM	SupComput e	Others	
		-	-	-	-	-	-	-	-	-	-	-	
	PLM	Siemens	PTC	Dassault Systèmes	CAXA	Extech	Others						
		25-30%	20-25%	20-25%	15-20%	5-10%							
	MES	Siemens	Rockwell	Baosight	BenQ Guru	Honeywell	General Electric	IntMes	PCITC	Mingjiang	SAP	SKTMAX	Others
		10-15%	5-10%	5-10%	5-10%	60-70%							
Control instrument	Small PLC	Siemens	Mitsubishi	Omron	Xinjie	Schneider	Delta	Panasonic	Rockwell	Others			
		35-40%	10-15%	5-10%	5-10%	30-40%							
	Medium/Large PLC	Siemens	Mitsubishi	Rockwell	Schneider	Omron	Delta	Others					
		50-55%	10-15%	10-15%	5-10%	10-20%							
	DCS	SUPCON	Emerson	HollySys	Honeywell	Siemens	Yokogawa	ABB	Zhishen	Schneider	Others		
		25-30%	15-20%	15-20%	5-10%	30-40%							
	CNC	FANUC	GSK	Mitsubishi	Siemens	SYNTEC	HuazhongC NC	Others					
		35-40%	10-15%	10-15%	5-10%	25-35%							
	IPC	Advantech	EVOC	Beckhoff	NORCO	Kontron	B&R	Siemens	ADLINK	Others			
		40-45%	10-15%	10-15%	5-10%	20-30%							
	HMI	Siemens	WEINVIE W	Pro-face	Schneider	Kinco	Omron	Delta	Mitsubishi	Beijer Electronics	Others		
		25-30%	15-20%	5-10%	5-10%	35-45%							
Automation Equipment	Industrial robots	FANUC	ABB	KUKA	YASKAWA	Epson	Yamaha	NACHI	Mitsubishi	Kawasaki	ESTUN	Inovance	Others
		10-15%	10-15%	5-10%	5-10%	55-65%							
	Breakdown of industrial robots												
	6-aixs robot	FANUC	ABB	KUKA	YASKAWA	NACHI	Kawasaki	Panasonic	ESTUN	OTC	Mitsubishi	EFORT	Others
		15-20%	10-15%	10-15%	10-15%	45-55%							
	Collaborative robot	Universal Robots	Aubo	Techman Robot	SIASUN	HANWHA	Hans Motor	ELITE Robot	JAKA	ABB	FANUC	Kawasaki	Others
		30-35%	20-25%	5-10%	5-10%	25-35%							
	Machine tool	SMTCL	QCMT&T	RIFA	Yawei	Mazak	AMADA	OKUMA	Makino	DMG MORI	TRUMPF	GROB	Others
		-	-	-	-	-	-	-	-	-	-	-	-
	Machine vision system	Cognex	Keyence	Hikvision	Daheng Imaging	SICK	Omron	Others					
		15-20%	15-20%	10-15%	10-15%	35-45%							
	Fiber laser	IPG	Raycus	Maxphotoni cs	nLight	Coherent	JPT Opto-electronics	FEIBO	Super Laser	HFB Photonics	Others		
		42%	24%	12%	5%	5%	3%	2%	2%	1%	3%		
	AGV	SIASUN	Yonegy	Jaten	Jingyuan	KSEC	Casun	Suneast	MTD	Others			
		15-20%	10-15%	10-15%	10-15%	40-50%							
Instrument	Spectrometer	Agilent	Thermo Fisher	Perkin Elmer	Shimadzu	Persee	Beifen-Ruili	Others					
		-	-	-	-	-	-	-					
	Tensile tester	Instron	MTS	Zwick	Shimadzu	LLOYD	Galdabini	Others					
		-	-	-	-	-	-	-					
	Roundness tester & Surface Profiler	Taylor Hobson	Mahr	Hommel	Mitutoyo	Accretech	TESA	Harbin Measuring & Cutting Tool	Taiming Optical Instrument	WALE	Others		
		-	-	-	-	-	-	-	-	-	-		
	Metallurgic microscope	Olympus	Zeiss	Leica	Nikon	Phenix	NOVEL	Others					
		-	-	-	-	-	-	-					

Note: (1) EPR — Enterprise Resource Planning; CAD — Computer-Aided Design; CAE — Computer-Aided Engineering; PLM — Product Lifecycle Management; MES — Manufacturing Execution Systems; PLC — Programmable Logic Controller; Small PLC: I/O ⩽ 256; Medium/Large PLC: I/O > 256; DCS — Distributed Control System; CNC — Computer Numerical Control; IPC - Industrial Personal Computer; HMI - Human Machine Interface; AGV — Automated Guided Vehicle. (2) We cover Cognex, Hikvision, Keyence, FANUC, IPG, Harmonic Drive, Inovance, and Han's Laser (Hans motor is a subsidiary of Han's Laser); other companies mentioned in this exhibit are not covered by Bernstein.

Source: MIR Databank; Qianzhan; GGII; "Annual report on Chinese Laser Industry 2020"; China Machine Tool & Tool Builders' Association; China Industrial Software Promotion Association; news reports; company reports; and Bernstein analysis

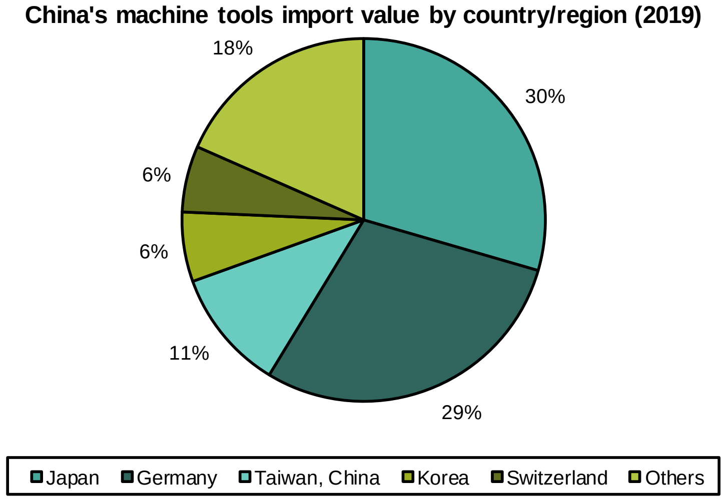
EXHIBIT 32: **Who leads where in industrial tech in China (US companies in dashed boxes) (2/2)**

Layer	Product	Brand / Market share											
Motor, drive and electrical components	AC Servo	Mitsubishi	YASKAWA	Panasonic	Delta	Siemens	Inovance	HCFA	Omron	Schneider	B&R	SANYO DENKI	Others
		10-15%	10-15%	5-10%	5-10%	55-65%							
	Linear motor	Akribis	Hans Motor	Sodick	Dynamikwell	HIWIN	Sankatec	YASKAWA	YOKOKAWA	Linear Motor	Chi Win	Linkhou	Others
		10-15%	5-10%	5-10%	70-80%								
	Low-voltage VFD	ABB	Siemens	Inovance	Schneider	Danfoss	INVT	Delta	Mitsubishi	YASKAWA	Rockwell	Vertiv	Others
		20-25%	15-20%	10-15%	5-10%	35-45%							
	Middle/High-voltage VFD	Hiconics	ABB	Zhiguang Electric	Siemens	Inovance	Tmeic	RXHK	Slanvert	Dongfang Hitachi	Vertiv	Others	
		10-15%	10-15%	5-10%	5-10%	55-65%							
	Push buttons/Indicator lamps	Schneider	Chint Electrics	Siemens	IDEC	Hongbo	DELIXI	Changjiang Electric	EAO	TAYEE	ABB	Fuji Electric	Others
		25-30%	10-15%	10-15%	5-10%	40-50%							
	Contactor	Schneider	Chint Electrics	Siemens	DELIXI	ABB	Tengen	Tianshui 213	LS Electric	Eaton	Fuji Electric	Others	
		25-30%	10-15%	10-15%	5-10%	30-40%							
	Relay	Schneider	Omron	Xinling Electrical	Weidmüller	ABB	Chint Electrics	IDEC	DELIXI	Others			
		20-30%	15-20%	10-15%	10-15%	30-40%							
Sensor	Rotary encoder	TAMAGAWA	Heidenhain	Yuheng Optics	Baumer	Pepperl+Fuchs	NEMICON	Omron	ELCO	Kübler	Koyo Electronics	SICK	Others
		15-20%	15-20%	5-10%	5-10%	45-55%							
	Optical linear encoder	Heidenhain	Renishaw	FAGOR	Others								
		50-55%	25-30%	10-15%	5-10%								
	Displacement sensor	Keyence	Panasonic	Balluff	Banner	SICK	Omron	Others					
		30-35%	5-10%	55-65%									
	Photoelectric switch	Keyence	Omron	Panasonic	SICK	Banner	Pepperl+Fuchs	AUTONICS	Balluff	Controlway	IFM	Others	
		25-30%	15-20%	10-15%	10-15%	30-40%							
	Proximity switch	Omron	Balluff	Pepperl+Fuchs	IFM	TURCK	Keyence	Controlway	AUTONICS	SONON	SICK	Contrinex	Others
		20-25%	10-15%	5-10%	5-10%	45-55%							
	RFID	Pepperl+Fuchs	Balluff	SICK	IFM	Others							
		10-15%	5-10%	5-10%	5-10%	55-65%							
	Safety sensor	SICK	Omron	Keyence	Banner	Controlway	Panasonic	Others					
		15-20%	10-15%	5-10%	5-10%	55-65%							
Precision component	Reducer	Nabtesco	Harmonic Drive	Sumitomo	Leader Drive	Nidec-Shimpo	APEX Dynamics	Nantong Zhenkang	QCMT&T	SEW Eurodrive	Li Ming Machinery	ALPHA	Others
		15-20%	10-15%	5-10%	5-10%	50-60%							
	Bearing (Global)	Schaeffker	SKF	Minebea	NTN	NSK	JTEKT	TIMKEN	NACHI	Others			
		>70% (Global)								-			
	Hydraulic component	Bosch Rexroth	Kawasaki	Eaton	Parker Hannifin	KYB	Danfoss	Hengli Hydraulic	Others				
		-	-	-	-	-	-	-	-				
	Pneumatic component	SMC	AirTAC	FESTO	Other overseas players		Other Chinese players						
		30-35%	20-25%	10-15%	20-25%		10-15%						
	Linear guide	THK	HIWIN	NSK	Bosch Rexroth	IKO	Ewellix	Schaeffler	PMI	Others			
		~78% in Asia	-	-	-	-	-	-	-	-			

Note: (1) VFD — Variable Frequency Drive; Low-voltage VFD: Voltage ⩽ 690V; Middle/High-voltage VFD: Voltage > 690V; RFID — Radio-Frequency Identification; (2) We cover Cognex, Hikvision, Keyence, FANUC, IPG, Harmonic Drive, Inovance, and Han's Laser (Hans motor is a subsidiary of Han's Laser); other companies mentioned in this exhibit are not covered by Bernstein.

Source: MIR Databank; Qianzhan; GGII; "Annual report on Chinese Laser Industry 2020"; China Machine Tool & Tool Builders' Association; China Industrial Software Promotion Association; news reports; company reports; and Bernstein analysis

EXHIBIT 33: **US is not among major exporters of machine tools to China**



Source: China Machine Tool & Tool Builders Association and Bernstein analysis

EXHIBIT 34: **Automotive example: CAE tools are important for product design and analysis; US companies (in dashed boxes) lead, but there are many non-US alternatives**

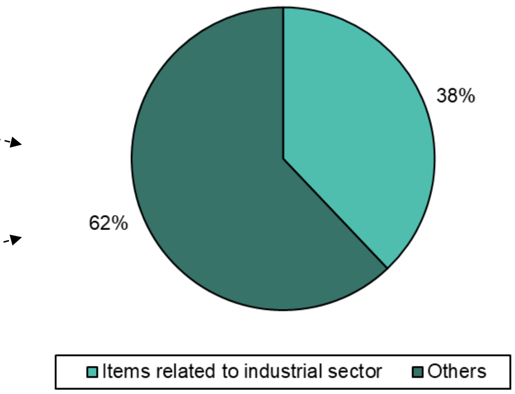
CAE in the automotive industry		
Area	Supplier	Software
Preprocessing/Postprocessing	Altair	HyperMesh
	BETA	ANSA
	ETA	VPG
Fluid dynamics	ANSYS	Fluent
	Simens PLM	Star-CD
	Altair	Acusolve
	Simens PLM	Star-CCM+
Multi Body Dynamics	MSC	Adams
	Dassault Systèmes	Simpack
	Altair	Motionsolve
Crash Analysis	ETA	Ls-Dyna
	Dassault Systèmes	Abaqus
	ESI Group	Pam-Crash
	Altair	Radioss
Fatigue and Durability Analysis	MSC	Nastran
	Altair	OptiStruct
	Dassault Systèmes	Abaqus
	MSC	Fatigue
NVH (Noise, Vibration, and Harshness)	Altair	OptiStruct
	MSC	Nastran
	ESI Group	VA One
Optimization	Dassault Systèmes	Tosca
	Altair	OptiStruct
	Dassault Systèmes	Isight

Note: All companies in the exhibit are not covered.

Source: Ruanfujia.com, company reports, and Bernstein analysis

EXHIBIT 35: **Among the 10 categories of US Commerce Control List only two (and within them, 38% of items) are directly related to industrial sector**

Commerce Control List Categories	
0	Nuclear & Miscellaneous
1	Materials, Chemicals, Microorganisms and Toxins
2	Materials Processing
3	Electronics
4	Computers
5 Part 1	Telecommunications
5 Part 2	Information Security
6	Sensors and Lasers
7	Navigation and Avionics
8	Marine
9	Aerospace and Propulsion



Source: US Department of Commerce and Bernstein analysis

WHERE DOES LOCAL SUBSTITUTION BEGIN AND END?

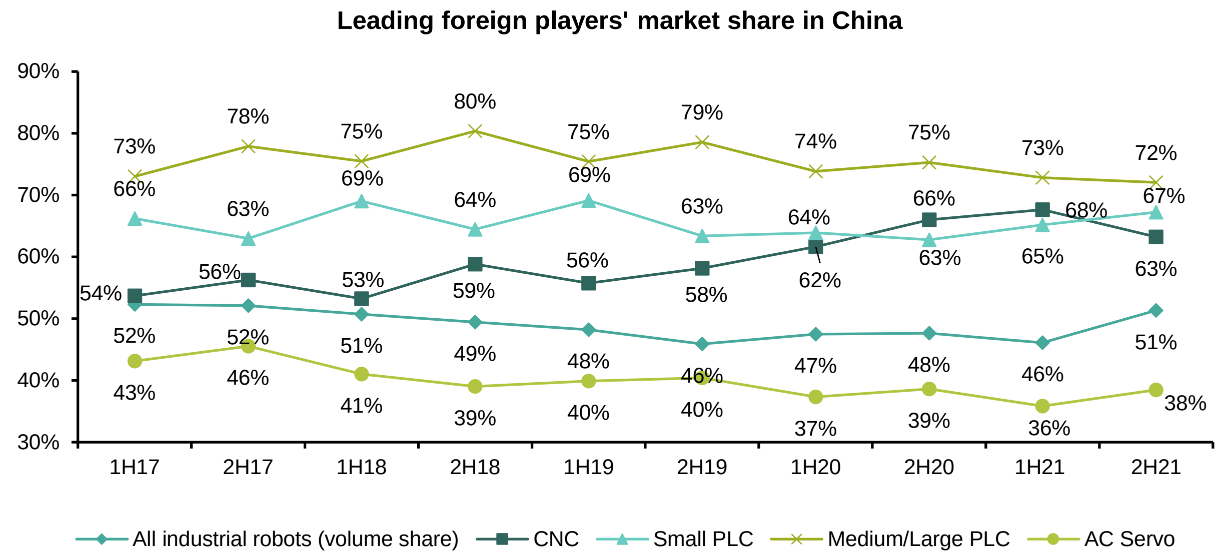
Another piece of the puzzle is Chinese factories. Are they voluntarily decoupling from foreign industrial tech for supply chain security or nationalism? Many factories have long avoided relying on a sole supplier, but because of the absence of US dominance, most Chinese companies do not feel pressed to further turn away from foreign products.

Local substitution only takes place where it makes business and technological sense, considering product performance and price. There is no evidence that substitution is accelerating since the US-China trade/tech war started in late 2018. Leading foreign players' shares across a broad range of automation products are surprisingly resilient (see Exhibit 36).

Unlike consumer products, there is little room for nationalism in manufacturing because the stake is too high. Those who chose inferior equipment for non-commercial reasons are probably an extinct species already, thanks to natural selection. A single robot's downtime costs hundreds of dollars per minute. An unplanned full plant shutdown costs an average of USD260,000 per hour across all industries with a mean downtime of four hours. In the automotive industry, the cost exceeds USD1mn per hour. Therefore, equipment mean time between failure (MTBF) is a critical performance measure for users, and it is often 2-10x longer than leading international brands. The MTBF of imported robots averages ~80,000 hours,[11] compared to ~8,000 hours for domestic brands (see Exhibit 37). It was reported that in 2018 only 0.4% of Chinese robots and robotic systems met China's "Industry Standards for Industrial Robots," which requires an MTBF of at least 50,000 hours. Similarly, a 2019 study[12] found that the MTBF of domestic CNC machine tools was ~2,000, compared to ~5,000 hours for imported ones (see Exhibit 38). It took ~9 hours on average for a CNC machine tool to get repaired every time it broke down.

[11] Some models, such as ABB-IRB-6700, have MTBF exceeding 400,000 hours.
[12] 马仕川. *国产数控机床可靠性分析与评价方法研究*. Master of Science thesis. Chongqing University of Science and Technology, 2019.

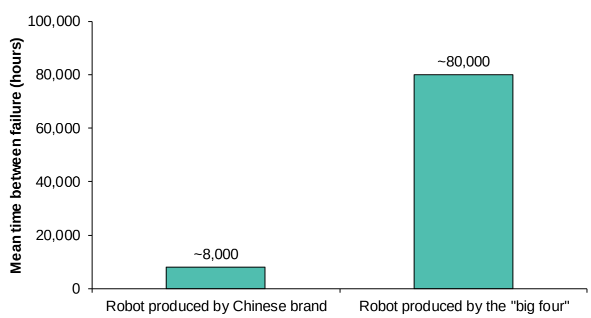
EXHIBIT 36: **Leading foreign player shares across a broad range of automation products remain stable after the start of US-China trade/tech war**



Note: (1) Industrial robots market share is volume share; the others are value share. (2) Foreign players included in each category are — industrial robots: FANUC, ABB, Yaskawa, KUKA, and Epson; CNC: FANUC, Mitsubishi, and Siemens; Small PLC (I/O ≤ 256): Siemens, Mitsubishi, Omron, and Schneider; Medium/Large PLC (I/O > 256): Siemens, Mitsubishi, Rockwell, and Schneider; Low-voltage VFD (Voltage ≤ 690V): ABB, Siemens, Schneider, and Danfoss; AC Servo: Yaskawa, Panasonic, Mitsubishi, and Siemens. (3) We cover FANUC among these names.

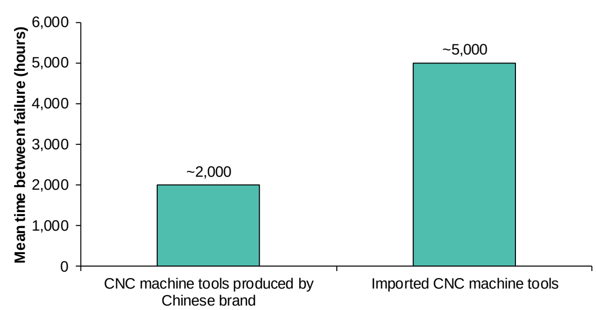
Source: MIR Databank and Bernstein analysis

EXHIBIT 37: **Domestic vs. "Big 4" robots: Significant gap in MTBF**



Source: Yicai.com and Bernstein analysis

EXHIBIT 38: **Domestic vs. imported CNC machine tools: Significant gap in MTBF**



Source: "Reliability Analysis and Evaluation Method of Domestic CNC Machine Tools" and Bernstein analysis

Reliability is the biggest gap between Chinese and foreign automation products. Besides that, there are other tangible and important performance gaps. In any market, customers' needs are diversified and some are more willing to trade lower price for lower performance; hence, local products become "good enough" and gain share. But "good enough" is not one size fits all, and substitution stops as soon as the low-hanging fruits are grabbed, because for higher-end users the same performance gap outweighs price discounts. This is an important reason why many leading foreign players kept their shares in China (see Exhibit 36) after initially giving up shares in the low-end many years ago. We provide some examples to show that even for seemingly mature technologies, such as servo motors, SW reducers, and small payload robots, substantial performance gaps persist. Admittedly, though, these gaps matter only to certain customer groups.

Servo motors

We compare similar models from Yaskawa and two leading Chinese brands (Inovance and Estun) in Exhibit 39. Yaskawa's servo motors and amplifiers have superior specs that impact real performance of the motors and the machines that use them:

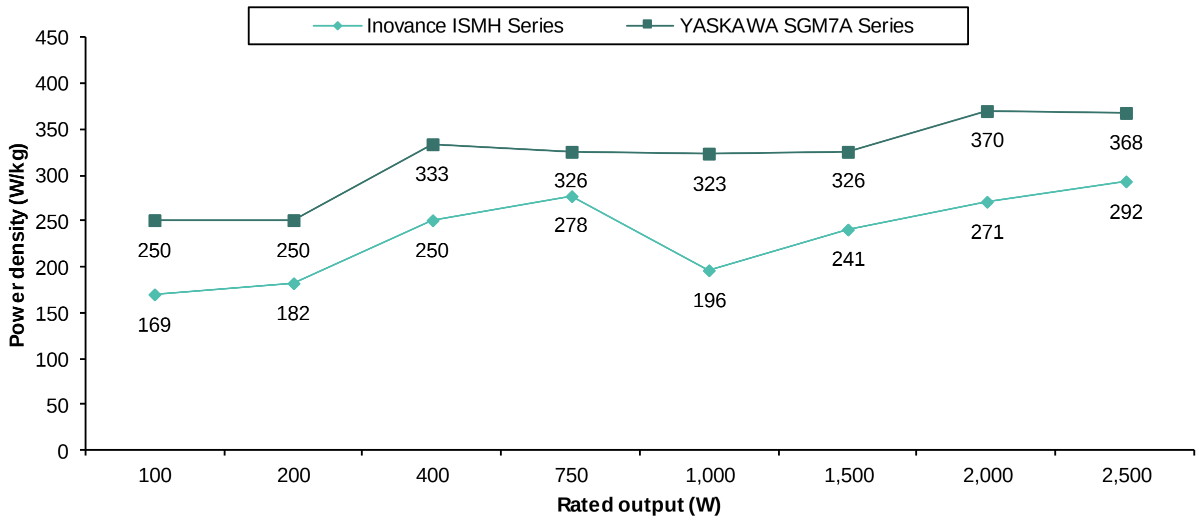
- Instantaneous maximum torque and motor moment of inertia: Higher torque and lower moment of inertia mean the motor can respond quicker with higher angular acceleration.
- Mass and power density: For a given output (750W in this example), lower mass means higher power density, which burdens the robot/machine that uses the motor with less load. Yaskawa servo motors consistently have higher power density than Inovance's across a broad range of output (see Exhibit 40).
- Bandwidth: Higher bandwidth allows shorter cycles and minimizes settling time.
- Torque control precision: Higher precision means better repeatability of position and allows higher speed and acceleration.

EXHIBIT 39: **Compared to leading Chinese brands, Yaskawa's servo motors and amplifiers have superior specs that result in tangible performance differences**

Servo motors				
Brand		YASKAWA (Japan)	Inovance (China)	ESTUN (China)
Model		SGM7A-08A	ISMH1-75B30CB-U2	EM3A-08AFA
Rated Output	W	750	750	750
Rated Motor Speed	rpm	3000	3000	3000
Maximum Motor Speed	rpm	6000	6000	6000
Rated Torque	N·m	2.39	2.39	2.39
Instantaneous Maximum Torque	N·m	8.36	7.16	7.16
Motor Moment of Inertia	$\times 10^{-4}$ kg·m^2	0.775	1.300	0.909
Mass	kg	2.3	2.7	2.6
Power Density	W/kg	326.1	277.8	288.5
Corresponding amplifiers				
Brand		YASKAWA (Japan)	Inovance (China)	ESTUN (China)
Model		SGD7W MECHATROLINK-III	IS620P	ProNet-08A
Speed control range		1:5000	1:5000	1:5000
Bandwidth (kHz)		3.1	1.2	-
Coefficient of speed fluctuation	for a load fluctuation of 0% to 100%	±0.01% of rated speed max.	0.5% of rated speed max.	±0.01% of rated speed max.
	for a voltage fluctuation of ±10%	0% of rated speed max.	0.5% of rated speed	0% of rated speed max.
	for a temperature fluctuation of 25℃±25℃	±0.1% of rated speed max.	0.5% of rated speed max.	±0.1% of rated speed max.
Torque control precision (repeatability)		±1%	±2%	-
Soft start time setting (s)		0-10	0-60	0-10

Source: Company reports and Bernstein analysis

EXHIBIT 40: **Yaskawa's servo motors have higher power density across the output range**



Source: Company reports and Bernstein analysis

Small-payload robots

We analyzed the local substitution trend in the Chinese industrial robot market recently and found mixed and limited success from domestic brands.[13] The light six-axis (payload ⩽ 20kg) segment saw the most share gain by Chinese companies, but a leading player such as FANUC was still able to maintain share. In Exhibit 41, we compare comparable models between FANUC and Chinese competitors. FANUC is head-and-shoulders above Chinese competition in almost every dimension. The most important ones include lower mass-to-payload ratio, higher repeatability, and higher speed (in all six axes). Path accuracy is not commonly quoted in manuals, but we understand the gap is even bigger there.

EXHIBIT 41: **Small-payload six-axis robots: FANUC outperforms leading Chinese brands in precision, speed, mass-to-payload ratio, and other important aspects**

Robot comparison: small-payload robot				
Brand		FANUC (Japan)	EFORT (China)	CROBOTP (China)
Model		M-10iD/10L	ER10-1600	CRP-RH14-10
Payload	kg	10	10	10
Mass	kg	150	185	170
Mass-to-payload ratio	-	15.0	18.5	17.0
Reach	mm	1636	1640	1440
Repeatabilly	mm	±0.03	±0.05	±0.08
Motion maximum speed				
J1 axis rotation	°/sec	260	170	169
J2 axis rotation	°/sec	240	160	169
J3 axis rotation	°/sec	260	180	169
J4 axis rotation	°/sec	430	330	280
J5 axis rotation	°/sec	450	360	240
J6 axis rotation	°/sec	720	600	520

Source: Company reports and Bernstein analysis

[13] See Robotics in China: Detailed data on demand cycle, local substitution, price trend, industry winners and losers.

Strain wave reducers

In SW reducers, the gap is smaller. Leader Drive claims precision and lifetime similar to Harmonic Drive. Within Chinese robot brands, Leader Drive already enjoys over 50% market share, although its share has not further increased in China since 2018, and its major overseas robot customer has so far been limited to one (Universal Robots).[14] The remaining gap, according to user feedback, is consistency. Clearly, the market's collective assessment is that Chinese SW reducers are good enough for most SCARA robots and low-end small-payload six-axis robots, and many collaborative robots, but not yet good enough for global mainstream six-axis robots.

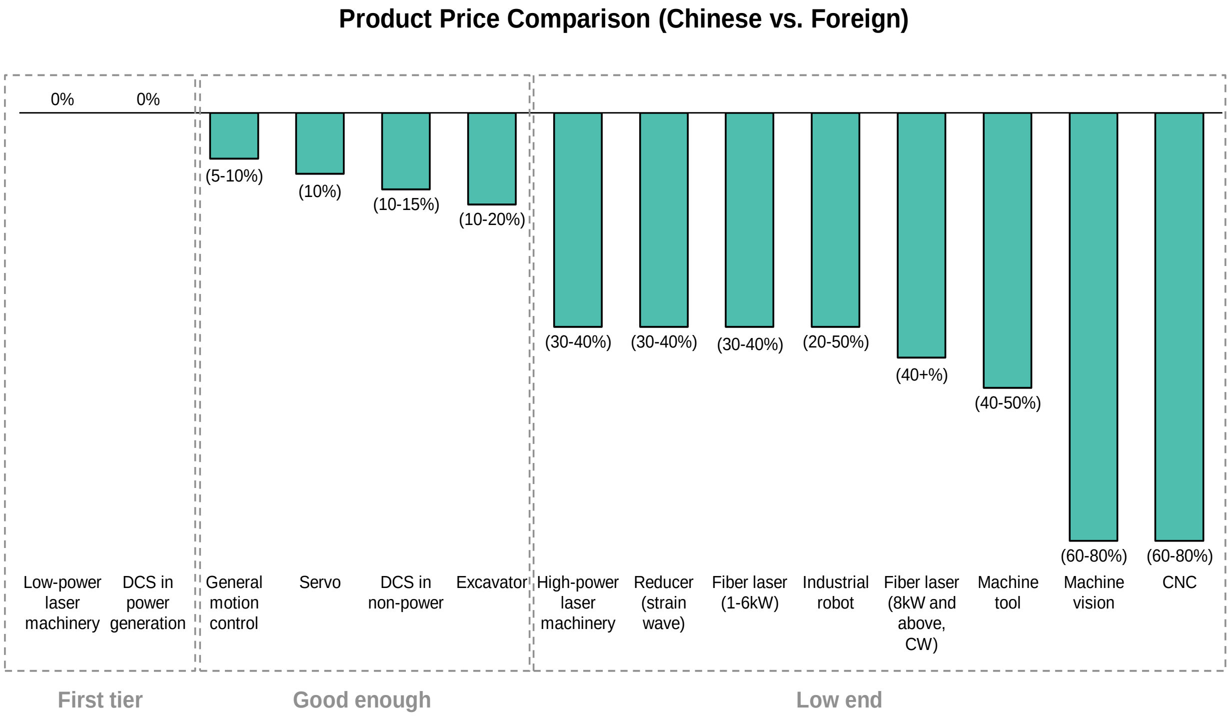
These performance gaps result from many factors including product design know-how, manufacturing recipe, end-industry domain expertise, and software. Despite decades of investment by Chinese companies and encouragement from the Chinese government, they have proved very difficult to overcome.[15] For different customers, the relevance of these product differences varies from trivial to critical, but it is possible to assess how meaningful the technology gaps are and whether they are closing, in each product segment. The most relevant indicator is the price gap between a Chinese product and that from an industry leader.

Take fiber laser as an example. Despite the popular belief of Raycus closing the gap vs. IPG, customers have voted otherwise with their money. The Raycus discount to IPG at every power level is 30-40%. This is not meaningfully different from three to five years ago. We would need to see a much smaller gap to believe that the two companies' technologies are getting closer.

Across product segments, price gap is also a good indicator of Chinese companies' technology level relative to industry leaders (see Exhibit 42). A shrinking or diminishing price gap, rather than a market share move, is the strongest signal of changing competitive dynamics. A 40-80% price difference indicates severe performance gaps that are often intolerable for mainstream users; external factors are rarely enough to change customers' product choice. A 0-20% price difference often indicates that the product performance gap although real is already only marginal for many customers, and the remaining gap may have more to do with branding and reluctance to change than anything else. At that point, certain catalysts could trigger accelerated substitution.

[14] See Global Automation: Baby shark, doo, doo ... Leader Drive IPO and read-across to Harmonic Drive.
[15] See "Surely you are joking, Mr. Analyst!" - Four maladies that hinder one's search for great industrial companies and Asian Industrial Tech: The making of Chinese global champions - a multi-industry framework and analysis.

EXHIBIT 42: **Price gaps are best indicator of technology gaps**



Note: DCS — Distributed Control Systems; CNC — Computer Numerical Control

Source: Bernstein estimates and analysis

THE MAKING OF CHINESE GLOBAL CHAMPIONS — MULTI-INDUSTRY FRAMEWORK AND ANALYSIS

SCREENING FOR CHINESE GLOBAL CHAMPIONS

Chinese companies exhibit a wide spectrum of performance and capabilities. At one end, a handful of highly profitable, technologically advanced leaders are emerging; at the other, loss-making, subscale copycats barely survive. Screening the industrial equipment space, we see four distinct clusters (see Exhibit 43):

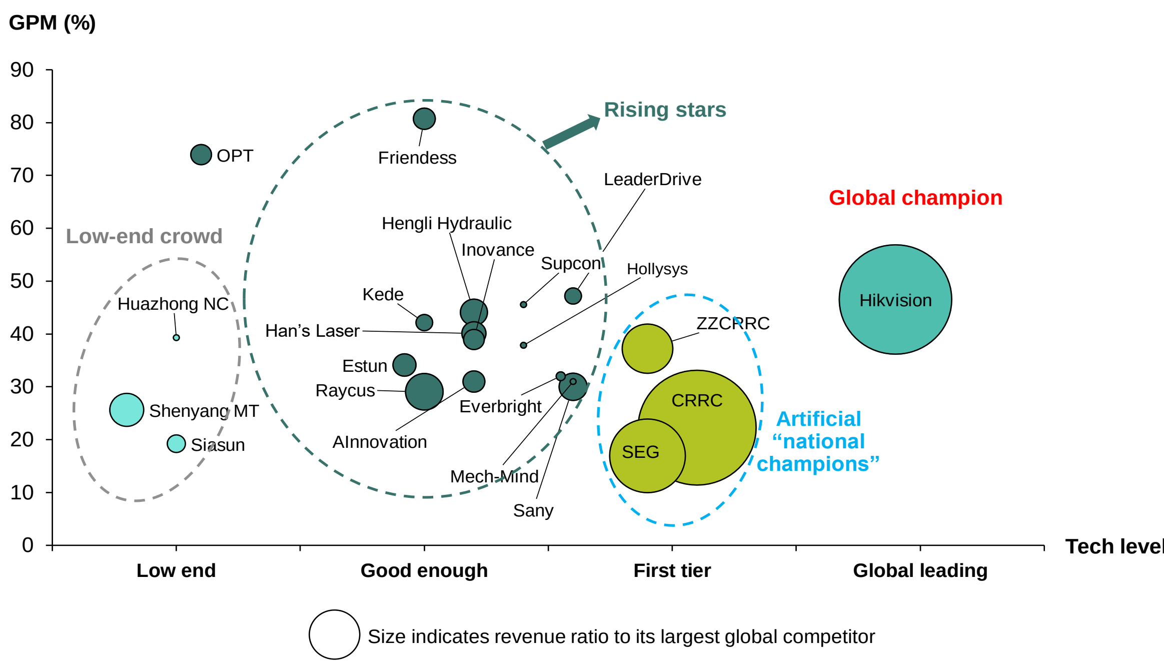
- **Global champion.** Hikvision is one of a kind, characterized by technology leadership, significant value creation, and a leading market position both in and outside China.

- **Rising stars.** This group houses a range of promising smaller companies — Estun in industrial robots, Inovance in motion control, Han's Laser in laser material processing equipment, Supcon and Hollysys in process automation, AInnovation and Mech Mind in manufacturing AI applications, Everbright in laser diode, Raycus and Maxphotonics in fiber laser, Leader Drive in SW reducer, Kede in five-axis CNC, and Friendess in laser machinery control software — that have all demonstrated quickly improving indigenous technology and consistent market share gain from foreign incumbents. Among Chinese players, they have stood out as the local tier 1 players.

- **Low-end crowd.** These are the majority of the Chinese industrial equipment sector. Their technology is so behind that even with significant price discounts to industry leaders, they can only compete among themselves in the low end. They suffer from low margin and return, as a result of adverse industry trends, value chain position, or competition.

- **Artificial "national champions."** This group mainly consists of companies such as CRRC, Zhuzhou CRRC, and Shanghai Electric.[16] At a glance, these companies have raised themselves from the low end, and have leading or even dominating market positions. Yet they reached this position at least partially through government-induced market-entry barriers and technology transfer, instead of indigenous development. We view this kind of success as artificial. As a result, their profitability and return are somewhat "regulated." They have reached a ceiling in both market position and technology level.

EXHIBIT 43: **Differentiation of Chinese industrial equipment companies**



Note: GP margins are FY2020 numbers except for Shenyang MT (where 2018 — the most recent profitable year — numbers are used); GPM for Mech Mind (private company) is our best estimate.

Source: Bloomberg, and Bernstein estimates and analysis

[16] Presumably, this group could also include a few other names in shipbuilding, heavy machinery, and power transmission and distribution equipment.

EXHIBIT 44: **Characteristics of an (upcoming) global leader from China**

Industry	Company	China position			Value creation		Technology		Global position	
		Domestic market share	Market share ranking in China	Free competition	GPM (2020)	ROE (2020)	Level	Source	Ex-China market share	Relative size to largest competitor
Video surveillance	Hikvision	35%	1	✓	47%	30%	Global leading	Indigenous	13%	240%
Laser machinery	Han's Laser High-power	~10%	1		40%	14%	Good enough		~1%	12%
	Han's Laser Low-power	~40%	1				First tier			>200%
Fiber laser	Raycus	24%	2		29%	19%	Good enough		<1%	23%
Laser diode	Everbright	9%	1-3		32%		First tier			2%
Industrial robot	Estun	4%	5+		34%	6%	Low end			11%
Reducer (strain wave)	LeaderDrive	55%	1		47%	9%	First tier			6%
Process control	Hollysys	~15%	2-4		37%	8%	First tier			1%
Laser equipment controller	Friendess	57%	1		81%	21%	Good enough			
AI	AInnovation	2%	1-5		29%		First tier			
Robot guidance	Mech-Mind				20-30%		First tier			
CNC	Kede	5%	3-5		42%		Good enough			6%
	Huazhong NC	<10%	5+		39%	(3%)	Low end			1%
Motion control	Inovance	16%	1		37%	8%	Good enough			9%
Machine tool	Shenyang MT	<10%	2-4		(9%)	(152%)	Low end		<5%	23%
Machine vision	Hikvision	14%	2		47%	30%	Good enough			14%
	OPT	<10%	5+		74%	21%	Low end		<1%	9%
Rail equipment	CRRC	100%	1	×	22%	8%	First tier	Transfer-red	<10%	264%
	ZZCRRC	30-60%			37%	11%			<5%	~50%
Power equipment	Shanghai Electric	~40%			17%	(5%)			<5%	110%
Excavator	Sany	~25%			30%	26%				16%

Note: Market share numbers are as of 9M21 where available, or 2020 otherwise; Mech Mind is a private company and its GPM is our best estimate.

Source: MIR Databank, Bloomberg, company reports, and Bernstein estimates and analysis

Our screening criteria — most of them self-explanatory — are detailed in Exhibit 44. We stress the following:

- Technology, technology, technology! This is the primary dimension for classification. It's a qualitative metric and inevitably involves our own judgment. Our criteria include:

  - Global leading: When a company is a first mover in new technologies and is able to set industry standards. In Hikvision's case, it led the industry's transformation from analog to digital, and later, the continued evolution to high-resolution systems. Currently, it is also leading both foreign and domestic players in using AI in video analytics and inventing enterprise applications by integrating video as part of enterprise digitalization.[17] Many of its new products front-run the closest competitor by six to 12 months.
  - First tier: When a Chinese company's technology is on par with a small group of industry leading players and is able to compete without a significant price discount. Examples include parts of Han's Laser's low-power business, Estun's welding robots (after Cloos integration), some AI industrial vision solutions from AInnovation/Smartmore/Aqrose, and Mech Mind in robotic guiding.
  - Good enough: When a company is able to carve out a "mid-end" segment, distinct from the low-end in pricing and product performance. It competes with the leading players for the same customer base and, with a meaningful price discount, is able to draw some demand from the high end. Examples include Inovance's motion control products, Hollysys and Supcon DCS, Estun's six-axis industrial robots, Leader Drive's SW reducers, and Raycus high-power fiber lasers.
  - Low end: When a company's technology and products are so inferior that even with significant price discount it is not able to compete with industry leaders for the same customer base. For mainstream demand, a low-end product is not usable no matter how cheap it is. Examples include CNC machine tools, RV reducers, industrial robots, and machine vision products from most Chinese brands (see Exhibit 42).

- Market position needs to be seen in light of government-induced entry barriers. For artificial "national champions" and a few others, their leading positions were helped by current or past entry restrictions. On the other hand, in the industries of Hikvision and the rising stars, not only was there minimal "protection" from the government, but imported products and foreign company participation were often encouraged (see Exhibit 45). This resonates well with the point we tried to make in earlier sections of this chapter: in Made in China 2025, the Chinese government's intention is first and foremost to encourage use of advanced industrial technologies, regardless of origin, so as to upgrade the Chinese manufacturing sector, rather than to favor Chinese suppliers and drive local substitution indiscriminately. Moreover, none of these equipment industries have current policy limiting foreign company participation (see Exhibit 46).

- Value creation is an important criterion. High "value add" indicates deep moat and know-how, and pricing power. Equipment makers without vertical integration can also add significant value. Furthermore, high margin and return indicate quality of operation and allow a company's development to be self-funded. We note that for the champion, runner-up, and rising stars, their heathy financials are not a result of government subsidies (see Exhibit 47).

[17] See Hikvision: Full speed and five platforms toward AIoT and digital enterprise.

EXHIBIT 45: **Counterintuitively, Chinese global leaders and rising stars emerge where foreign company participation is encouraged, rather than restricted**

	Government protection	Government encouragement for foreign entry (2007-2017)
Video surveillance		√ (high-resolution digital camera)
Laser machinery		√ (Laser cutting, welding, precision manufacturing equipment)
Fiber laser		√ (high-power laser source)
Industrial robot		√ (Articulated / welding robot)
Reducer (strain wave)		
Process control		√ (Fieldbus control system, PLC, flow meter)
CNC		√ (5 axis CNC)
Motion control		
Machine tool		√ (high-end CNC machine tool)
Rail equipment	Restricted to Sino-foreign cooperation/JV before 2017	
Thermal PGE	Certain thermal PGE restritcted to sino-foreign cooperation/JV before 2012	
Wind PGE	Restricted to Sino-foreign cooperation/JV before 2012	
Excavator	Certain CE restricted to Sino-foreign cooperation/JV before 2012	
Diesel engine	Certain diesel engine restricted to Sino-foreign cooperation/JV before 2015	

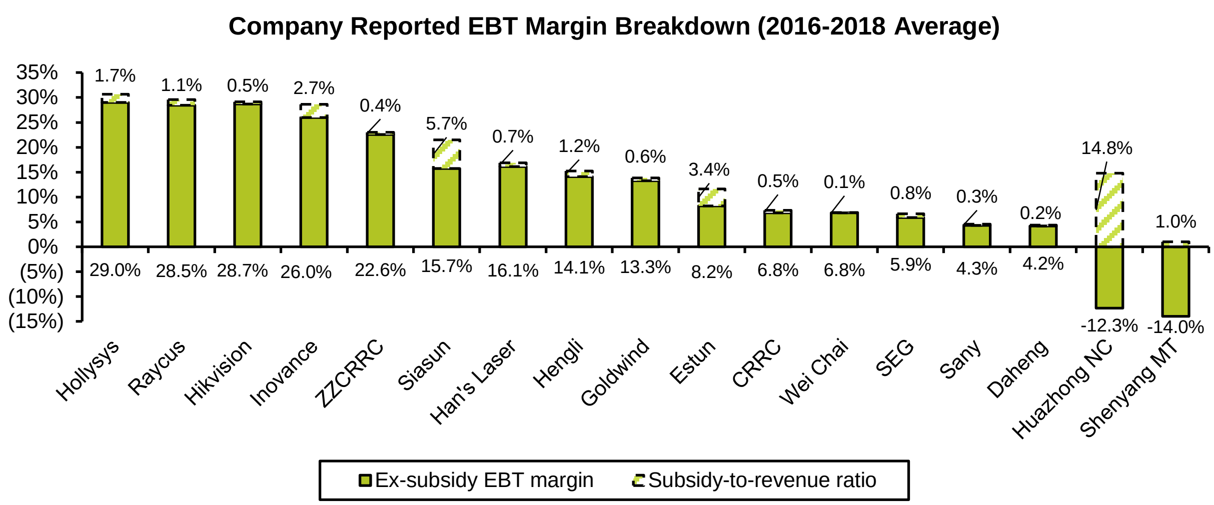
Source: NDRC "Foreign Investment Industry Guide" (2007, 2011, 2015, 2017, and 2018 versions) and Bernstein analysis

EXHIBIT 46: **Today, very few manufacturing segments still have restrictions on foreign company participation**

Manufacturing industry	Restrictions on foreign investment
Printing & publication	Chinese parties must have >50% holding in publication printing
Nuclear fuel and radioactive material processing	Foreign investment prohibited in radioactive mineral smelting, processing, and nuclear fuel production
Chinese medicine processing and manufacturing	Foreign investment prohibited in steaming, frying, simmering, calcining and other processing of Chinese medicines and production of secret prescription Chinese medicines
Automotive manufacturing	Chinese parties must have >50% holding in non-EV and non-special-purpose motor vehicles manufacturing
Telecommunication equipment manufacturing	Foreign investment prohibited in production of satellite TV broadcasting ground receiving facilities and key components
Other manufacturing	Foreign investment prohibited in production of Xuan paper and ink ingot

Source: NDRC "Foreign Investment Industry Guide" (2018 version) and Bernstein analysis

EXHIBIT 47: **For the champion and rising stars, their healthy return is not boosted by government subsidies**



Source: Company reports and Bernstein analysis

THE MAKING OF CHINESE GLOBAL CHAMPIONS

When all stars are aligned, a Chinese company rises to become a (current or future) global leader. But what are these "stars"? Internal (company specific) factors (good management, culture, continued capability building, etc.) are necessary but insufficient. We are most interested in the external (industry level) factors, in order to explain why the champion and rising stars only emerge in certain industries but not others.[18] This approach, we believe, takes the randomness of "where the capable people are" out of the equation and, instead, focuses on what's inherent to a business, and allows one to follow a small number of industries and companies to identify opportunities and monitor risks to global incumbents.

[18] For readers with a more cynical view toward Chinese companies, take this as the alternative version of the question: "Why is there something rather than nothing?".

Before applying a general framework to all industrial equipment companies, we first look at what allowed Hikvision to rise from the pack. We identify the following:

- Along the "components — products — integrated solution" chain, the company's core strength is in "products," with a large number of SKUs (>25,000 in Hikvision's case), driven by diversified applications and customer requirements (i.e., not off-the-shelf).
- Therefore, there is sufficient value-add in product design and customization (not just "assembly"). The manufacturing process itself is important but not a critical differentiator.
- Furthermore, there is no outsized customer or supplier to extract value and squeeze the equipment maker.
- Its touch points with customers provide a constant stream of insights for innovation, strengthening the point of value-add in product design. Conversely, high value-add leads to high margins, self-funding fast innovation and growth.
- China demand happens to be the high-end, most innovative demand in the world, allowing a Chinese company to rise as a technology first mover.
- Once a solid position in product is established, it expands to integrated solutions to form an additional moat, and to take even more advantage from the innovative China demand.
- Due to the required customization and frequent product iteration, R&D staff is a sufficiently big portion of all employees (30-50%). With the huge wage gap between Chinese and Western engineers, such a Chinese company enjoys a cost advantage much more sustainable than that from China production.

From this discussion, with a slight leap of faith, we come to believe the following are the key makings of a Chinese global champion:

- China is the origin of high-end, innovative demand;
- The company is in a favorable part of the value chain;
- Core technology is in product design and solution, as opposed to manufacturing "recipe" and platform software, which are two technology black boxes; and
- High ratio of R&D and engineering staff provides sustainable cost advantage.

These factors are detailed in Exhibit 48. Hikvision and AI in manufacturing players (e.g., AInnovation and Mech Mind) have the blessing of all four factors, and the remaining rising stars benefit from at least three of them.

EXHIBIT 48: **Makings of a Chinese global champion — four industry-level factors drive differentiation**

Industry	Nature of China demand		Value chain position		Technology differentiator				Source of cost advantage
	Growth	High end and innovative?	Outsized supplier or customer?	Leader GPM (2020)	Manufact. "recipe"	Software	Product design	Solution & customization	Ratio of R&D staff
Video surveillance	15-20%	✓	N	47% (Hikvision)		★	✓	✓	47% (Hikvision)
Laser machinery – High-power	15-20%		Y	40% (Han's Laser)		★	✓	✓	35% (Han's Laser)
Laser machinery – Low-power	10-15%	✓	N	〃	〃	〃	〃	〃	〃
Fiber laser	15-20%		N	29% (Raycus)	✓✓		✓		22% (Raycus)
Laser diode	15-20%		N		✓✓		✓		36% (Everbright)
Industrial robot	25%		N	30-35% (Estun)	✓	★★	✓	✓	64% (Siasun) 37% (Estun)
Reducer (strain wave)	30%		N	47% (LeaderDrive)	✓✓		✓✓	✓	13% (LeaderDrive)
Process control	5-10%	✓	N	38% (Hollysys)		★	✓	✓	20% (Hollysys)
Laser equipment controller	20-30%	✓	N	81% (Friendess)		★	✓	✓	48% (Friendess)
AI	50-100%	✓	N	30-50% (AInnovation / Smartmore)	✓	★★	✓	✓	54% (AInnovation)
Robot guidance	50-100%	✓	N	20-30% (Mech-Mind)	✓	★★	✓	✓	50-60% (Mech-Mind)
CNC	10-15%		N	39% (Huazhong NC)		★★	✓		43% (Huazhong NC)
Motion control	5-10%		N	39% (Inovance)		★	✓	✓	26% (Inovance)
Machine tool	5%		Y	25% (Shenyang MT)	✓✓		✓		9% (Shenyang MT)
Machine vision	20-30%	✓	N	50-55% (Hikvision)		★★	✓	✓	47% (Hikvision)
Rail equipment	<5%	✓	Y	22% (CRRC) 37% (ZZCRRC)	✓		✓		21% (CRRC)
Power equipment	〃	✓	Y	17% (SEG)	✓		✓		36% (Goldwind) 32% (SEG)
Excavator	〃		N	30% (Sany)	✓		✓		13% (Sany)

Note: Mech Mind is a private company and its GPM and R&D staff ratio are our best estimate; we use 2018 GPM for Shenyang MT as 2019-20 numbers are negative.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

Nature of China demand

In most industries, China is the home to low-to-mid-segment demand. To use a single example from the machine tool industry, China lags developed markets both in CNC ratio and in the type of CNCs commonly used (see Exhibit 49).

Yet, there are noticeable exceptions. When China demand is the high-end and the most innovative, Chinese companies are not necessarily playing a "catching up" game, but can compete in, or even define, the cutting edge of an industry. In video surveillance, China was home to most of the technology inflections in the last decade, including the adoption of IP-based systems, the adoption of high-definition and 4K cameras, the commercialization of AI in video analytics, and the creation of enterprise video digitalization applications. In laser material processing, thanks to Apple's relentless focus on using the most advanced manufacturing technologies and continued production line sophistication, China has also become the home to some of the most innovative low-power laser applications.[19] In the emerging field of AI in manufacturing, Chinese startups working with willing Chinese customers are inventing and commercializing more first-time-ever applications than anywhere else.[20]

In addition to Hikvision and Han's Laser, artificial "national champions" have also enjoyed the benefits of high-end Chinese demand — high-speed rail lines (see Exhibit 50) and third-generation nuclear power stations in China outnumber any other market by many fold. This has contributed to the current position of these companies, but demand in these industries is mostly saturating with little growth.

For some rising stars, China demand may not yet represent the high end, but is moving in the right direction. For example, in DCS, the environmental/safety/efficiency upgrade of power and chemical plants in China is calling for IIoT applications. The rise of cobots has allowed Leader Drive to expand its customer base beyond the low-end Chinese robot makers and enlist Universal Robots as a key customer. The explosive adoption of ultra-high-power fiber lasers is shaping product development at Raycus and Maxphotonics.

China's industrial policy, as discussed in the previous section, has a clear priority in creating high-end demand. It takes various forms, ranging from providing incentives for the use of advanced automation technologies, to raising environmental and energy efficiency requirements on manufacturers, to encouraging the adoption of AI and digitalization in manufacturing. We believe these measures, instead of indiscriminative subsidies, are the most effective role a government can play to incubate successful Chinese companies.

[19] See Global Automation: The iPhone impact - evolution of three automation technologies and their outlook in 2018.

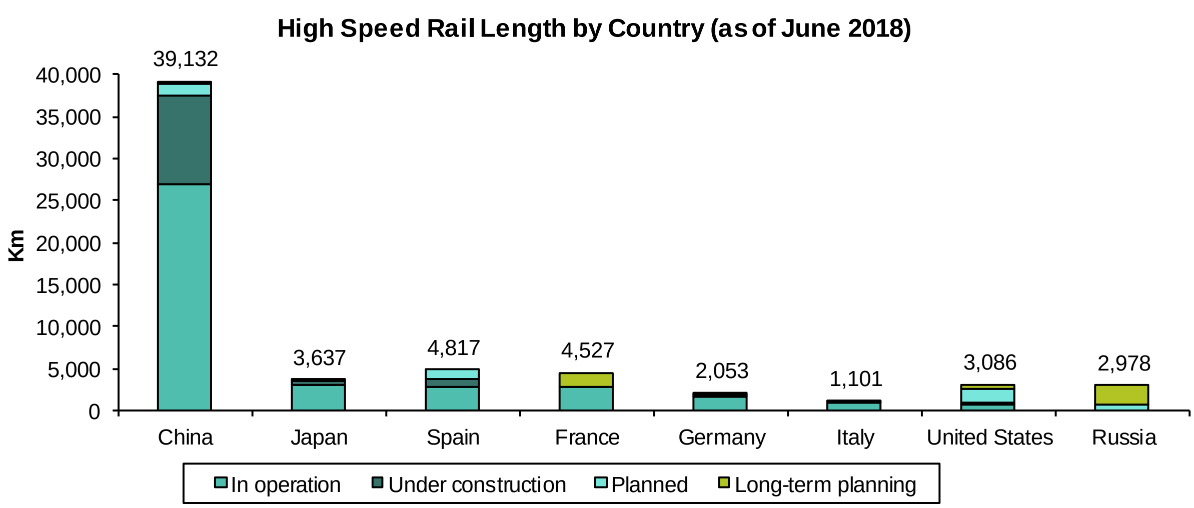
[20] See Artificial Intelligence chapter of this *Blackbook*.

EXHIBIT 49: **China lags developed markets in the type of CNCs commonly used**

	FANUC CNC Series 0*i*	FANUC CNC Series 30*i*
Max number of axes controlled	21	96
Max number of axes controlled simultaneously	4	24
Application	Stamping press/lathe/compact machining center	One for all kinds of machine tools
Selling point	Value for money	High-end machining, extreme precision, suitable for machining all kinds of shapes
Main customer	Chinese & Indian machine tool makers	Japanese & European machine tool makers

Source: Company websites and Bernstein analysis

EXHIBIT 50: **China is practically the only important market for high-speed rail**



Note: High-speed rail data here refers to railway lines in which operating speed is greater than or equal to 250 km/h.

Source: International Union of Railways and Bernstein analysis

Value chain position

Successful companies do not all vertically integrate, but in part of the value chain, they need to have sufficient value-add in order not to be squeezed by outsized suppliers or customers.

We will look at the sources of value-add shortly. Here, we just point out that GP margin is a good metric to assess a company's value chain position,[21] because in essence it compares a company's pricing of products to its production cost — in between, it is the additional value from product design and solutions. A pure assembler would naturally have lower

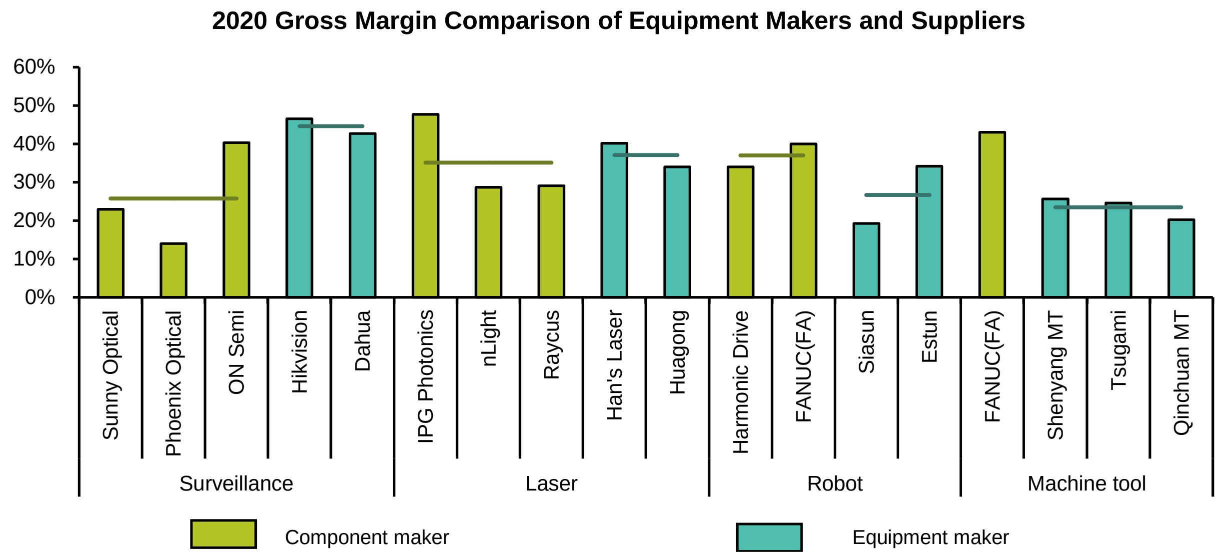
[21] Value-add, measured by revenue deducting procured material, is probably an even better and more direct metric, but the data is not always available for all companies.

value-add, hence lower GP margin, than a producer of proprietarily designed products, even if the latter also outsources all production activities.

In the universe we examine, champions and rising stars are generally in a favorable part of the value chain, showing higher GP margin than their suppliers, and the low-end crowd are clearly squeezed (see Exhibit 51). Going through the individual industries in Exhibit 48, we are also able to identify whether they are overshadowed by suppliers or customers.

The value chain dynamic is not fixed. Take robot makers as an example. European companies such as ABB and KUKA also outsource most key components, and FANUC and Yaskawa also buy reducers from Nabtesco and Harmonic Drive. Yet, with their advanced product design and scale, their relationship with suppliers is drastically different from what most Chinese robot makers experience. For example, Harmonic Drive charges 50%+ more for its reduction gears to Chinese customers than to the Big 4.

EXHIBIT 51: **In the universe we examine, champions, runners-up, and rising stars are generally in a favorable position, showing higher GP margin than their suppliers, while the low-end crowd are clearly squeezed**



Note: The lines are category average values. ON Semi GPM shown here is that of its image sensor group; Huagong GPM shown here is that of its laser material processing system segment; FANUC GPM shown here is an estimate for its FA segment; we use 2018 GPM for Shenyang MT as its 2019-20 numbers are negative.

Source: Bloomberg, and Bernstein estimates and analysis

Technology differentiator

Value add is closely linked to the core technology differentiators in each industry. We believe there are four archetypes of technology differentiators:

- Manufacturing "recipe." This applies to a wide range of precision mechanical components, with reducers[22] being the best example (see Exhibit 52). The critical

[22] In this category, RV reducers, with more components than SW reducers, also require a much more sophisticated manufacturing "recipe."

know-how is in the numerous details of the manufacturing processes, typically including specialty materials, unique surface and heat treatment methods, and machining procedures, which remain a blackbox to copycats. In addition, economy of scale tends to be significant.

- Advanced software. In robotics, the control software is as important as the robot itself. For machine vision and CNC, product performance and functions are primarily determined by the embedded software (see Exhibit 54). Yet, the algorithm is optimized according to hardware specs, and the development is an integrated process. This is also a typical technology blackbox. For instance, the precision of a machine vision system made by a typical EM manufacturer is 1/10 pixel, while that of a Keyence product can reach 1/128 pixel.

- Product design. Some industries have more diversified customer demand than others, and it is critical to design-to-need, with unique functions and a broad range of products. Video surveillance (see Exhibit 53) and laser material processing are two examples. Components or manufacturing processes can hardly produce differentiation and, therefore, some companies may choose to outsource manufacturing completely.

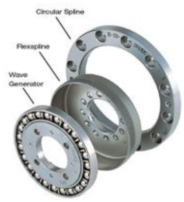
- Customized solutions. When there is unique know-how in tailoring, choosing, configuring, and installing products for a customer, it becomes a solution. The differentiation is above and beyond the product portfolio itself but is usually enabled by a very large number of SKUs (see Exhibit 55). AI in manufacturing applications, machine vision, laser material processing, and video surveillance are good examples.

While none of the four archetypes is inherently superior, there is a difference when it comes to competition. The first two are not "reverse engineerable," while the latter two are. Therefore, attackers get a starting point and can improve from there. When product design and solution are the key differentiator, *and* China represents the high-end, most innovative demand, the combination is very powerful, and Chinese companies are in a sweet spot. Indeed, as we have seen, Hikvision, Han's Laser, Estun, Friendess, AInnovation, and Mech Mind are in such a sweet spot.

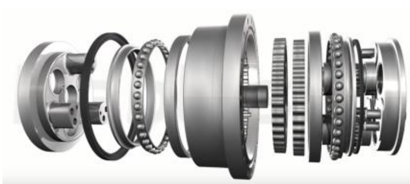
We have previously dubbed the difference between Chinese "electrical engineers" (such as Hikvision) and "mechanical engineers" (such as precision components makers). The former are remarkably more successful than the latter. Although it oversimplifies the picture and Chinese mechanical engineers (e.g., Hengli, Leader Drive, and Shuanghuan) have made impressive progress in the last five years, the key idea is based on the four archetypes of technology differentiators and, at the high level, it still holds.

EXHIBIT 52: **Reducers are an example where critical know-how is in the manufacturing recipe, more so for RV reducers**

Strain wave reducer



RV reducer



Source: Wiki Commons and Bernstein analysis

EXHIBIT 53: **Video surveillance has a broad range of products that are design-to-need with unique functions**

Hikvision Recent Product Examples

Non-flash IR dual sensor night camera

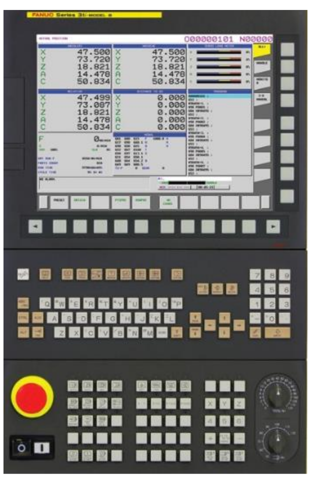
"Dual-eye" passenger flow counting camera for retail

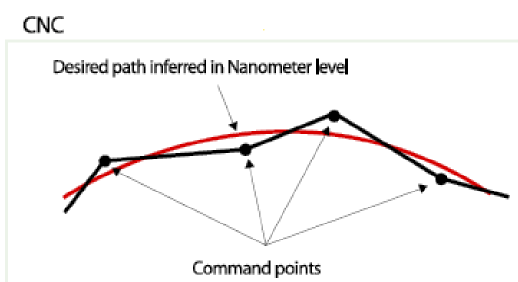
Noise-maker capture camera system

"Overall view" transportation surveillance camera

Source: Company website and Bernstein analysis

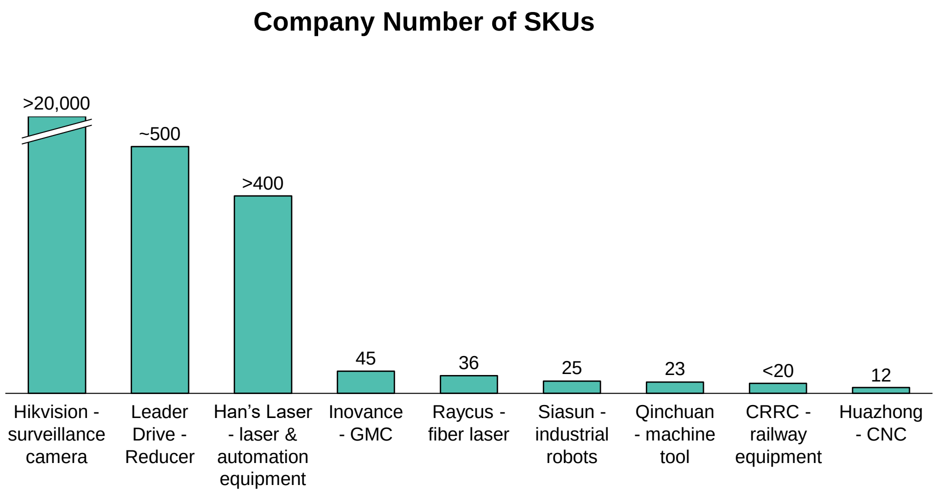
EXHIBIT 54: **CNC performance and functions are primarily determined by embedded software**





Source: Wiki Commons and Bernstein analysis

EXHIBIT 55: **Customized solutions often come with a very large number of SKUs**

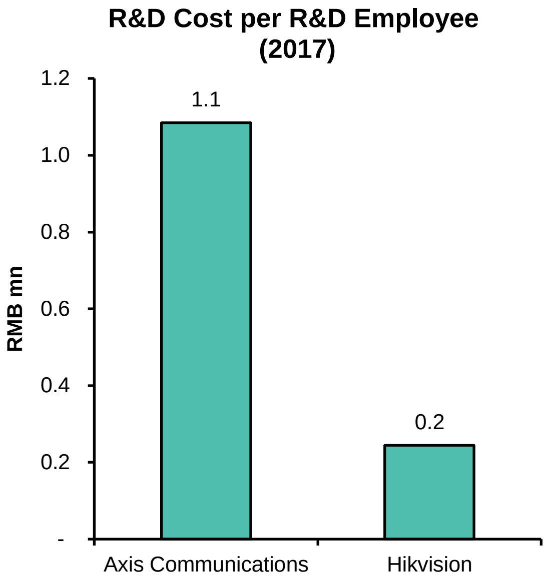


Source: Company reports and websites, and Bernstein analysis

Source of cost advantage

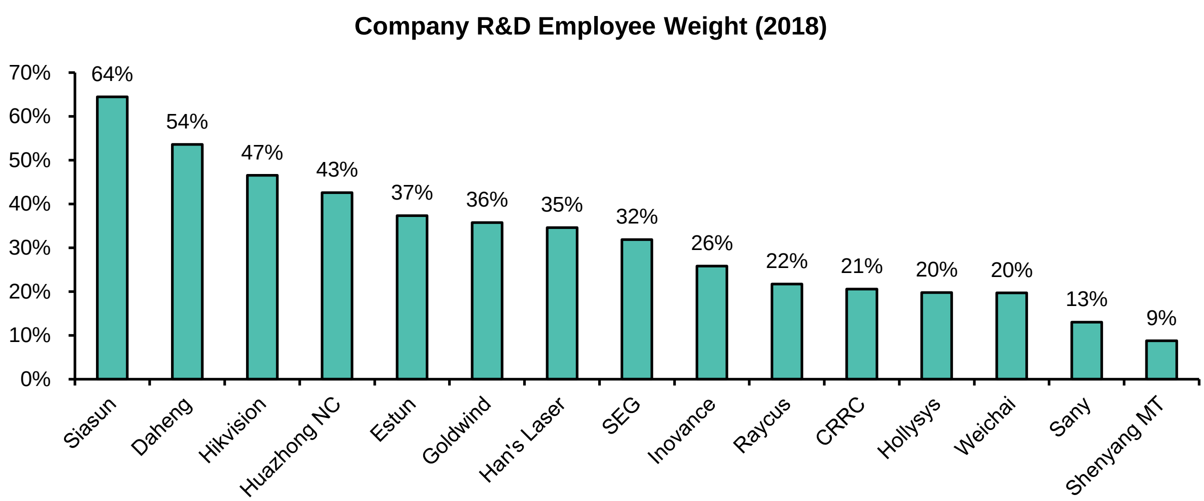
Chinese companies generally have a cost advantage. Yet, not all cost advantages are sustainable. When the cost gap is primarily a result of low-cost factory workers, the gap is greatly reduced when foreign companies localize their production to China. R&D is a function that multinational companies typically will not move to a low-cost country, for fear of losing their IPs. Engineers' cost difference is also one of the largest between China and Western countries (see Exhibit 56). In industries that naturally require a higher portion of employees in R&D (see Exhibit 57) for product and customized solution development, Chinese companies enjoy the most sustainable cost advantage.

EXHIBIT 56: **Engineers' cost is >4x higher in Western countries than in China**



Source: Company reports and Bernstein analysis

EXHIBIT 57: **In industries that naturally require a higher portion of employees in R&D, Chinese companies enjoy the most sustainable cost advantage**



Source: Company reports and Bernstein analysis

ROBOTICS

Long-term demand outlook, user economics, a technology deep-dive, and the local champion

HOW MANY ROBOTS DOES CHINA NEED IN 2030?

MANUFACTURING LABOR SHORTAGE

There is much talk about a manufacturing labor shortage in China, but little data to show its magnitude and impact. Some important questions remain: Why did the situation seem to suddenly worsen in 2020? Is it temporary or chronic? To what extent can automation help?

Unlike the upcycle in 2017, now for the first time a manufacturing labor shortage is a leading driver for robot demand in China. Sampling data from ~100 cities across China shows that the level of manufacturing job vacancies has almost doubled since the end of 2019 (see Exhibit 58), and manufacturing jobs are accounting for a quickly increasing portion of job vacancies (see Exhibit 60).

The manufacturing labor shortage was directly associated with the structural inflection of the migrant worker population. Despite the continued growth of China's total population, 2020 marked the first annual decline (-1.8%) in the number of migrant workers (see Exhibit 59), who contribute almost 70% of China's total manufacturing workforce (see Exhibit 61). This downward trend is chronic: based on age demographics (see Exhibit 64), economists forecast a further -7% decline in the migrant worker population from 2020 to 2025 (see Exhibit 59).

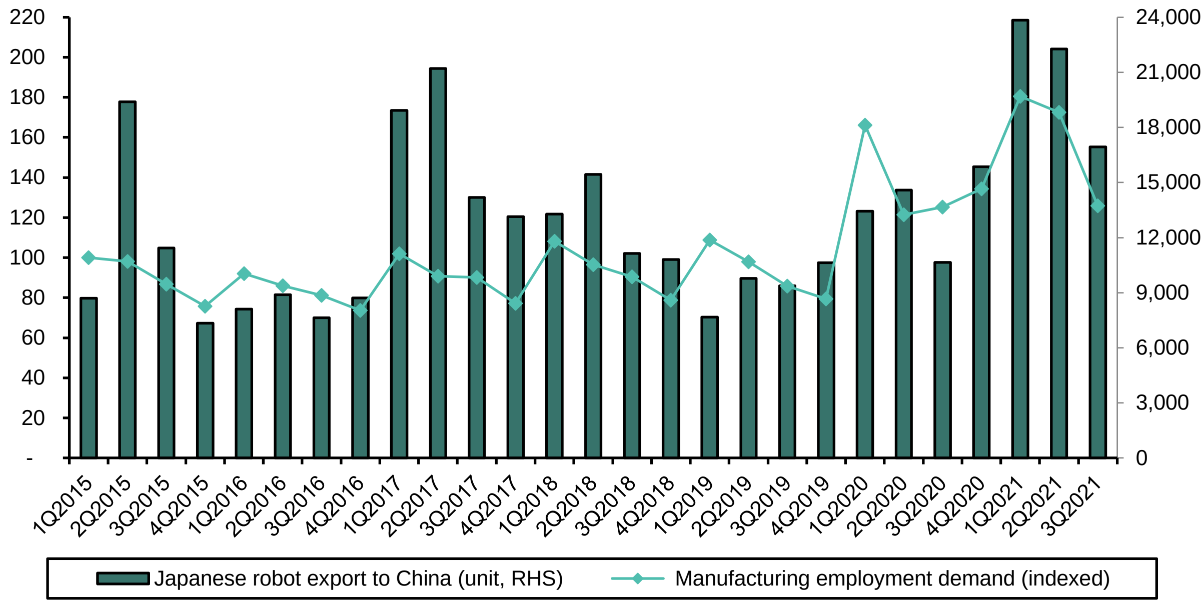
Worse yet, two important factors aggravate the tight labor supply beyond the headline numbers. First, manufacturing is losing to service in the labor force competition (see Exhibit 62 and Exhibit 63). The trend started around 2013, but apparently accelerated after 2018 and broke an important balance after 2020. The rise of China's new economy has created more job options that offer not only better work conditions and more flexibility, but also better pay (see Exhibit 65).

Second, the remaining migrant workers are less willing to go out of their home province (see Exhibit 66). With this trend, the imbalance of labor supply-demand sharply deteriorated in China's manufacturing hubs. For example, over 60% of manufacturing enterprises and employment are concentrated in Eastern China, while only 36% of migrant workers originate in the region (see Exhibit 67).

Automation is an important remedy, if not a cure. We analyzed the nation's top 100 most in-demand job vacancies published every quarter and found not only a significant portion of these job vacancies in manufacturing, but also 30-50% of these jobs can at least be partly automated (see Exhibit 68). At the top of the list are readily automatable tasks such as packaging, welding, handling, and metal lathing.[23]

To factory owners, automation is no longer a consideration of pure cost parity — the intensifying labor shortage gives automation first movers the additional advantage of stable production to win market share. Since the shift in China's demographics is a decade-long trend, and its impact on automation has just become material for the first time, we think the strong automation demand in China may last beyond the length of a normal cycle.

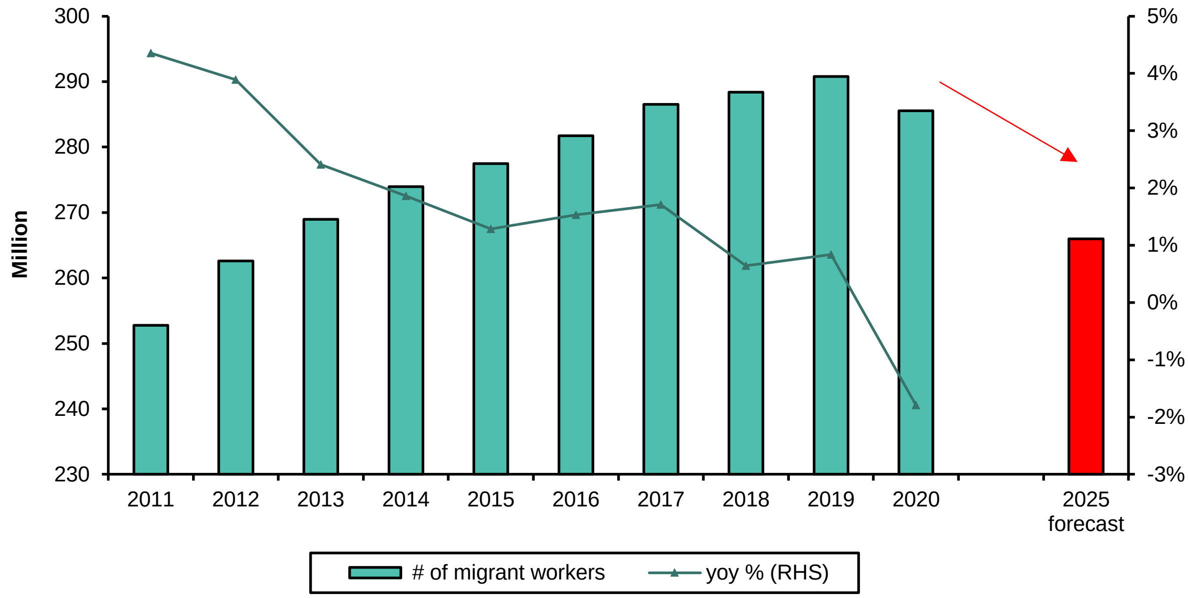
EXHIBIT 58: **Unlike the upcycle in 2017, now for the first time manufacturing labor shortage is a leading driver for robot demand in China**



Source: China Ministry of Human Resources and Social Security, Trade Statistics of Japan, and Bernstein analysis

[23] For an in-depth discussion of the benefiting automation technologies, see Automation: The Day After... Structural shifts post-Covid-19 & the case for unmanned factories and human-robot collaboration.

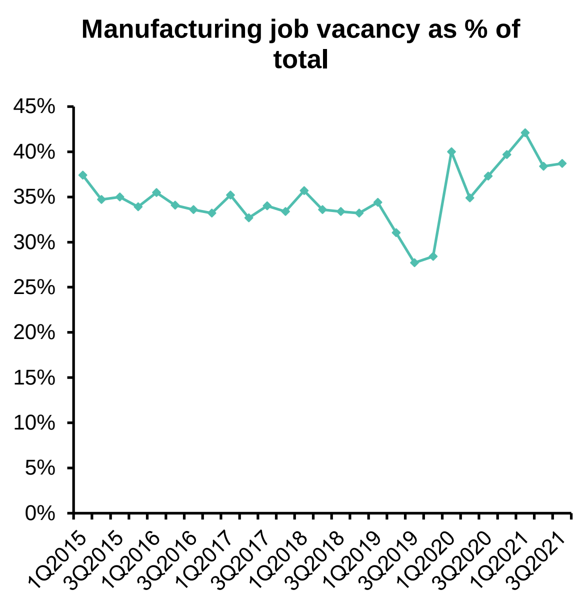
EXHIBIT 59: **2020 marked an inflection, i.e., the start of chronic shrinking of migrant worker population in China**



Note: 2025 forecast is by Caiyi Lin, Deputy Director of the China Chief Economist Forum research institute.

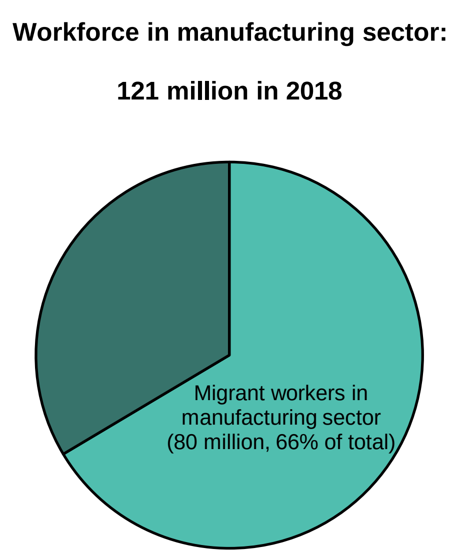
Source: China NBS, Wind, China Chief Economist Forum, and Bernstein analysis

EXHIBIT 60: **Manufacturing sector accounts for a quickly increasing portion of reported job vacancies**



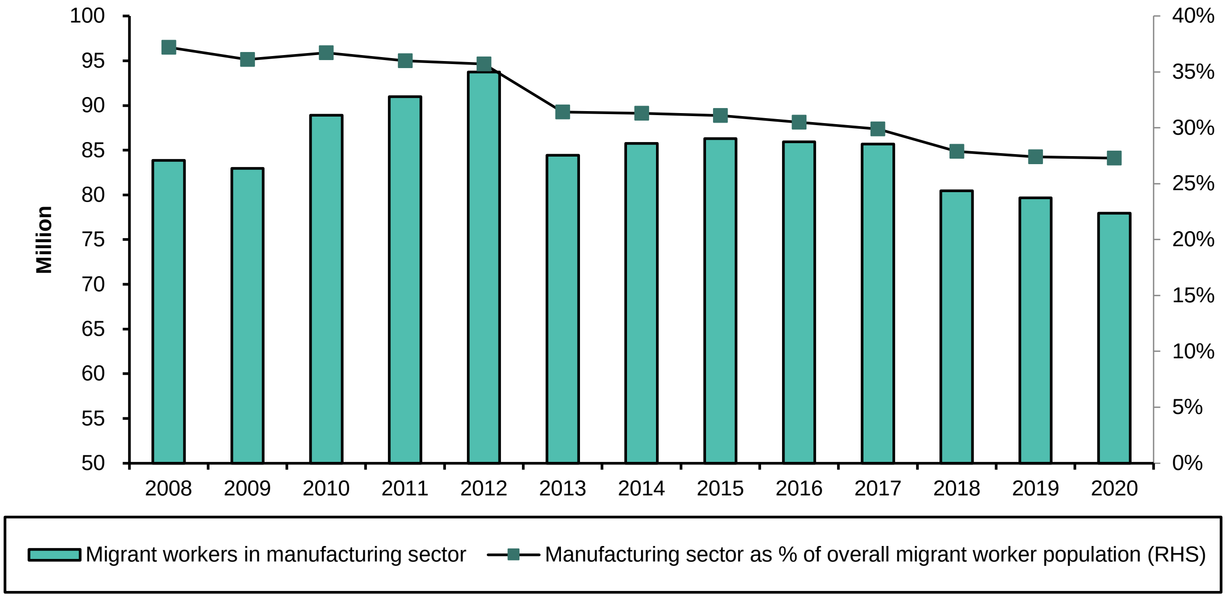
Source: China Ministry of Human Resources and Social Security, and Bernstein analysis

EXHIBIT 61: **Migrant workers account for ~70% of manufacturing workforce in China**



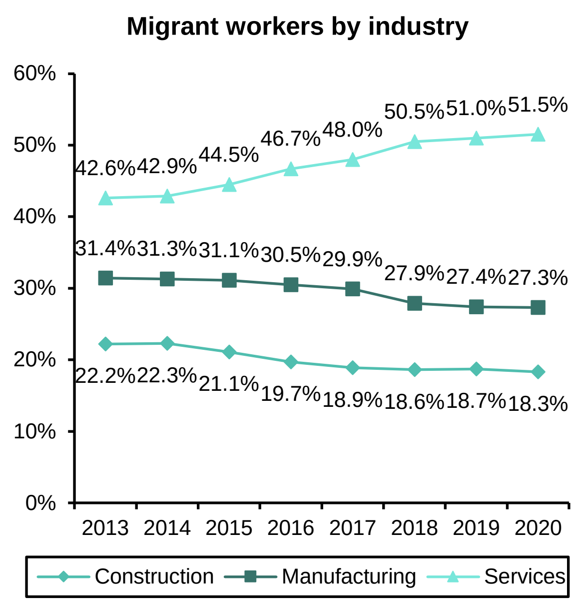
Source: China NBS and Bernstein analysis

EXHIBIT 62: **Migrant worker population in manufacturing sector peaked in 2012 and the decline is accelerating**



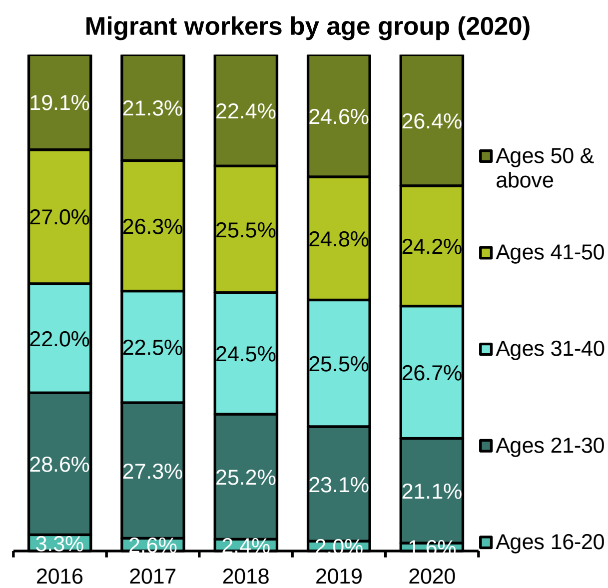
Source: China NBS and Bernstein analysis

EXHIBIT 63: **Not surprisingly, migrant workers are shifting from manufacturing to service**



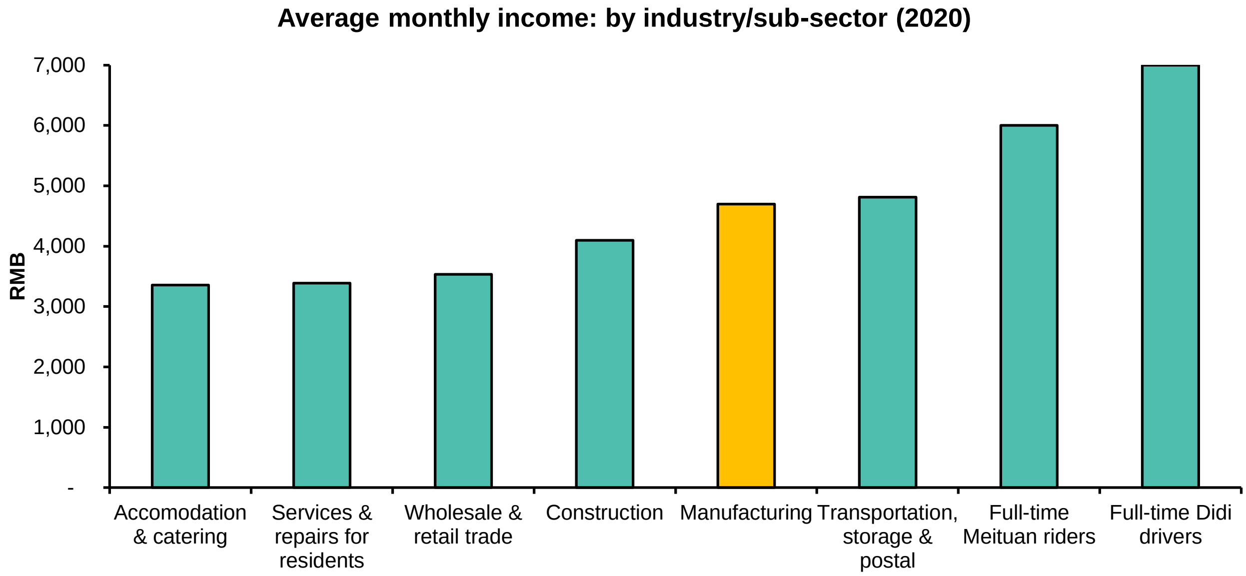
Source: China NBS and Bernstein analysis

EXHIBIT 64: **With younger migration population shrinking the fastest, the pressure on manufacturing is only going to increase in the long term**



Source: China NBS and Bernstein analysis

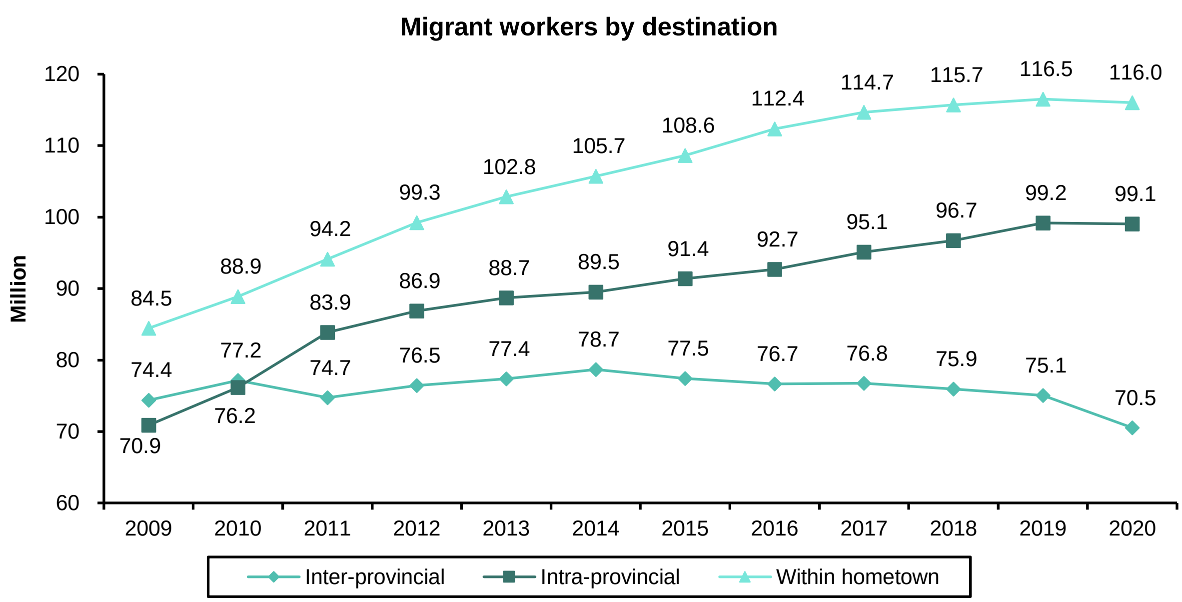
EXHIBIT 65: **"New economy" creating better options than working in factories**



Note: Meituan rider monthly income is based on estimates and analysis by the Bernstein Asia Internet team; the Didi driver monthly income is based on estimates and analysis by the Bernstein Asia Logistics & Transport team. For more information on these stocks see BernsteinResearch.com.

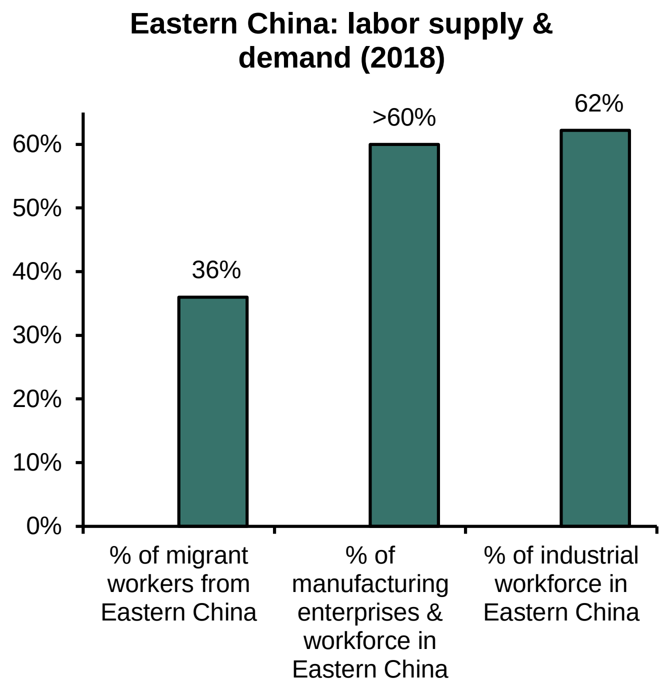
Source: China NBS, company reports, and Bernstein estimates and analysis

EXHIBIT 66: **Aggravating overall labor shortage is lower willingness of remaining migrant workers to travel far...**



Source: China NBS and Bernstein analysis

EXHIBIT 67: **...resulting in severe imbalance of manufacturing labor supply and demand in key regions**



Note: Eastern China includes Beijing, Tianjin, Hebei. Shanghai, Jiangsu, Zhejiang, Fujian. Shandong, Guangdong, and Hainan.

Source: China NBS, people.com.cn, and Bernstein analysis

EXHIBIT 68: **Automation can mitigate labor shortage in 30-50% of the most in-demand manufacturing jobs**

"Automatable" job vacancies	Supply shortage rank in period								
	3Q21	**2Q21**	**1Q21**	**4Q20**	**3Q20**	**2Q20**	**1Q20**	**4Q19**	**3Q19**
Packaging	12	14	10	13	14	10	5	20	11
Metal lathing	13	13	12	8	10	7	10	9	8
Welding	9	11	13	10	11	8	6	8	9
Instrument and meters manufacturing	29	8	14	84	20				
Handling	26	36	34	28	36	26	9	14	10
Auto parts remanufacturing			35		74				
Battery manufacturing worker	67	65	45						
Printed circuit manufacturing	99	45	46		60				
Vacuum electronic device parts	83		54	33					
Capacitor manufacturing worker	80		58			45	25	43	
Electrical machinery manufacturing		52	61		79				
CNC machine tool operator	78	76	67	57	48	54	32	34	30
Plastic molding manufacturing	90		68		78	90		59	59
Electrical connector manufacturing			70			73	36		68
Metal heat treatment	71	67	80	82		14	77		93
Belt conveyer operator			82		81				
Mechanical cutting			84					75	53
Punch press	59	69	86	89	43	43	56	77	49
Air conditioner manufacturing	81		88						
Machine tending			91			74			81
Furniture manufacturing			94						
Casting	97	78	96	78		39	76	69	
Bench worker		72		95	56	69	84	80	
Grinding					64	53			94
Industrial cleaning					92				
Drilling machine operator					93				
Equipment inspection						93			
Medical material & product manufacturing						99	78		
Resistor manufacturing							34		
Discrete semiconductor devices & IC installation							43		
Number of "automatable" vacancies in top 100	**15**	**13**	**22**	**11**	**16**	**16**	**14**	**11**	**12**
Number of manufacturing vacancies in top 100	**40**	**39**	**42**	**36**	**38**	**39**	**44**	**38**	**36**
% of "automatable" in manufacturing vacancies	**38%**	**33%**	**52%**	**31%**	**42%**	**41%**	**32%**	**29%**	**33%**

Note: The listed job vacancies are ranked each quarter based on the extent of labor supply shortage, based on data collected in more than 100 cities across China; the rank is left blank if the specific job position did not appear in the Top 100 vacancies of that quarter.

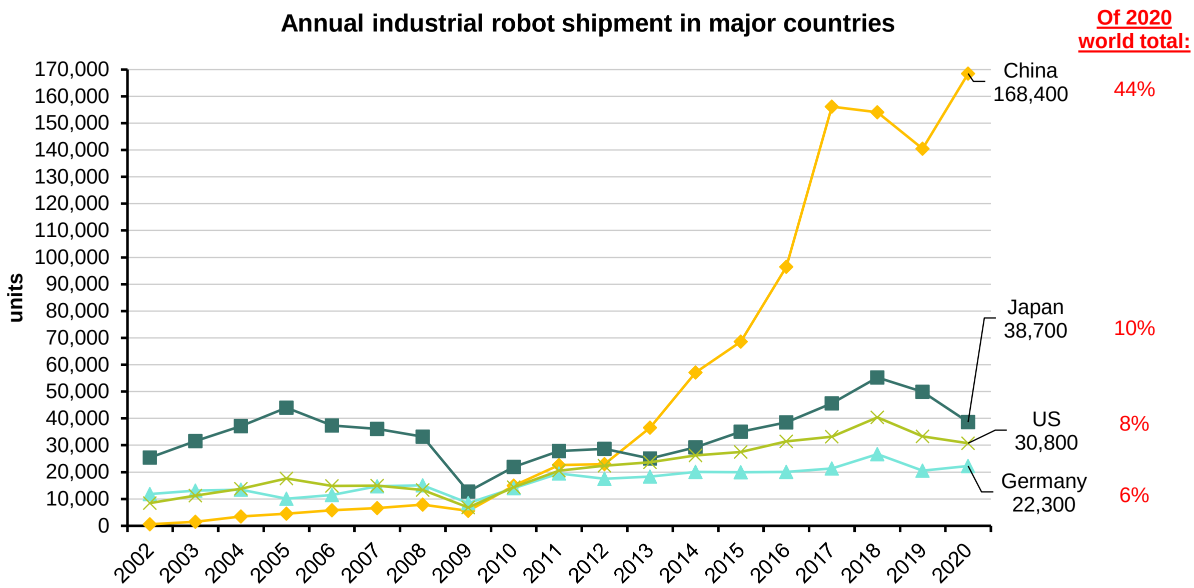
Source: China Ministry of Human Resources and Social Security, and Bernstein analysis

QUANTIFYING THE LONG-TERM DEMAND

China's industrial robot adoption took off around 2010. After a decade of fast growth, it now accounts for 44% of the global annual robot shipment (see Exhibit 69) and >30% of operational stock. For how much longer can Chinese robotics keep growing at this pace?

The methodology to assess this is as follows. We first set China robot density scenarios in 2030, benchmarking to other economies. With proper assumptions on replacement cycle, these scenarios allow us to calculate annual shipment and growth. We then assess the social impact of these density scenarios by looking at the labor substitution effect of robots, and compare it to China's labor force trend. The bottom line is: the increase of robots needs to be adequate to help China alleviate the labor shortage but not pressure employment.

EXHIBIT 69: **China now accounts for 44% of annual global industrial robot shipment**



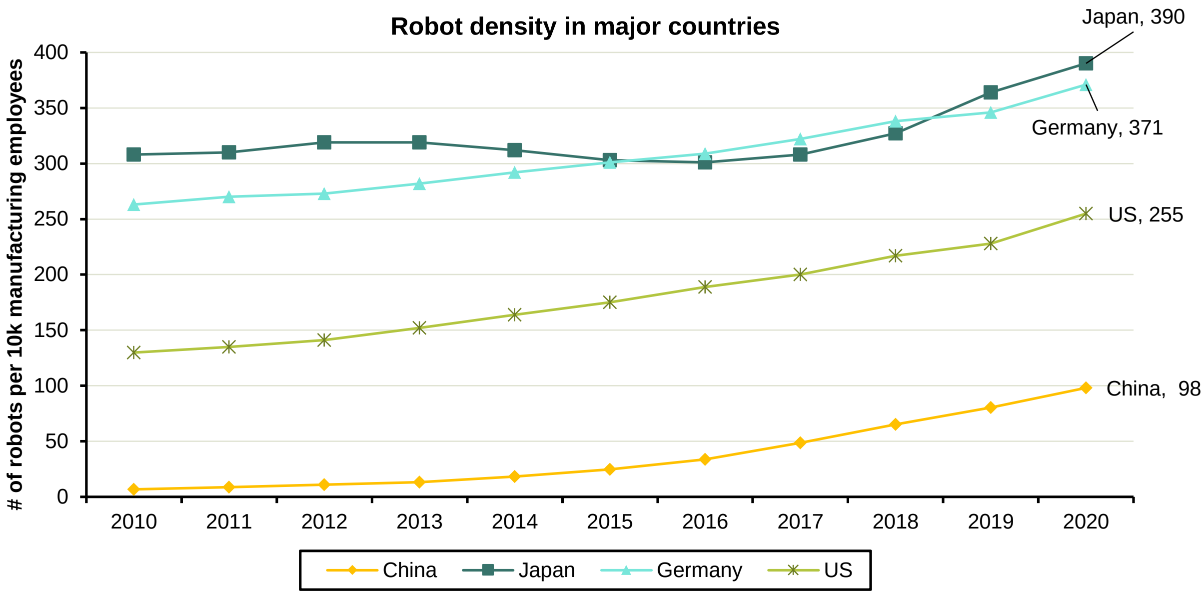
Source: IFR and Bernstein analysis

Despite a decade of phenomenal growth, China's robot density, calculated as the number of installed robots per 10,000 manufacturing employees, is still relatively low — only ~25% of Japan/Germany or ~40% of the US (see Exhibit 70).

Here we refer to robot density figures provided by the International Federation of Robotics (IFR), the most followed data source of the industry, but with an important adjustment that led to a much lower density figure for China. This is because, after cross-checking with each country's government data and statistics from the International Labor Organization (ILO), we found that the IFR has understated China's manufacturing labor size by over 50% (see Exhibit 71 and Exhibit 72), hence, overstating robot density by over 2x.[24] In our calculations, we used the employment figure published by the China National Bureau of Statistics (NBS) (see Exhibit 72).[25] If one chose to use the ILO figure, China's robot density would have been a further ~35% lower than that shown in Exhibit 70.

[24] For other countries, the manufacturing employee numbers implied by the IFR are reasonably close to other data sources.
[25] Figure does not include employment in rural non-private manufacturing enterprises.

EXHIBIT 70: **However, China's robot density still lags far behind major developed countries**



Note: We use robot density data provided by the IFR for Japan, Germany, and the US. For China, we compute the robot density level with IFR robot operating stock data and manufacturing employment statistics from the China NBS.

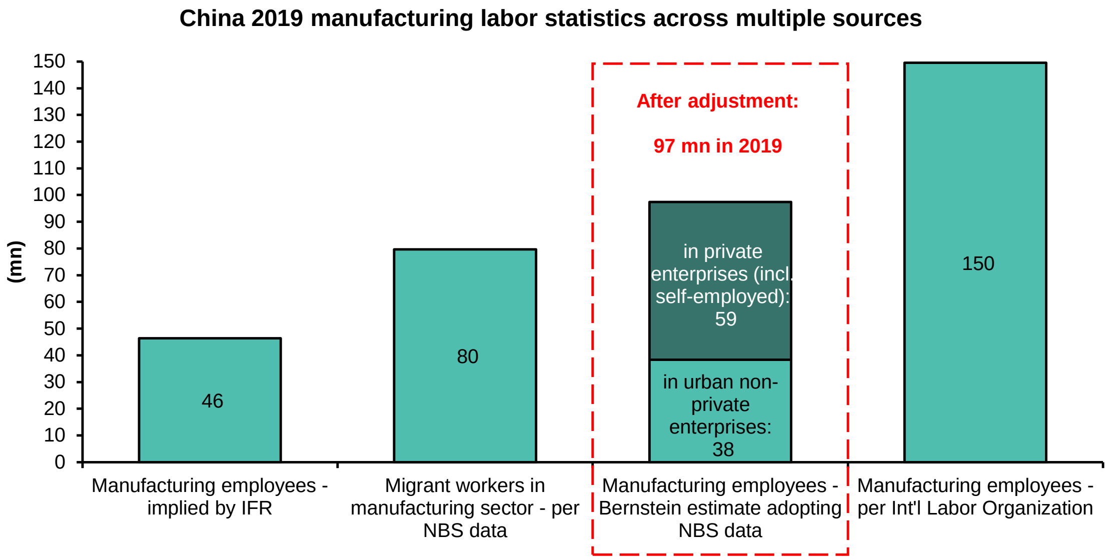
Source: IFR, Wind, China NBS, and Bernstein analysis

EXHIBIT 71: **China's manufacturing labor size is understated by over 50%, hence robot density is overestimated by over 2x by the IFR**

Year: 2019	IFR robot density (units / 10K manufacturing employees)	IFR operational stock ('000 units)	Manufacturing employees implied by IFR (mn)	Manufacturing employees per official statistics (mn)	Manufacturing employees per Int'l Labor Organization (mn)
China	187	783	46.4	97.4	149.5
Japan	364	355	9.7	10.7	10.7
Germany	346	222	6.4	7.8	8.1
US	228	300	13.1	12.8	16.8

Source: IFR, Wind, China NBS, Haver, Germany Federal Statistical Office, US Bureau of Labor Statistics (BLS), Japan Ministry of Internal Affairs and Communications Labor Force Survey, International Labor Organization (ILO), and Bernstein analysis

EXHIBIT 72: **China manufacturing labor size: cross-checking with multiple sources confirms that the IFR implied number is too small; we use official data from China NBS to derive adjusted robot density**



Source: IFR, Wind, China NBS, ILO, and Bernstein analysis

Our two scenarios are for China's robot density to reach 400 and 500 in 2030, respectively. The first (400) means that in 2030, China will reach the robot density level of Japan and Germany in 2021. The second (500) implies that China will fully close the robot density gap vs. Japan and Germany in 2030 (see Exhibit 73).

At first glance, both scenarios may seem quite aggressive. But robot density is not that much a function of how developed or how wealthy a country is, but a function of labor force structure and robotic technology. Japan's initial industrial robot buildout started in the 1980s, and its robot density exceeded 300 in the mid-1990s; the next 20 years saw a ~30% robot stock decline offsetting a similar shrinkage in labor force, so density hovered around 300, till it took off again in 2018 (see Exhibit 74). The re-acceleration of robot growth in recent years is seen across Japan, Germany, and the US (see Exhibit 70). We believe this is helped by: (1) advancement of robotic technology greatly expanding the scope of robot application[26]; (2) decline of integration cost having significantly shortened customer payback and therefore expanded the customer base; and (3) a shrinking working population in manufacturing. While in the past robot density differentials largely reflected the labor cost difference and the relative size of the automotive industry of a country, because robot adoption was expensive and robotic applications were concentrated, going forward as robot adoption continues to proliferate and "cost parity" includes the majority of Chinese manufacturers, the difference between China and Japan/Germany with regard to robot adoption will gradually diminish.

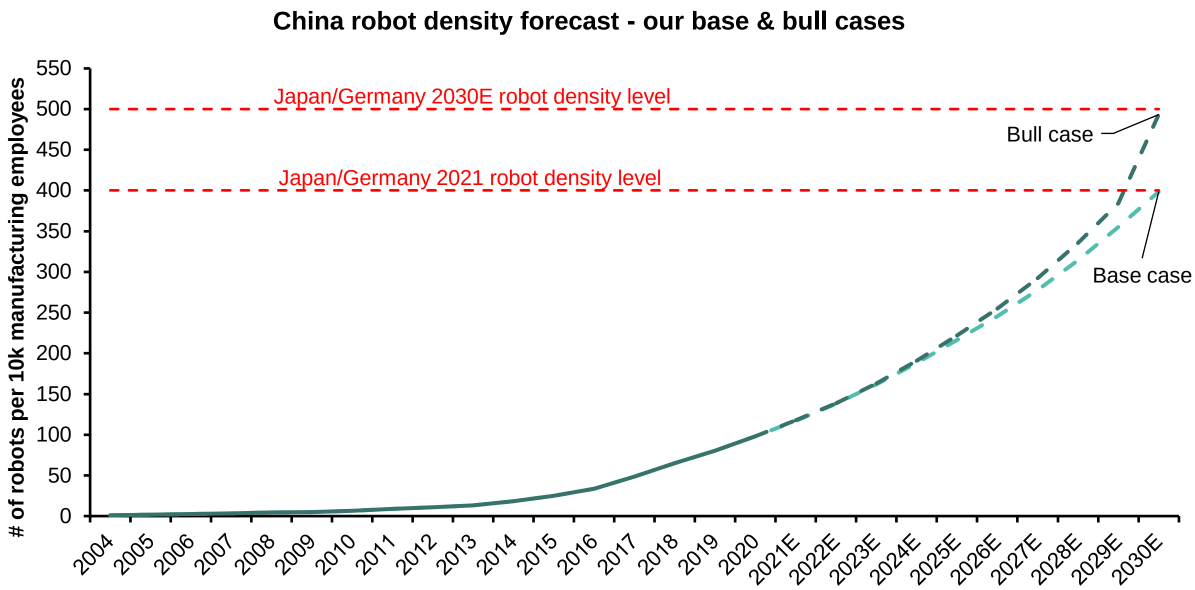
Assuming an average robot usage life of nine years, the two density scenarios correspond to an annual shipment CAGR of 12% and 16% through 2030, respectively (see Exhibit 76).

---

[26] Vision, autonomous trajectory planning with AI, robotic offline programming, and collaborative robots are among the most important. See The Long View: A moving boundary of automation.

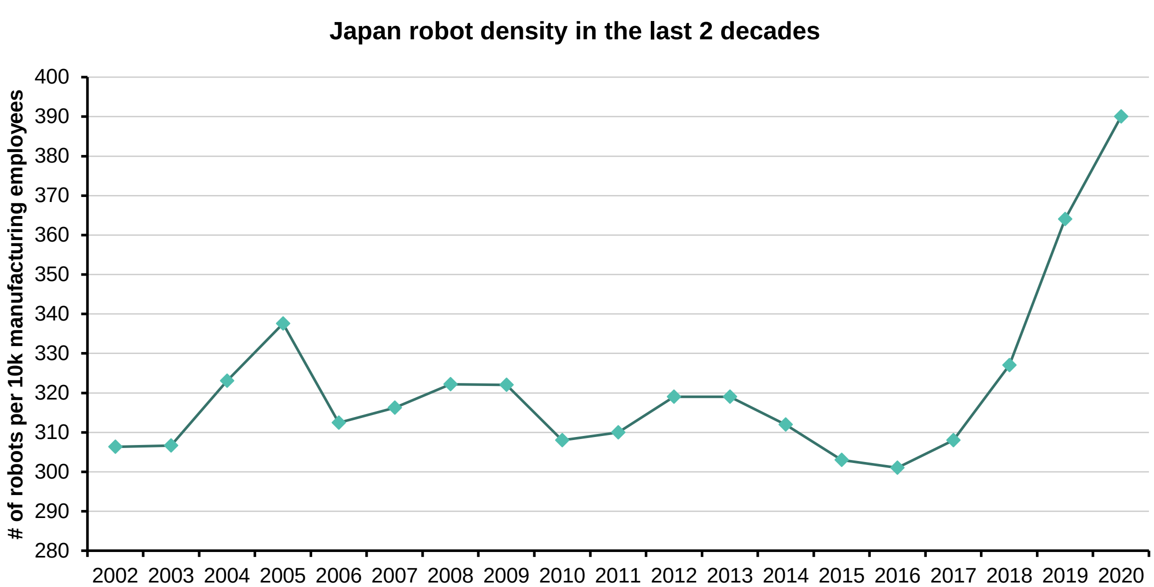
For the same 2030 density, shorter usage life assumptions result in higher shipment growth. Automotive OEMs typically use robots for two platform cycles, i.e., ~15 years. The rising demand from other industries may indeed shorten the average replacement cycle, thus creating additional demand on top of our growth estimates (see Exhibit 76).

EXHIBIT 73: **China robot density scenarios — our base case is for China density in 2030 to reach Japan/Germany level in 2021**



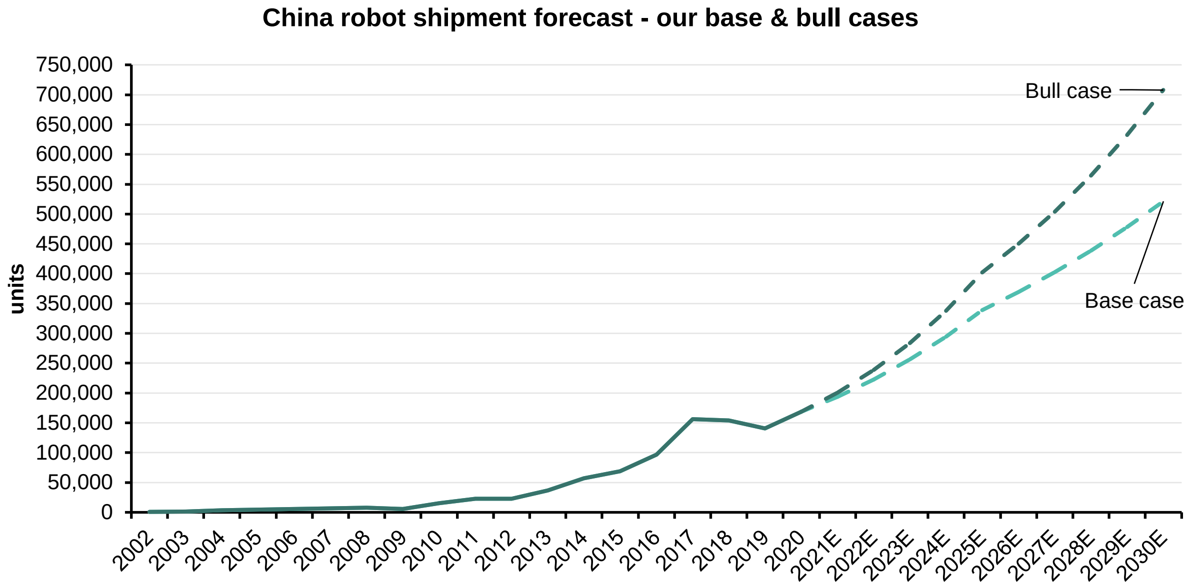
Source: IFR, Wind, China NBS, and Bernstein estimates and analysis

EXHIBIT 74: **Technology advances have significantly expanded the scope of industrial robot applications since 2017, resulting in a stunning re-acceleration of robot adoption in Japan**



Source: IFR, Haver, Japan Ministry of Internal Affairs and Communications Labor Force Survey, and Bernstein analysis

EXHIBIT 75: **China robot shipment will reach 500-700k units p.a. by 2030 in our scenario forecasts**



Source: IFR, and Bernstein estimates and analysis

EXHIBIT 76: **Assuming nine-year average usage life of robots, the two density scenarios correspond to annual shipment CAGRs of 12% and 16%, respectively, through 2030**

Average usage life (years)	2020-2030 CAGR for annual shipment								
	8%	9%	10%	11%	12%	13%	14%	15%	16%
6	253	270	293	308	323	336	364	404	421
7	272	283	308	329	343	373	405	438	456
8	294	306	332	360	383	399	436	450	469
9	329	348	369	391	398	422	448	475	493
10	349	369	389	412	435	460	487	505	534
11	360	379	400	422	445	479	501	533	553
12	377	390	403	424	446	487	496	522	551

Base case (12%, 9 years: 398) — Bull case (16%, 9 years: 493)

Source: IFR, Wind, China NBS, and Bernstein estimates and analysis

Under the two density scenarios, China's robot operational stock will increase to 3.4-4.2 million units by 2030, from ~1 million units today (see Exhibit 77). What's the likely social impact?

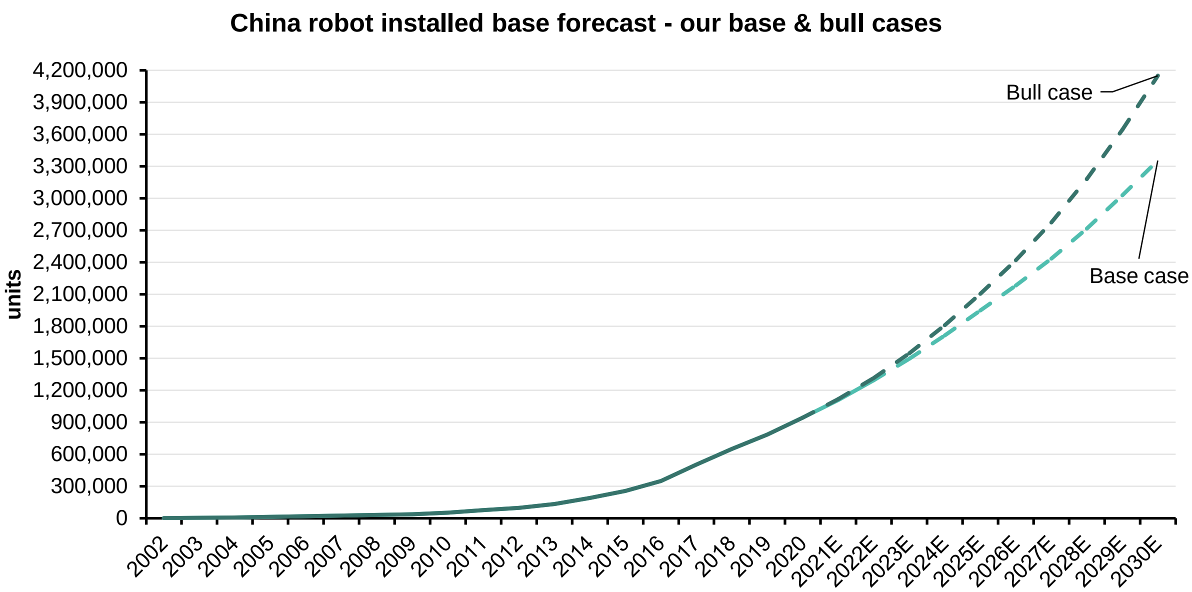
There has been various research on industrial robots' displacement effect on manufacturing jobs. The estimates vary from each robot replacing six jobs to creating a small number of jobs.[27] The most recent and most cited MIT research showed that for the

[27] Considering both manufacturing and non-manufacturing jobs, our own research found that robots' impact on employment is neutral to slight positive in the automotive industry. See Do robots kill jobs? - A three-exhibit answer from the automotive industry.

entire US economy, each robot replaces ~3 people (see Exhibit 78). We use this for our calculation.

Assuming China's manufacturing labor force continues to decline at the current rate (-1.3% p.a.), China will have 12 million fewer workers between now and 2030 (see Exhibit 79). Certain independent economists' forecasts see a much more severe decline in the front-line factory workforce. For example, the number of China's migrant workers in manufacturing is estimated to become 20 million fewer by 2025. Under the 400-robot-density scenario, China's robot operational stock will grow by ~2.4 million units in 2020-30, offsetting a 7.3-million reduction in human workers. The 500-robot-density scenario offsets a 10-million reduction. Considering the continued growth of China's manufacturing sector but also additional productivity gains from other factors, both cases are in the ballpark "adequate" to alleviate the labor shortage in China — certainly not too aggressive to create systematic unemployment pressure (see Exhibit 80).

EXHIBIT 77: **Our scenarios correspond to 3.4 million to 4.2 million robot operational stock in China in 2030**



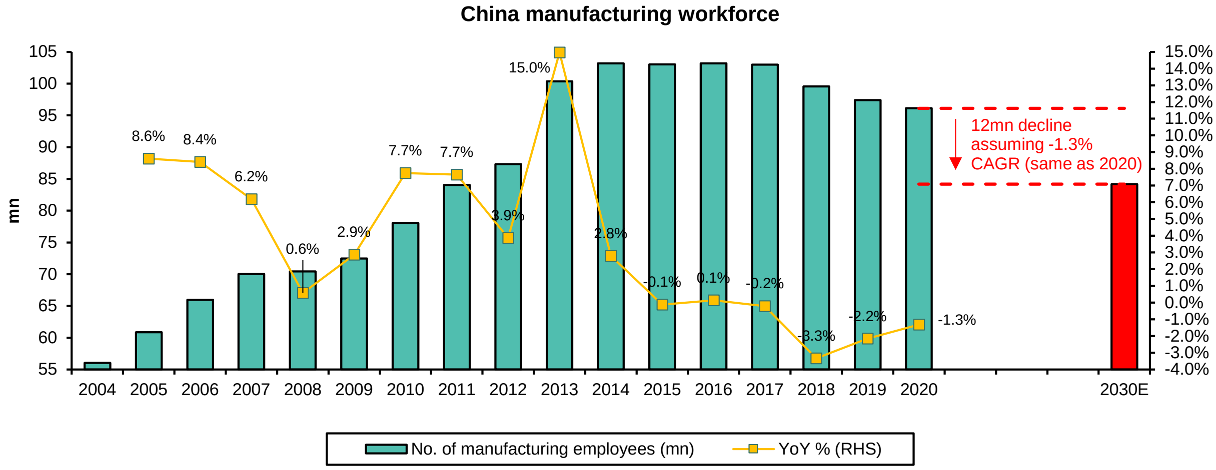
Source: IFR, and Bernstein estimates and analysis

EXHIBIT 78: **On average, each robot replaces around three manufacturing jobs**

Labor market study	US (front-line)	US (overall employment)	Germany	Japan	Our assumption
Jobs per robot (minus indicates reduction of jobs)	-6	-3.3	-2	Small positive	-3

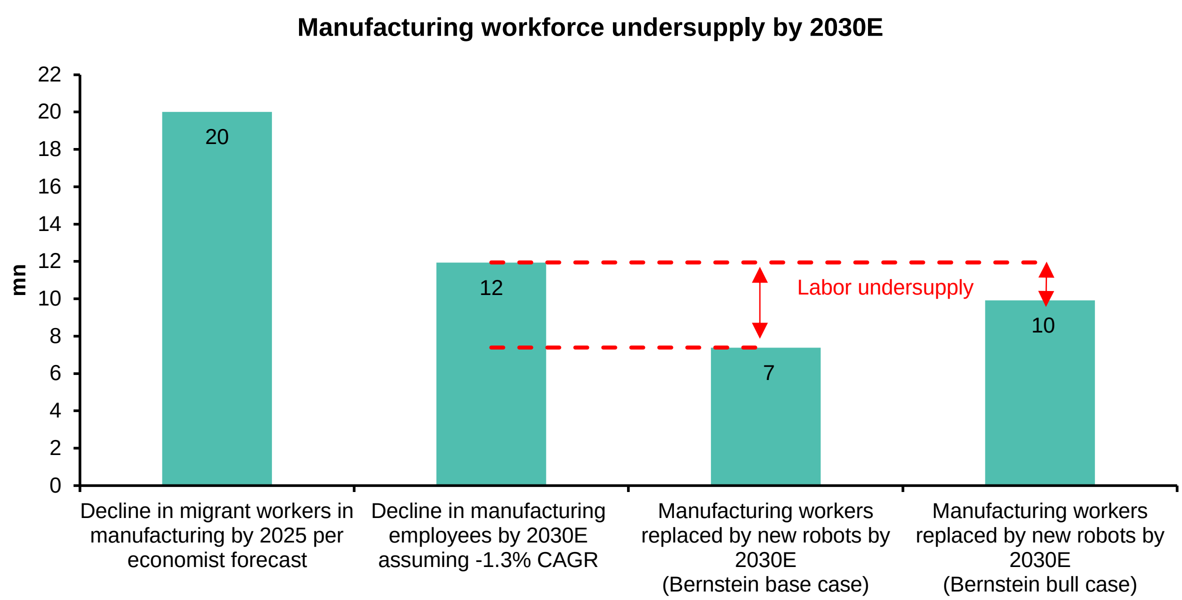
Source: *Acemoglu, Daron, and Pascual Restrepo*, "Robots and Jobs: Evidence from US Labor Markets"; *Dauth, Wolfgang, et al.* "The rise of robots in the German labour market"; *Adachi, Daisuke, Daiji Kawaguchi, and Yukiko Saito,* "Robots and Employment: Evidence from Japan, 1978-2017", and Bernstein estimates and analysis

EXHIBIT 79: **China's manufacturing labor force has been declining in recent years; at the current run rate China will have 12 million fewer manufacturing employees by 2030**



Source: Wind, China NBS, and Bernstein estimates and analysis

EXHIBIT 80: **Operational stock of 3.4 million to 4.2 million robots will be barely enough to alleviate the labor force shortage in China**



Note: 2025 migrant worker population forecast is by Caiyi Lin, Deputy Director of the China Chief Economist Forum research institute.

Source: China NBS, Wind, China Chief Economist Forum, and Bernstein estimates and analysis

CHINA ROBOT GROWTH IN 2020 AND 2021

Post the Covid-19 lockdown, robot demand in China quickly recovered in 2Q20 and saw further acceleration in 2H20 and 2021 (see Exhibit 81). Robot shipment in China expanded 14% yoy in 2020 and 47% yoy in 2021 (see Exhibit 82).

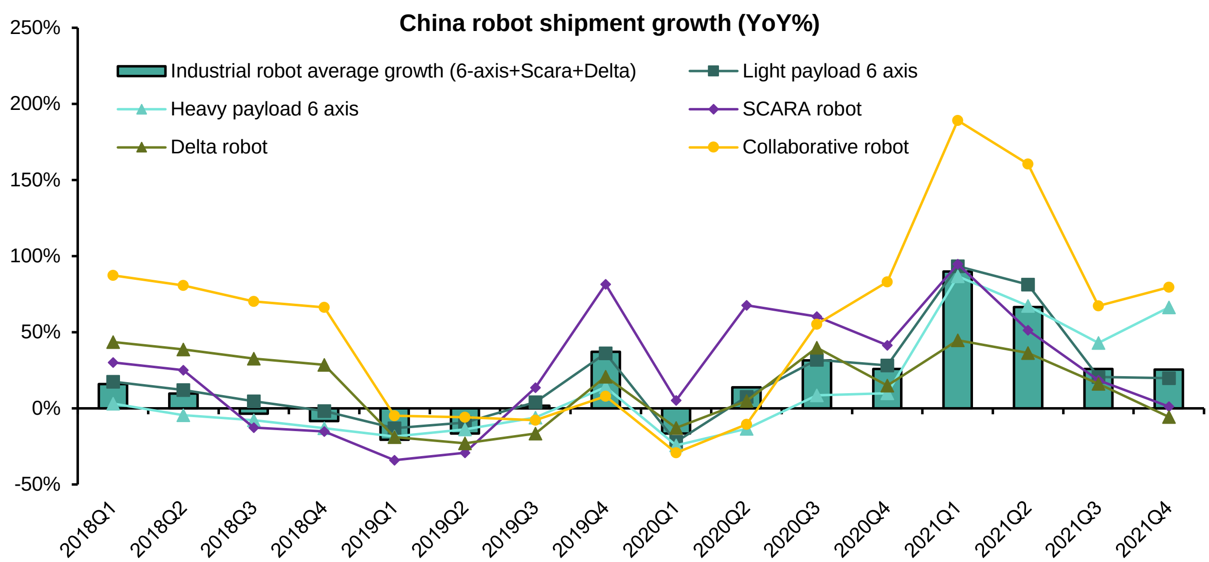
Cobot growth lagged industrial robots from 2Q19 to 2Q20 due to the former's disproportionate exposure to SMEs. With five quarters of "pent-up" demand after 3Q20, cobot growth rebounded strongly, significantly higher than industrial robots (see Exhibit 81).

Growth of heavy six-axis robots (payload >20kg) remained lower than other product segments in 2H20. This is consistent with the strong capex recovery in electronics and general manufacturing, and continued (but narrowing) decline in the automotive industry (see Exhibit 81). In 2H21, heavy six-axis robots outperformed the average.

End-industry demand cycles resulted in the expansion of the light six-axis (payload <20kg) and the SCARA segments, and the shrink of the heavy six-axis segment in 2020. The trend is reversing in 2021 (see Exhibit 83).

End-demand is diversified. In 2021, automotive OEMs and components suppliers accounted for 19% of total robot shipment (see Exhibit 84), and robot demand from lithium battery, logistics, healthcare, semiconductors, etc., grew faster than the industry average, while demand from auto components, auto electronics, and auto OEMs lagged the most (see Exhibit 85).

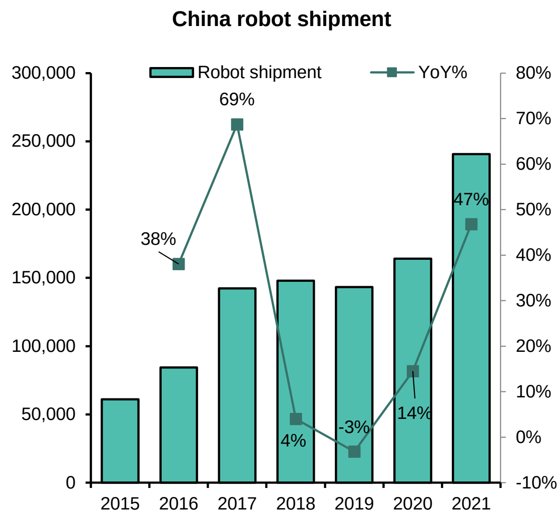
EXHIBIT 81: **Robot demand saw further acceleration yoy growth in 2021; cobots started to outgrow industrial robots again**



Note: Light payload refers to robots with payload ≤ 20kg; heavy payload refers to robots with payload > 20kg — "Industrial robot average" does not include collaborative robots.

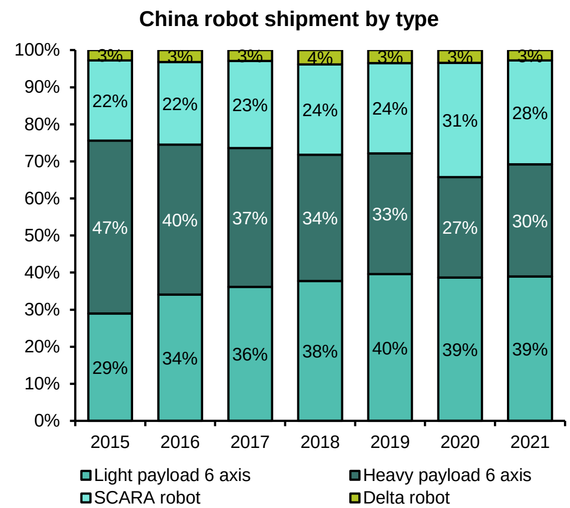
Source: MIR Databank and Bernstein analysis

EXHIBIT 82: **China robot shipment grew in 2020 and 2021, despite Covid-19**



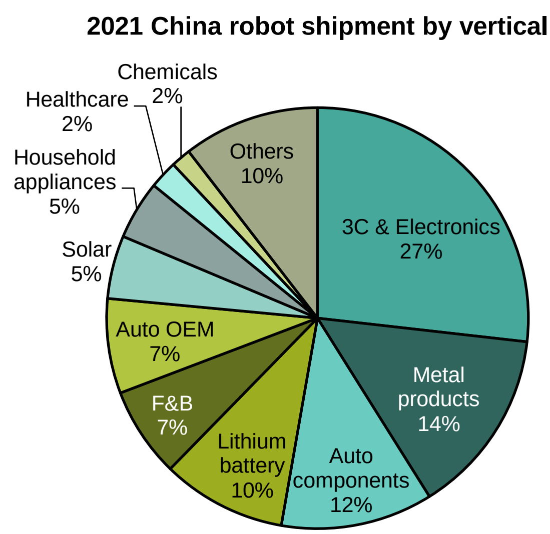
Source: MIR Databank and Bernstein analysis

EXHIBIT 83: **Product segment share: Heavy six-axis gained share in 2021**



Source: MIR Databank and Bernstein analysis

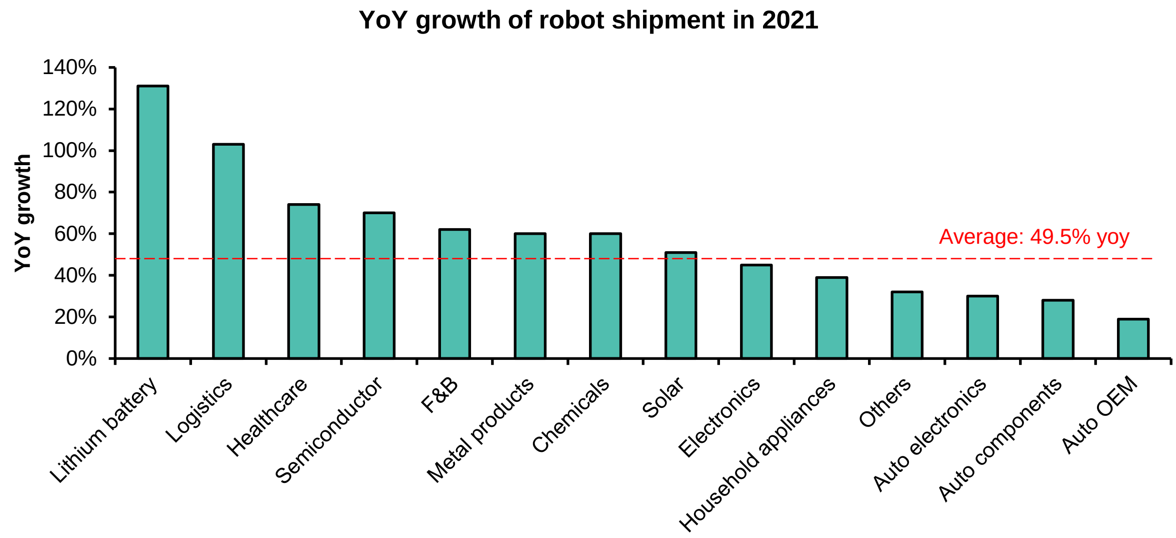
EXHIBIT 84: **China robot shipment by end-industry**



Note: Includes cobots.

Source: MIR Databank and Bernstein analysis

EXHIBIT 85: **Robot shipment growth by end-industry in China (2021)**



Note: Includes cobots.

Source: MIR Databank and Bernstein analysis

CROSSING THE RUBICON: ROBOTIC USER ECONOMICS

User economics is a key driver for robot adoption. In this section, we analyze the payback trends in China by examining two representative use cases.

ROBOT/COBOT MACHINE TENDING

Machine tending is one of the high-potential and faster-growing robot applications. China's leading collaborating robot (cobot) brand, AUBO Robotics, shared a typical use case (see Exhibit 86). At the client factory, each operator used to manually tend to two machine tools; after deploying cobots, every operator is able to look after six machine tools, allowing the factory to expand capacity without additional workers.

Depending on the cycle time and setup of production, a robot can tend to more than one machine tool. In another example from the heavy machinery (crane) industry, each FANUC robot takes on three machine tools in one production cell and improves labor efficiency by 400% (see Exhibit 87).

EXHIBIT 86: **Cobot for machine tending (AUBO example)**

Source: AUBO Robotics website

EXHIBIT 87: **A single robot tending multiple machine tools (FANUC example)**

Source: FANUC

Considering the different scenarios, we assume an average of 1.5 machine tools tended by each robot.

AUBO is a lower-cost Chinese brand, with models priced in the RMB50,000 to RMB100,000 range. For comparison, we also consider a similar 5kg-payload model (UR5) from Universal Robots, the leading global cobot brand, which sells at a ~70% premium vs. AUBO.

In addition to the cobot itself, integration accounts for a significant part of the cost to users. For machine tending, we estimate that to be 60% of cobot price. This includes the cost of grippers, other accessories, software, and integrator labor for design and installation.

With these assumptions and wage data in China (see Exhibit 88), we calculate that payback is currently ~1.3 years for the AUBO i5 and ~2.2 years for the UR5. While there is not a single magic number for payback, we understand that in China adoption starts to take off at 2.5-3 years for large enterprises with long-term business stability and 1.5-2 years for SMEs. On average, 2-2.5 years seem the Rubicon when it comes to robot payback and adoption. Crossing this band, it's a point of no return.

For the same application, payback was 3.5-5.5 years in 2017 and has sharply declined since then due to the combination of labor cost inflation and cobot (including integration) cost deflation. It only entered the above mentioned "optimal" range after 2020. This partly explains the exponential demand growth we are experiencing now (see Exhibit 89).

EXHIBIT 88: **Cobot machine tending economics**

Cobot application: machine tending
Before deploying cobots, 1 worker was able to tend to 2 machine tools;
After deploying cobots, 1 worker is now able to look after 6 machine tools.

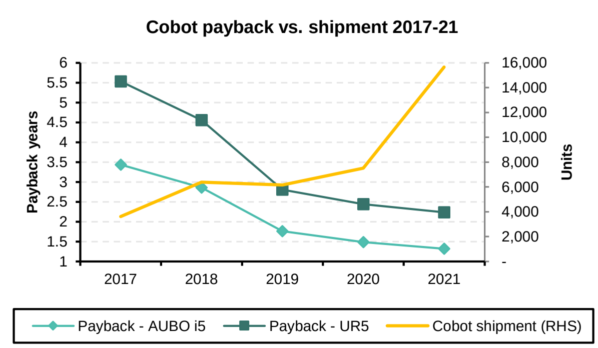
Illustration of economics (every 6 machine tools, all in RMB yuan)

Annual labor cost	# of workers	Unit cost	# of shifts	Sub-total
Before	3	86,400	2	518,400
After	1	86,400	2	172,800
Annual labor cost saved				345,600
Cobot cost	# of cobots	Cobot price	Integration cost (% of cobot price)	Sub-total
Cobot option 1: AUBO i5				
Upfront cobot investment	4	71,400	60%	456,960
Payback years				1.3
Cobot option 2: UR5				
Upfront cobot investment	4	120,600	60%	771,840
Payback years				2.2
Assumptions				
Monthly total labor cost		7,200		
Monthly worker salary		6,000		
Plus: welfare+misc %		20%		
# of machine tools attended by 1 cobot		1.5		
Operational years - AUBO i5		4.8		
Operational years - UR5		6.8		

Note: Additional system integration cost includes the cost of grippers, software, sensors, base frame, etc.

Source: AUBO Robotics, Universal Robots, MIR Databank, Jobui, various industry experts, and Bernstein estimates and analysis

EXHIBIT 89: **Cobot machine tending payback has shortened drastically since 2017, partly explaining the exponential demand growth**



Source: AUBO Robotics, Universal Robots, MIR Databank, Jobui, various industry experts, and Bernstein estimates and analysis

EXHIBIT 90: **Welding robot application: Estun Cloos robot speed welding in Henan Junton Vehicle factory**

Source: Cloos website and Bernstein analysis

ROBOT WELDING

Due to the demanding working environment and long training period required, welding is an area of particularly severe labor shortage in China over the past few years. In a summary report of most-wanted job vacancies across 100 Chinese cities published by the Ministry of Human Resources and Social Security, welding worker is consistently among the top few jobs.

With a modest 10% productivity enhancement (mainly due to less downtime between tasks), one robotic welding cell (see Exhibit 90) on average replaces 1.1 welding workers but adds 0.5 FTE as the robot operator. The cost benefit comes from the FTE reduction as well as wage difference between welding workers and robot operators — the latter is cheaper (see Exhibit 91).

Here we also consider two scenarios of robot choice: the Estun EWAS (used for thin-plate welding) and the Cloos QWAS (used for thin- and medium-plate welding). They cost approximately RMB100,000 and RMB200,000, respectively, including the robot, welding gun, welding power source, and welding process software package. Compared to machine tending, the additional integration cost (mainly for process customization and work piece handling) is higher here at ~150% of the robot price (see Exhibit 91).

Our calculations show that the payback is ~1.8 years for the Estun EWAS and ~2.4 years for Cloos QWAS. Similar to machine tending, robotic welding payback has also shortened drastically since 2017 and crossed the critical 2-2.5 year mark over the last two to three years (see Exhibit 92).

LOOKING AHEAD

Naturally, with labor cost inflation and robot technological advancement going forward, economics will only become even more supportive of increasing robot adoption. We illustrate next how payback will evolve under three scenarios of wage inflation (3%, 5%, and 8% annually) in the next five years, for both cobots and welding robots (see Exhibit 93 and Exhibit 94).

China's current level of robot density (~100 robots/10k manufacturing employees) is only a quarter that of Japan or Germany. In the previous chapter, we estimated that China will need 3.4 million to 4.2 million industrial robots in 2030, up from ~1 million today (see Exhibit 77). This implies an annual robot shipment CAGR of 12-16% (see Exhibit 95). Coupled with a worsening labor shortage, favorable robot economics will help fuel this adoption super cycle.

We want to make a special note on cobots. Cobots enable automation at the granular, single-worker level, so that manufacturers who cannot or do not wish to adopt fully automated lines are able to choose where and how much to automate. In the last two years, cobots have seen very fast expansion of use cases into diversified industries, processes, and SMEs (see Exhibit 96). This was enabled by expanding SKUs, integration/accessory ecosystems, process software packages and, as shown in this section, shortening payback periods. Cobots are currently around 7% of all industrial robots both in China and globally, and we forecast this ratio to increase to mid-teens by 2025 (see Exhibit 97). For Harmonic Drive, cobots currently drive about 10% of demand. For Leader Drive, because Chinese players' share in cobots (>75%) is much higher than in industrial robots (~30%), the cobot contribution is much higher at 40%+.

Besides strong growth, the Chinese cobot industry is undergoing some important changes. Both the global and local incumbent leaders — Universal Robots and AUBO, respectively — are under increasing competitive pressure from new rising stars Elite and JAKA (see Exhibit 98). Elite, e.g., aims to establish itself in a favorable pricing ladder where it uniquely occupies the mid-segment sweet spot — its new CS series are priced 30% higher than older models, but still cheaper than the comparable UR model. Elite's gross margin is above 50% and is expected to further improve as the business scales.

EXHIBIT 91: **Robotic arc welding economics**

Welding robot application

1 welding robot replaces 1 welding worker with 10% extra productivity enhancement;
1 welding robot operator can look after 2 welding robots.

Illustration of economics (every 2 welding robots, all in RMB yuan)

Robot scenario 1: Estun EWAS for thin-plate welding

Annual labor cost	# of workers	Unit cost	# of shifts	Sub-total
Before (welding workers)	2.2	103,680	2	456,192
Of which: monthly salary		7,200		
Monthly total (plus welfare+misc)		8,640		
After (welding robot operator)	1.0	87,840	2	175,680
Annual labor cost saved				280,512
Upfront robot investment	of robots	Robot price	Integration cost (% of robot px)	Sub-total
	2	100,000	150%	500,000
Payback years				1.8

Robot scenario 2: Cloos QWAS for thin & medium-plate welding

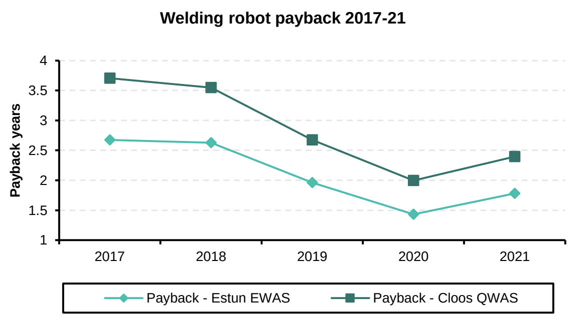
Annual labor cost	# of workers	Robot price	# of shifts	Sub-total
Before (welding workers)	2.2	134,784	2	593,050
Of which: monthly salary		9,360		
Monthly total (plus welfare+misc)		11,232		
After (welding robot operator)	1.0	87,840	2	175,680
Annual labor cost saved				417,370
Upfront robot investment	# of robots	Robot price	Integration cost (% of robot px)	Sub-total
	2	200,000	150%	1,000,000
Payback years				2.4

Assumptions		
Monthly total - welding robot operator	7,320	
Monthly salary - welding robot operator	6,100	6,100
Plus: welfare+misc %	20%	
# of workers replaced by 1 robot	1.1	
# of robots per operator	2.0	
Robot operational years	8.6	

Note: Robot price refers to the cost of the entire welding robot station, including power and welding guns. Additional system integration cost includes the cost of software, sensors, base frame, and other ancillary parts.

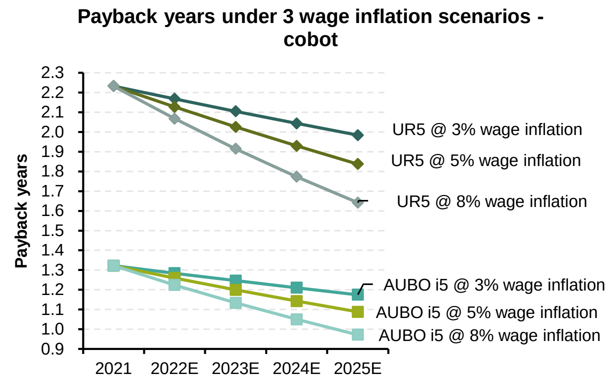
Source: Jobui, various industry experts, and Bernstein estimates and analysis

EXHIBIT 92: **Welding robot payback crossed the 2-2.5 year mark in 2019-20**



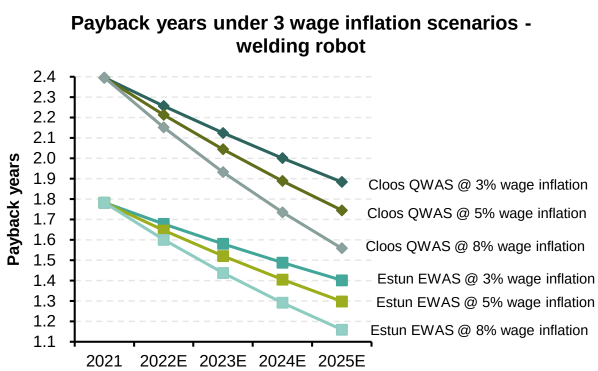
Source: Jobui, various industry experts, and Bernstein estimates and analysis

EXHIBIT 93: **Labor cost inflation will continue to shorten payback period and fuel robotic super cycle (cobot machine tending example)**



Source: AUBO Robotics, Universal Robots, MIR Databank, Jobui, various industry experts, and Bernstein estimates and analysis

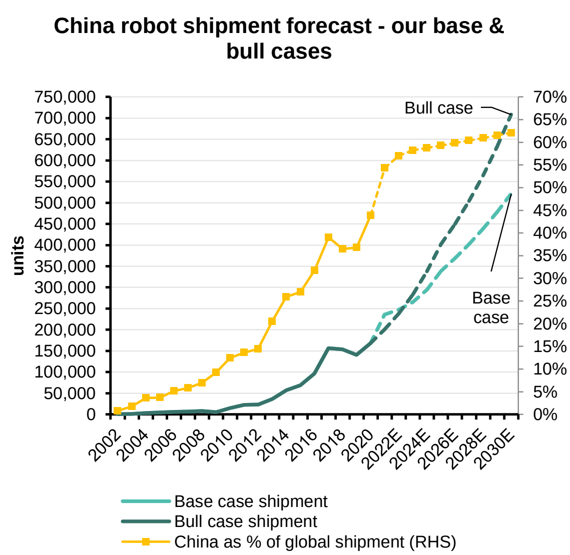
EXHIBIT 94: **Labor cost inflation will continue to shorten payback period and fuel robotic super cycle (robotic arc welding example)**



Note: Wage inflation is on an annual basis; we assume 3% p.a. robot and integration cost deflation going forward compared to 6% p.a. in 2017-19.

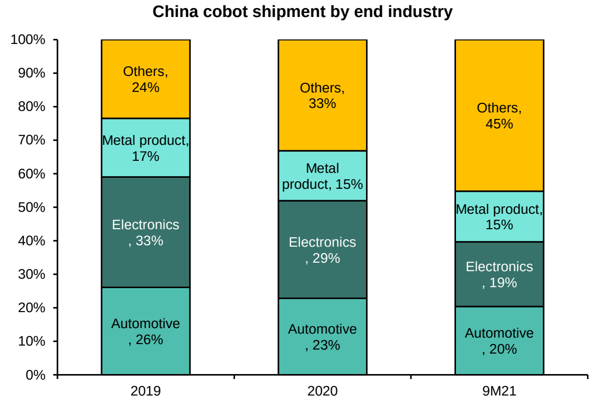
Source: Jobui, various industry experts, and Bernstein estimates and analysis

EXHIBIT 95: **Robot annual shipment in China will likely continue to increase at a mid-teen CAGR through 2030**



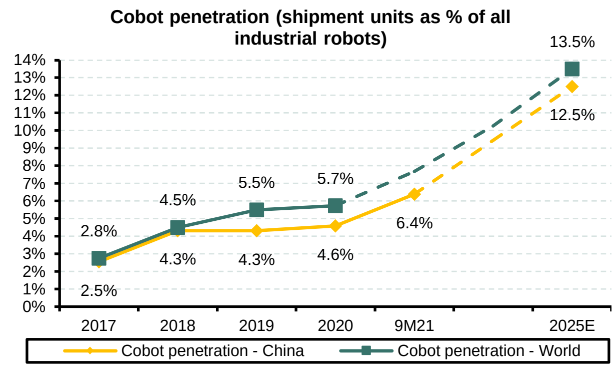
Source: IFR, and Bernstein estimates and analysis

EXHIBIT 96: **Cobot adoption is taking place in a broad range of end-industries**



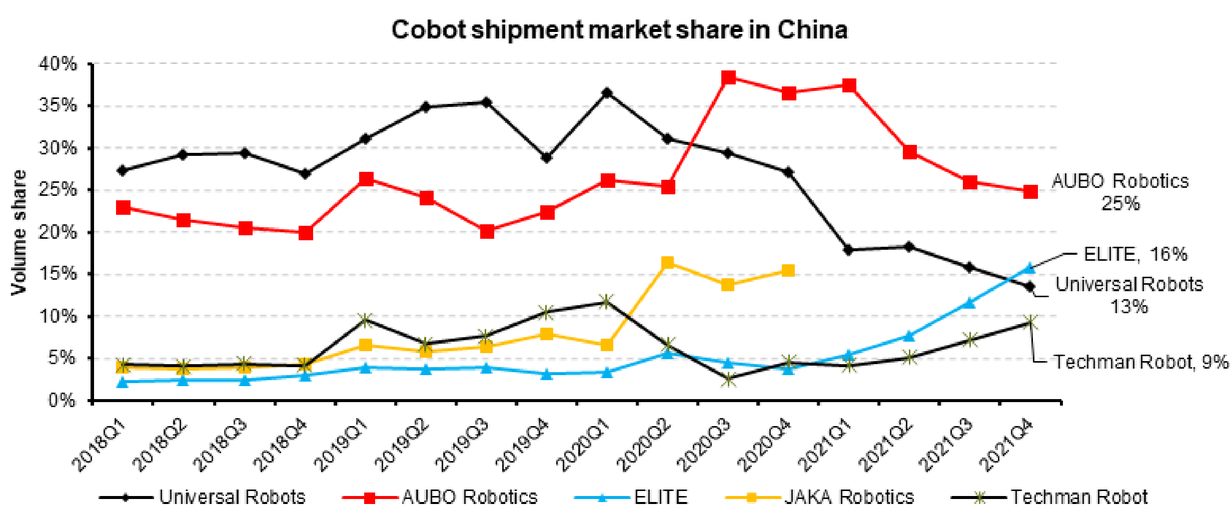
Source: MIR Databank and Bernstein analysis

EXHIBIT 97: **Cobot penetration at ~7% of all industrial robots; forecast to reach mid-teens % by 2025**



Source: MIR Databank, IFR, and Bernstein estimates and analysis

EXHIBIT 98: **Elite is rapidly gaining market share in China from UR and local incumbent, AUBO**



Source: MIR Databank and Bernstein analysis

ROBOTIC TECHNOLOGY DEEP DIVE

This section purposes to challenge the conventional wisdom of what robotic technology is and how robot players differentiate. Specifically, we show that a robot is not the sum of servo motors and reducers, and that robot makers are not assemblers. Knowing this helps one gain confidence on the wide moat of FANUC as the leading global robot maker and the competitive strengths of Estun over other Chinese robot makers.

ROBOT TECHNOLOGY BEYOND MOTORS AND REDUCERS

Robot building blocks

The key components of a robot are well known — a controller, a teach pendant (HMI), and, in each axis, a servo motor and reducer pair known as an actuator (see Exhibit 99). Two common misconceptions arise, however, from this popular view of a robot:

- That robot technology is nothing but the sum of motors and reducers, and robot makers are mere assemblers; and

- That software can be isolated from hardware and potentially offloaded to third-party developers, making robots a largely commoditized product in the future.

These are the two main reasons people underestimate the technology barrier of robotics. Motors and reducers are >50% of a robot's BOM, but the technology and value of a robot is not proportional to the costs of its components. The overall structural design, electronics, and various unseen layers of software explain 80-90% of performance differential by our estimate. We introduce an alternative "software view" of a robot, illustrated in Exhibit 100. It has three connected but distinctive layers:

- **The model — robot movement planning** comes up with a target trajectory, taking input from the requirements of the process, the 3D model of the robot and its external environment, and instructions given by the operator online[28] or offline[29] (see Exhibit 101). The target trajectory needs to be efficient and viable, e.g., avoiding collision, singularity,[30] or exceeding the mechanical limits of the axes. This step usually happens in an external controller (e.g., IPC) that is connected to the robot.

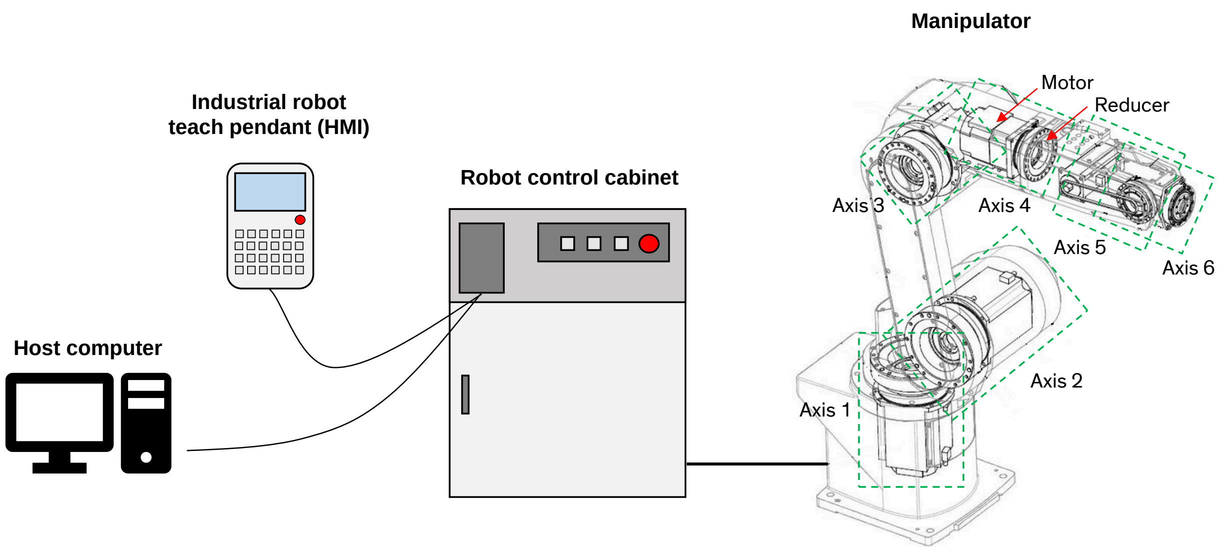
- **The control** is the core software embedded in the robot controller. Trajectory planning tells the robot where to go, and the robot control interpolates the multi-axis movement and tells each axis what to do to get there.[31] The control algorithm takes the planned trajectory and detailed robot parameters as input, performs kinematic and dynamic analysis, and thereby instructs each axis in real time its angle, angular velocity, and torque to execute the planned trajectory. Six-axis robots have six coupled degrees of freedom, and the calculation quickly becomes prohibitively difficult.[32]

[28] In online robot programming, the operator stops the robot from its productive work and switches it to "programming mode." One then uses a teach pendant to move the robot to desired positions and record each movement. Alternatively, with some robot models, one can hold the robot around the workspace, move it to desired locations and record the points or exact path.
[29] Offline robot programming is gaining traction nowadays. All the programming is done in a simulated environment without the presence of the robot (hence, "offline"). It allows one to reduce downtime, speed up system integration, and make continual improvement.
[30] At singularity, the robot loses the ability to move in one or more directions and is therefore "locked."
[31] Sometimes, trajectory planning is defined to include not only end-of-arm trajectory, but also the trajectory of each axis (i.e., multi-axis interpolation). In that definition, trajectory planning becomes a shared function of the robot controller and the external controller (e.g., an IPC).
[32] "Coupled" means there is no axis solely responsible for "x-direction" and another solely responsible for "angle" — each end-point location is jointly determined by the position of all axes. Other than robots and some high-end machine tools, the motion of most types of machinery has "uncoupled" degrees of freedom and is, therefore, much easier to control.

- **The motion — a servo motor drive** in each axis converts the control signal from the robot controller to the voltage/current input for the servo motor, thereby generating precise motion of the axis.

The middle layer, robot control, is part of a robot maker's key know-how. Since the kinematic and dynamic analysis is based on intimate knowledge of the hardware (both the components and the overall structural design), it cannot feasibly be done by third parties.[33] The movement planning (model) layer sees collaboration between robot makers and third-party developers, both providing application/process packages, trajectory planning algorithms and, sometimes, offline programming platforms. The servo drive (motion) layer is where the motor know-how lies. It is important for robot performance, but rarely a key differentiator.

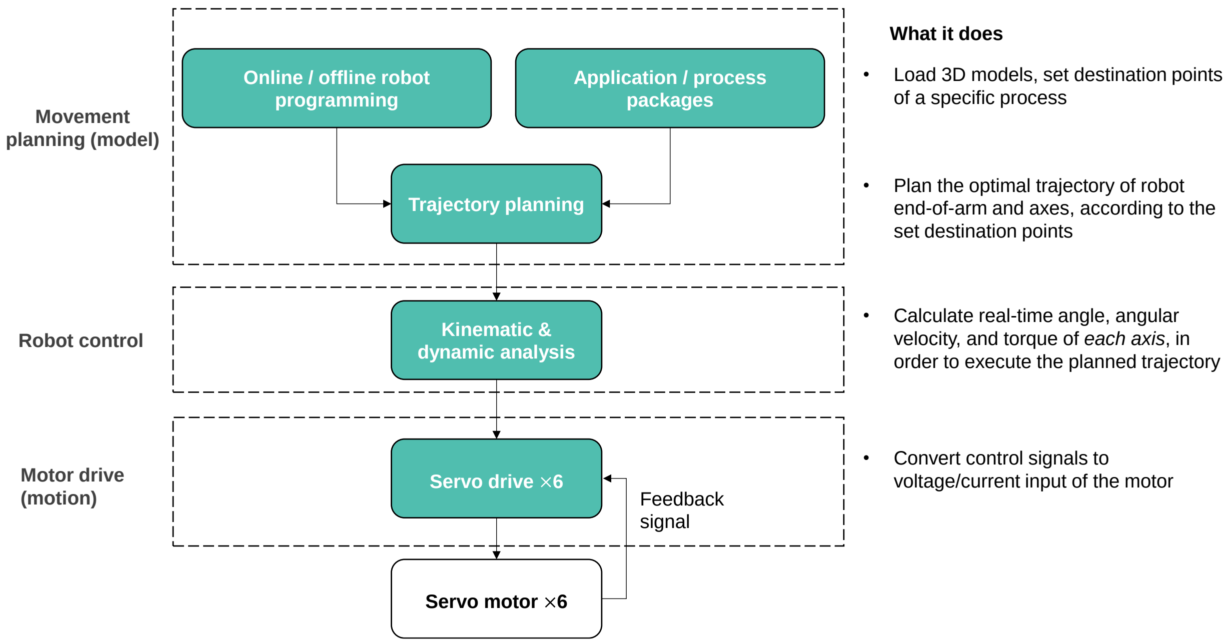
EXHIBIT 99: **Robot building blocks: hardware view**



Source: Wiki Commons and Bernstein analysis

[33] There are some exceptions to this for SCARA robots, which are much simpler than six-axis robots.

EXHIBIT 100: **Robot building blocks: software view**



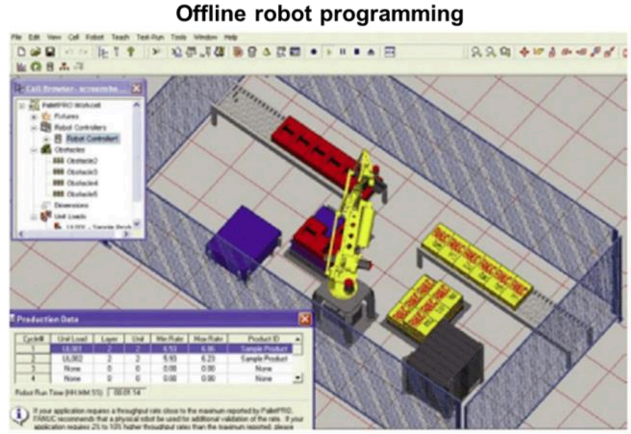
Note: A teach pendant is a device which you plug directly into the robot. Using its interface, you move the robot to the desired positions and record each movement. For hand-guiding, you physically guide the robot around the workspace, moving it to the desired locations and recording the points or exact path.

Source: "Design of industrial robot control system" and Bernstein analysis

EXHIBIT 101: **Robot programming: online vs. offline**

Online robot programming

Offline robot programming



Source: FANUC and Bernstein analysis

From technology to performance

Building a (good) robot is far more than assembling the components. Exhibit 102 shows robotic technology building blocks (hardware and software) and common performance issues. It is a complex matrix. Improving on any single aspect typically requires systematic effort.

Let's first examine the most referenced but oft-misunderstood robot spec, precision. There are three precision metrics (see Exhibit 103):

- Repeatability: How precisely the robot returns to an unspecified position repeatedly.
- Point accuracy: How precisely a robot reaches a commanded absolute position.
- Trajectory accuracy: How precisely a robot follows the desired trajectory.

Repeatability is the only precision metric appearing in a robot spec sheet. For modern robots, it is typically ±0.02~0.05mm and hardly different across brands. Point and trajectory accuracy data is difficult to obtain but is typically 1 to 3 orders of magnitude worse than repeatability (see Exhibit 104). Compared to repeatability, the accuracy gaps are much more significant across brands.

High accuracy (both point and trajectory) has become increasingly important in recent years because of the expanding robotic applications and adoption of offline programming, which requires precise mapping between the "virtual world" (what the robot is programmed to do) and the "real world" (what the robot actually does) (see Exhibit 105).[34] Improving accuracy has as much to do with mechanical components, assembly quality, controller electronics (all hardware factors), robot control algorithms, and trajectory planning algorithms (all software factors), as with servo motors and drives.

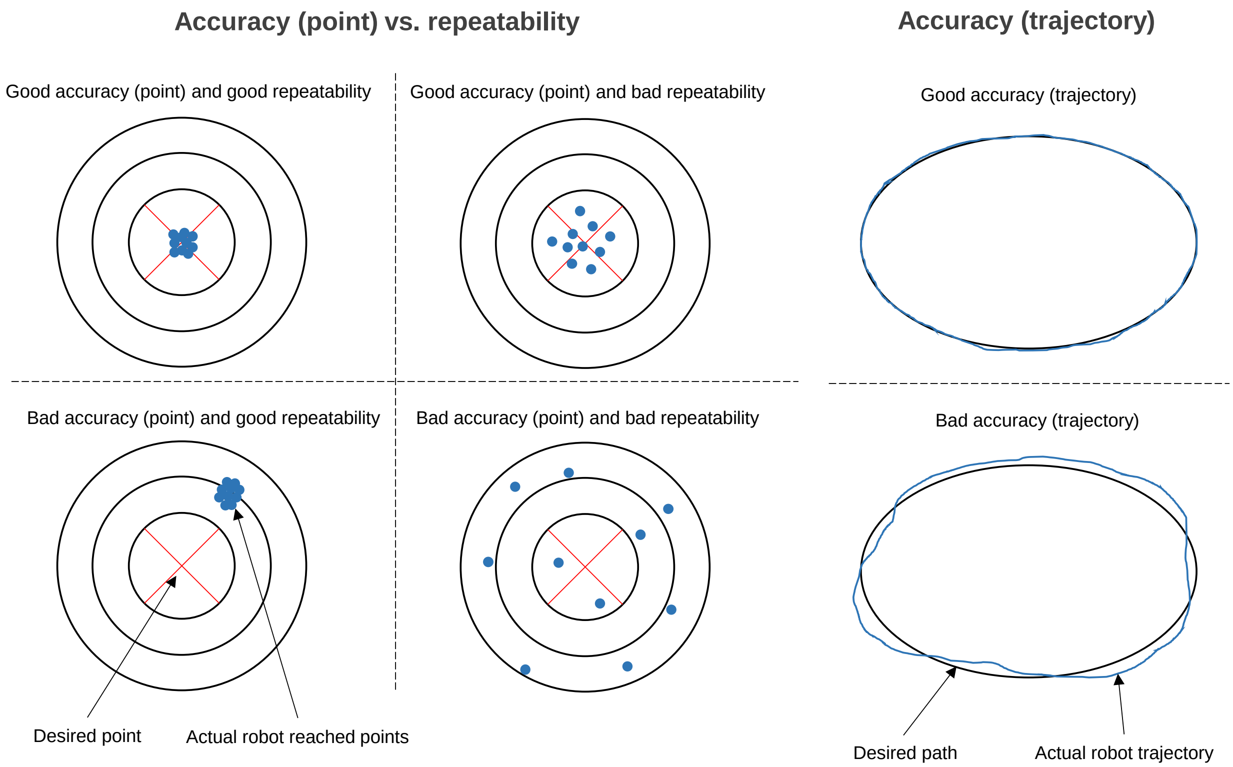
EXHIBIT 102: **Robot common performance issues and technological causes**

<table>
<tr><th colspan="2" rowspan="2">Technology
Performance</th><th colspan="3">Mechanical</th><th colspan="3">Electronics</th><th colspan="2">Control algorithms</th><th colspan="3">Movement planning</th></tr>
<tr><th>Components design/quality</th><th>Assembly</th><th>Structural design</th><th>Robot controller</th><th>Servo drive</th><th>Servo motor</th><th>Motor control</th><th>Robot control</th><th>Offline programming</th><th>Trajectory planning</th><th>Application packages</th></tr>
<tr><td rowspan="3">Precision</td><td>Repeatability</td><td colspan="2" rowspan="3"></td><td></td><td></td><td rowspan="4">Noise</td><td rowspan="3">Encoder error</td><td></td><td rowspan="7">Error in kinematic / dynamic model, or multi-axis interpolation</td><td></td><td rowspan="3">Error in multi-axis interpolation</td><td></td></tr>
<tr><td>Point accuracy</td><td></td><td></td><td></td><td rowspan="2">Error between simulation and real environment</td><td></td></tr>
<tr><td>Trajectory accuracy</td><td></td><td>Long control cycle</td><td rowspan="5">Motion delay between axes, error in control algorithm and parameters</td><td></td></tr>
<tr><td colspan="2">Speed</td><td></td><td></td><td></td><td></td><td>Poor dynamic performance</td><td></td><td>Unoptimized trajectory</td><td rowspan="2">Unoptimized processing parameters</td></tr>
<tr><td colspan="2">Reliability and lifespan</td><td colspan="2"></td><td></td><td colspan="3">Poor electronic quality, poor diamagnetic/anti-seismic design</td><td></td><td>Singularity</td></tr>
<tr><td rowspan="2">Dynamic performance</td><td>Vibration</td><td></td><td></td><td rowspan="2"></td><td colspan="3" rowspan="2">Electronic noise, long control cycle or communication latency</td><td></td><td></td><td></td></tr>
<tr><td>Dynamic response</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Source: Texas Instruments, Analog Devices, jiqizhixin.com, CSDN, "Analysis and experimental study on trajectory error of serial robot," and Bernstein analysis

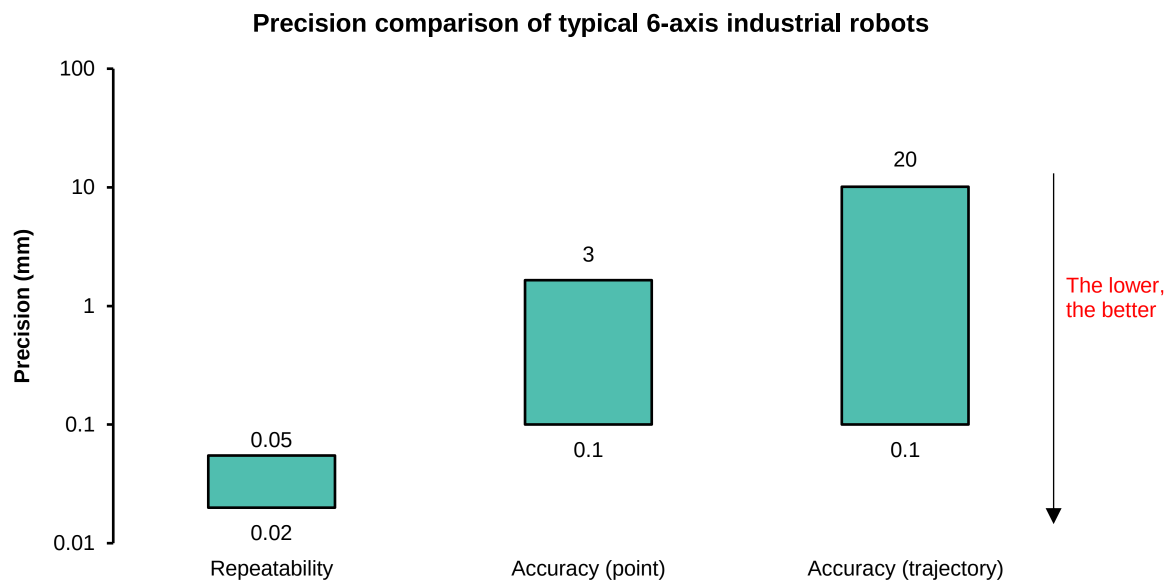
[34] Exhibit 105 also shows that Delta and SCARA robots are mostly used in point-to-point applications, where accuracy is less relevant than repeatability. This is partly why Chinese robot makers have a much smaller gap in these product categories compared to articulated six-axis robots.

EXHIBIT 103: **Illustrating three types of robot precision: repeatability, point accuracy, and trajectory accuracy**



Source: Xeryon.com and Bernstein analysis

EXHIBIT 104: **Typical precision of six-axis industrial robots**



Source: "Analysis and experimental study on trajectory error of serial robot," "Kinematic analysis based trajectory accuracy compensation method for industrial robot," company websites, and Bernstein analysis

EXHIBIT 105: **High repeatability is easier to achieve, but high accuracy is important for offline programming and broad applications**

<table>
<tr><th rowspan="2">Typical industrial robot applications</th><th colspan="3">Precision requirement</th><th colspan="3">Typical industrial robots used</th></tr>
<tr><th>High repeatability</th><th>High accuracy (point)</th><th>High accuracy (trajectory)</th><th>Delta robot</th><th>SCARA robot</th><th>6-axis robot</th></tr>
<tr><td>Pick and place</td><td rowspan="7">✓ (when online programming)</td><td rowspan="8">✓ (when offline programming)</td><td></td><td rowspan="3">✓</td><td rowspan="5">✓</td><td rowspan="13">✓</td></tr>
<tr><td>Case packing</td><td></td></tr>
<tr><td>Assembly</td><td></td></tr>
<tr><td>Machine tending</td><td></td><td></td></tr>
<tr><td>Inspection</td><td></td><td></td></tr>
<tr><td>Palletizing</td><td></td><td></td><td></td></tr>
<tr><td>Spot welding</td><td></td><td></td><td></td></tr>
<tr><td>Bin picking</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Arc welding</td><td></td><td></td><td rowspan="5">✓</td><td></td><td></td></tr>
<tr><td>Metal bending</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Painting and dispensing</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cutting, grinding, deburring and polishing</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Gluing, adhesive sealing and spraying materials</td><td></td><td></td><td></td><td></td></tr>
</table>

Source: Jabil, Inovance, FANUC, and Bernstein analysis

We highlight the following technical know-hows (see Exhibit 102) that set a good robot apart from a bad one:

- **Mechanical design:** Quality of mechanical components and assembly have a direct impact on precision, reliability, and consistency. Furthermore, different structural designs (even when motors and reducers are the same) impact speed and dynamic performance (e.g., vibration).

- **Electronics:** To allow precise, complex, and coordinated movement of multiple axes in space, a robot's control signal interval is typically <1/1,000 of a second. Because calculation and data transmission both take time, every microsecond counts. Data transmission between the robot controller and servo drives alone takes ~5% of the signal interval (see Exhibit 106).[35] In order to save precious time for calculation in high-speed applications, FANUC has built integrated control-drive circuitry to minimize data transmission latency.

- **Robot control algorithm:** A robot's accuracy is directly affected by the parameters in the kinematic model (e.g., distance between two joints). Many techniques have been proposed to improve the estimation of the parameters and trajectory accuracy. Moreover, accurate dynamic parameters and models allow for higher speed and

[35] Here we also show that: (1) for CNC machine tools, signal intervals are even shorter and data transmission delay is a more serious issue, and (2) the typical latency of 5G is 0.5-1ms, similar to the full signal interval of robots and, therefore, too slow for real-time robotic control.

stability. For example, the recent release of Estun's new robot-control algorithm without hardware changes, enabled Estun to achieve 50% enhancement in vibration suppression and significantly higher axis speed (see Exhibit 107).

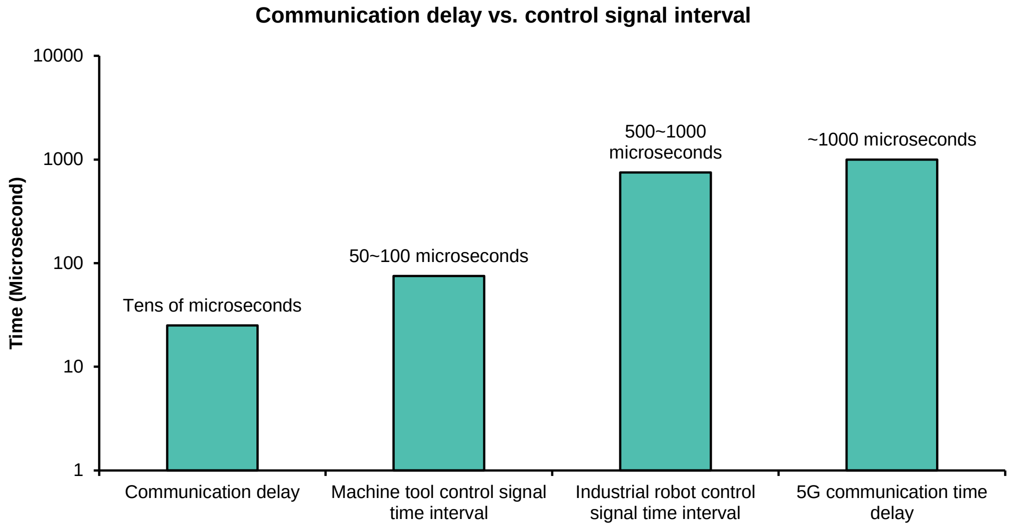
- **Trajectory planning:** As discussed earlier in this chapter, optimally planned trajectory enhances speed and avoids collision, singularity, or exceeding mechanical limits of the axes. For most robotic applications, the trajectory is planned once and executed repeatedly, until the task is changed months or years later. In "autonomous" robotic applications (e.g., adaptive welding and bin picking[36]; see Exhibit 108), however, trajectories vary and are calculated anew using environmental parameters (e.g., vision signals) in each cycle. In these applications, autonomous trajectory planning becomes a key differentiating capability.

- **Application software:** Prebuilt, process-specific software packages make robot applications easier and better performing. This requires a robot maker to have deep and broad process know-how and is an important part of the robot maker's offering. Compared to emerging players, leading robot makers carry a much broader selection of these packages (see Exhibit 109). Using arc welding as an example, the application software automatically tracks the weld seam and generates a nonlinear trajectory to compensate for the variance of distance between the pieces to be welded (see Exhibit 110). In addition, it generates sophisticated time-dependent arc parameters (e.g., current and voltage) optimized for the specific task and coordinated with the robot movement.

- **Offline programming:** Many offline programming platforms have been developed by robot makers and third-party players (see Exhibit 111). Generally speaking, a robot maker's own offline programing platform allows for more precise projection from the "virtual world" to the "real world" with higher ease of use.

[36] See Collaborative Robot: Bin picking - latest progress and enabling technologies for a multi-billion-dollar opportunity.

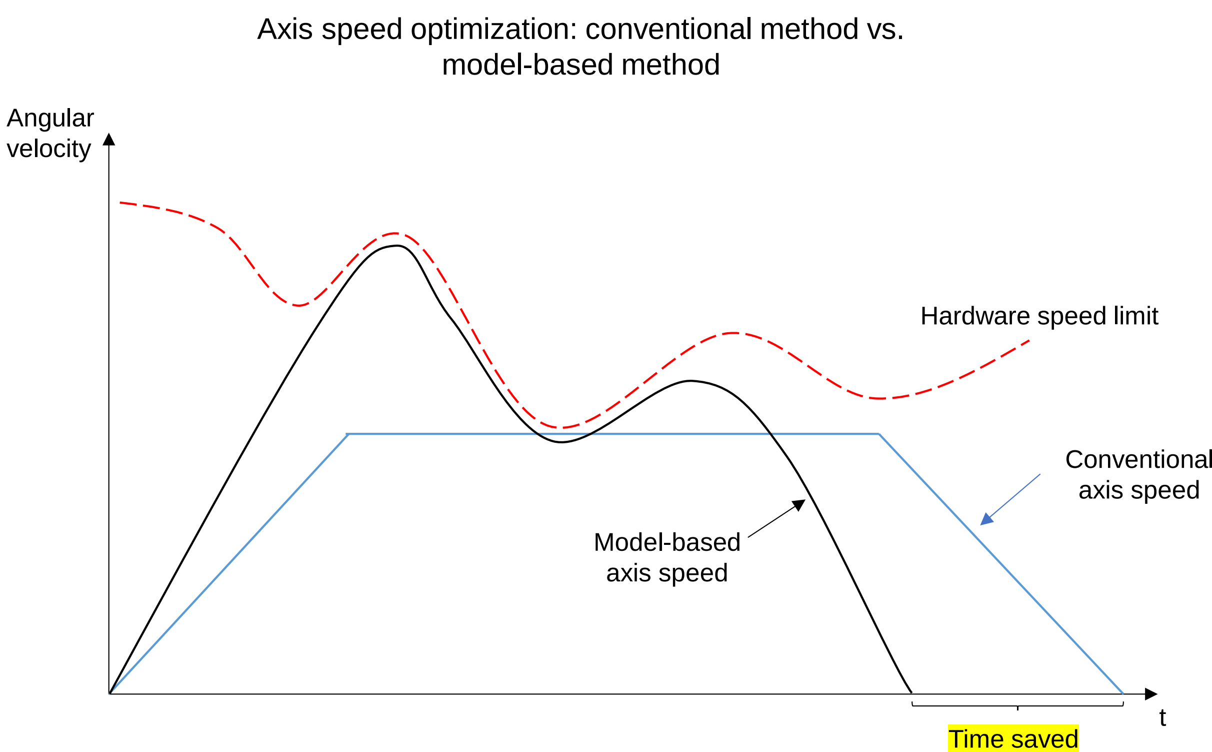
EXHIBIT 106: **With short signal interval in robotics and CNC, control electronics need to be carefully designed to minimize signal communication latency**



Note: A microsecond is a millionth of a second.

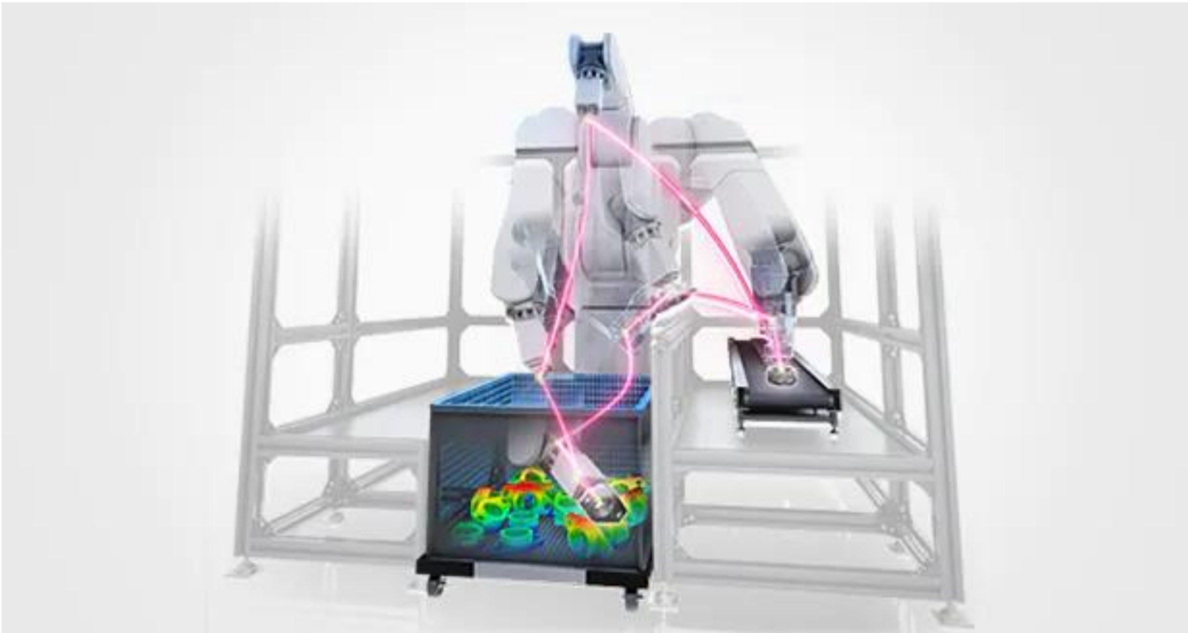
Source: Analog Devices and Bernstein analysis

EXHIBIT 107: **Axis speed optimization through better control algorithm**



Source: Estun, OFweek.com, and Bernstein analysis

EXHIBIT 108: **Bin-picking: Trajectory varies and is calculated in real time for each pick**



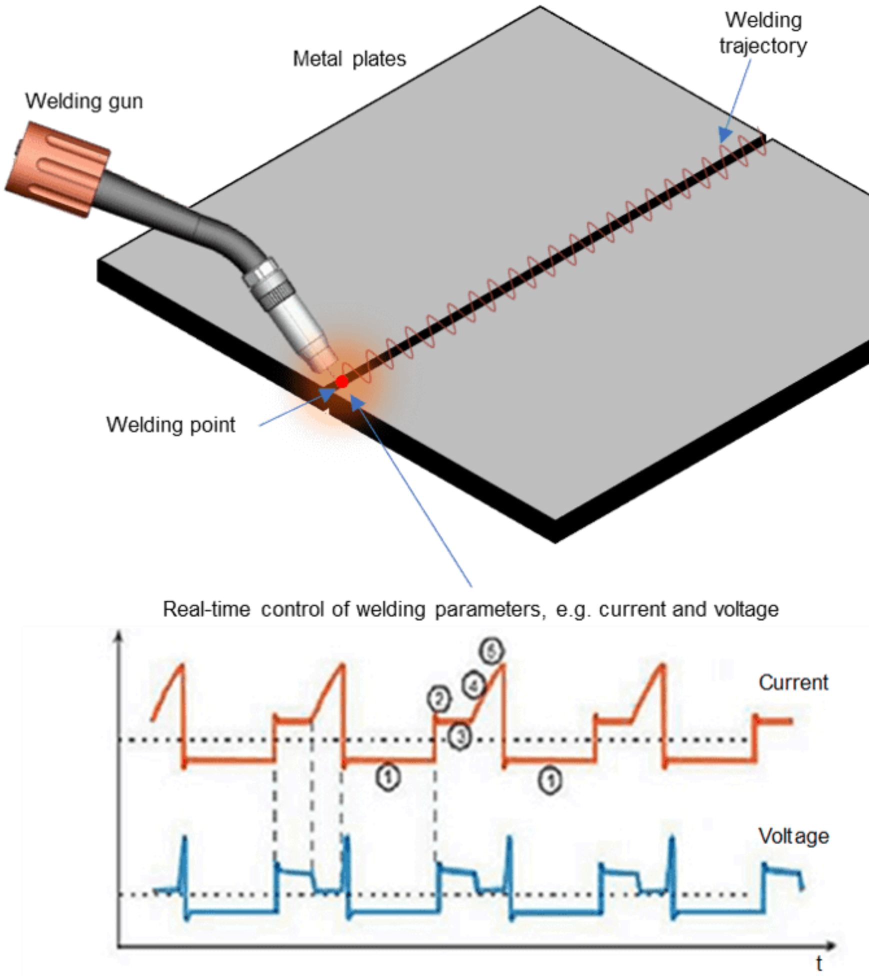
Source: Keyence and Bernstein analysis

EXHIBIT 109: **Comparing the list of application software provided by several robot makers**

Brands	ABB	KUKA	Estun	Efort
Application software	3D Printing	Arc welding	Arc welding	Palletizing
	Arc welding	Spot welding	Spot welding	Pick and place
	Spot welding	Palletizing	Palletizing	Grinding
	Assembly	Bin-picking	Pick and place	Arc welding
	Machine tending	Pick and place	Metal bending	Painting
	Machining	Cooperation of robots and conveyors	Soft float	
	Laser cutting	Machining	Drilling	
	Painting	Force/torque control	Painting	
	Palletizing	Material handling	Gluing	
	Vision-guided random flow picking and packing	Laser cutting and laser welding	Punching	
	Cooperation of robots and stamping machine	Spot welding on aluminum components		
	Cooperation of robots and plastic injection moldingmachine	Seam detection and seam tracking		
	3D vision-guided robot dispensing path tuning	Seam search		
		Automatic setup and checking of the TCP (Tool Center Point)		
		Object & code recognition		
Total number	13	15	10	5

Source: Company websites and Bernstein analysis

EXHIBIT 110: **Arc welding application software plans complex robot movement and coordinated arc parameter to optimize welding quality**



Source: Cloos, Peitian, and Bernstein analysis

EXHIBIT 111: **Robot offline programming platforms offered by robot makers and third-party developers**

Offline programming platform	Brands	Headquarters	Company type
RobotStudio	ABB	Switzerland	Robot maker
KUKA.Sim	KUKA	Germany	Robot maker
Motosim	Yaskawa	Japan	Robot maker/Motion control
RoboGuide	FANUC	Japan	Robot maker
MelfaWorks	Mitsubishi	Japan	Robot maker
EstunStudio	Estun	China	Robot maker
RoboPlan	CLOOS (Acquired by Estun)	Germany	Robot maker
ER-Factory	Efort	China	Robot maker
GSK Robotassist	GSK	China	Robot maker
InoRobotLab	Inovance	China	Motion control
Robotmaster	Hypertherm	USA	Third party
Mech-Viz	Mech-Mind Robotics	China	Third party
PQArt	C.H.L Robotics	China	Third party
RobotWorks	Compucraft	Israel	Third party
ROBCAD	SIEMENS	Germany	Third party/Motion control
DELMIA	Dassault Systèmes	France	Third party
ROBOmove	QD Robotics	Italy	Third party

Note: Chinese companies are highlighted in lime/gray.

Source: Company websites and Bernstein analysis

WHO IS THE FAIREST OF THEM ALL?

Empirical evidence of performance differential

We often say the Big 4 are the best robot makers, FANUC is the best among the four, and Estun's robot technology is leading in China. What supports these statements? Detailed performance data are rarely made public, but we make a best effort to show the empirical evidence for accuracy (see Exhibit 112 to Exhibit 114), speed (see Exhibit 147), weight-to-payload ratio (see Exhibit 148 and Exhibit 149), and different levels of robot hardware customization. We then compare industry players' strengths along the key technology building blocks (see Exhibit 115).

In a direct comparison of trajectory accuracy, ABB easily prevails over Chinese brands (see Exhibit 112). ABB's tested model, the IRB 6700, has higher payload and longer reach, both of which make it more difficult to achieve high accuracy, and yet its trajectory accuracy (±0.09mm for linear motion and ±0.23mm for circular motion) is at least an order of magnitude better compared to SIASUN and a low-tier Chinese brand (unspecified in the referenced test).

Differentiation also exists among the Big 4. A circular motion test shows trajectory accuracy of ±0.1mm for FANUC, and ±0.2-0.4mm for Yaskawa and ABB (see Exhibit 113).

We have not been able to find experimental data on Estun robots, but we examined a metal calabash 3D printed by a Cloos robot (see Exhibit 114). The uniform patterns in the magnified image indicate better-than-1mm trajectory accuracy and consistent speed in circular motion, as well as stable and coordinated control of material deposition, all maintained over an hour or longer. Estun's own-brand thin-plate arc welding robots (EWAS series) have an excellent point accuracy of 0.5mm, much better than other Chinese brands.

A real test for these robots is "small circle" welding, because it requires near-perfect three-dimensional trajectory accuracy to maintain not only circular movement but also precise distance between the welding gun and the workpiece. Estun's EWAS robots are capable of welding 12mm-diameter circles, superior to all other local products and comparable to global leaders such as OTC.

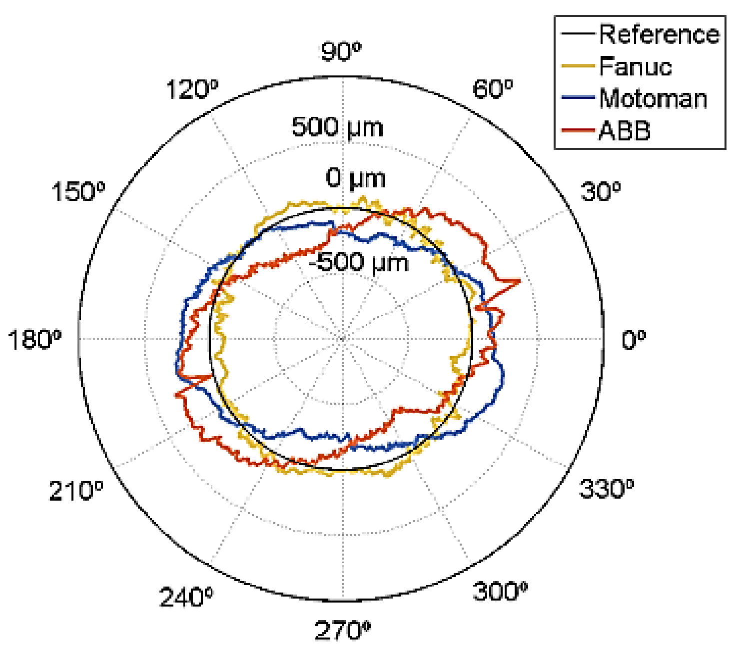
EXHIBIT 112: **ABB easily prevails over Chinese brands in trajectory accuracy, despite little difference in repeatability**

Brands	ABB	SIASUN	(A low tier Chinese brand)
Model	IRB 6700	SR4C	LR20-KEBA
Payload	200 kg	4 kg	20 kg
Reach	2600 mm	672.8 mm	1730 mm
Speed in test	40 mm/s	10 mm/s	20% max. speed
Repeatability	0.05 mm	±0.03 mm	±0.05 mm
Max. deviation in linear motion	0.09 mm	0.98 mm	4.8 mm
Max. deviation in circular motion	0.23 mm	2.4 mm	6.0 mm

Note: LR20-KEBA is equipped with six servo systems from SANYO and robot control system from KEBA.

Source: "Trajectory precision compensation method for industrial robot based on kinematics analysis," "Analysis and experimental study on trajectory error of serial robot," Zhihu.com, company websites, and Bernstein analysis

EXHIBIT 113: **FANUC's trajectory accuracy is the best even among first-tier robot brands**

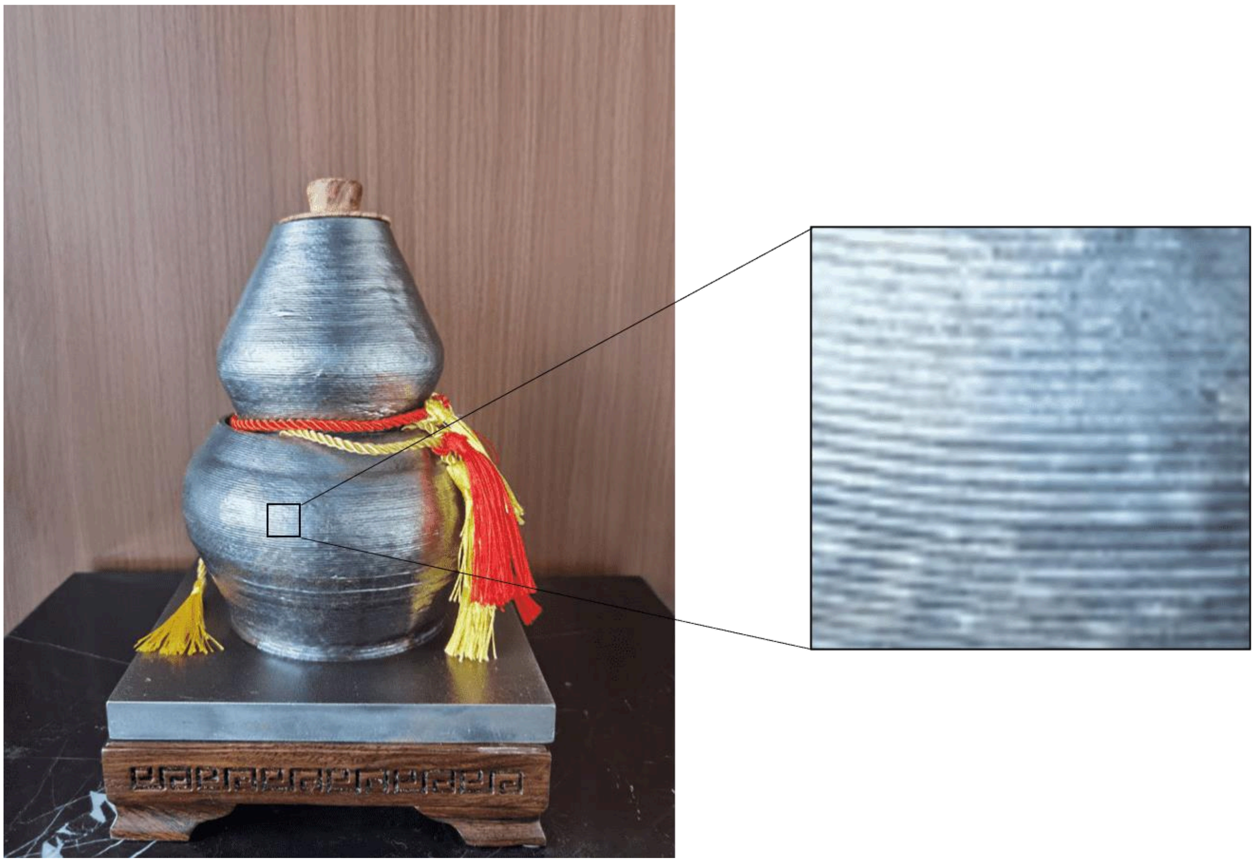


Note: The test was performed with horizontal circular path of radius of 100mm and tool center point speeds of 17mm/s for the three robots (FANUC LR Mate 200iC, ABB IRB120, and Yaskawa Motoman MH5S).

Source: Slamani, Mohamed, Ahmed Joubair, and Ilian A. Bonev. "A comparative evaluation of three industrial robots using three reference measuring techniques." *Industrial Robot: An International Journal* (2015), and Bernstein analysis

Comparing robot speed, FANUC is again the best. Among the Chinese brands, Inovance and Estun are better than the rest (see Exhibit 147).[37] Across the payload range, Estun robots usually have the best weight-to-payload ratio among Chinese brands (see Exhibit 148 and Exhibit 149), indicating better product design and control technology. The last aspect we note is that Estun has by far the broadest range of six-axis robot SKUs and application software packages in China.

EXHIBIT 114: **Metal calabash 3D printed by a Cloos robot, demonstrating high accuracy, excellent process coordination, and long-use stability**



Source: Estun and Bernstein analysis

Paths of differentiation

Many factors, including all those appearing in Exhibit 102, contribute to performance differentiation. Along the robotic value chain, companies have different levels of vertical integration and areas of technological strengths (see Exhibit 115). We believe the robot control algorithm is the single most critical "component," albeit an intangible one, in determining a robot's performance. It sets the first-tier robot makers apart from the second

[37] Inovance's speed specs are even higher than Estun's in this exhibit, but considering the Estun model under comparison has 20% higher payload and 6% longer reach than Inovance's, the slight difference in angular speed does not indicate technology difference.

and third tiers. Application package is a further differentiator, defining the very best, such as FANUC and Universal Robots, in six-axis and collaborative robots, respectively.

EXHIBIT 115: **Robotic players' technical capabilities and competitive strengths**

Technology		FANUC	Estun			Yaskawa	Inovance	GSK	Teradyne		Mech-Mind	Kindred Systems	Righthand Robotics	Mujin
			Estun	CLOOS	Trio				UR	Energid				
Hardware	Servo motor/drive	■ ☆	■	■		■ ☆	■ ☆	■						
	Controller	■	■	■	■ ☆	■	■	■	■					■
	Reducer			■										
Software	Motor control	■	■	■		■ ☆	■ ☆	■						
	Robot control	■ ☆	■ ☆	■ ☆	■ SCARA	■	■	■ ☆	■ ☆					■
	Offline programming platform	■	■	■	■	■	■	■	■	■	■			■
	Autonomous trajectory planning	■		■						■ ☆	■ ☆	■ ☆	■ ☆	■
	Application packages	■ ☆	■	■ ☆		■			■ ☆	■				■ ☆
Has CNC?		■	■					■						

Note: Highlighted cells indicate areas of substantial capability; stars indicate competitive strengths. Kindred Systems is owned by Ocado (OCDO.UK, covered by Bernstein European Food Retail & Food Delivery team); Teradyne (TER.US) and Yaskawa (6506.JP) are not covered.

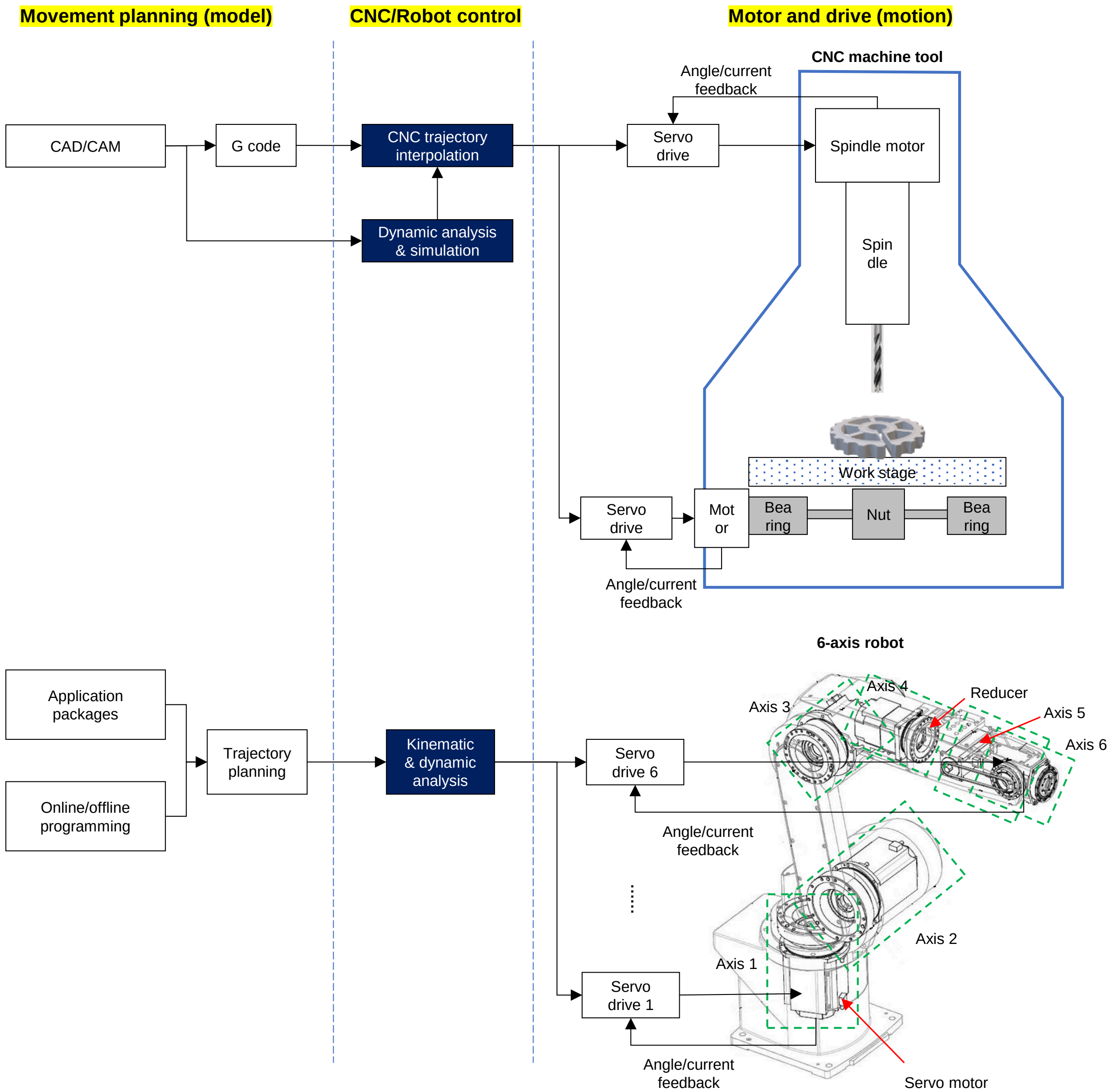
Source: Company websites and Bernstein analysis

The hardware and software architecture of a robot (see Exhibit 99 and Exhibit 100) bears many similarities to a CNC machine tool (see Exhibit 116). The robot and CNC control algorithms are both responsible for kinematic and dynamic analysis, and multi-axis joint interpolation, building the critical link between movement planning and servo motion. Given the overlap in control technology, it is no surprise that the world's best robot maker, FANUC, was already a leading CNC player when it started in the robotic business. Estun took a very similar path, about three decades later.

The other common path — taken by Yaskawa in Japan and Inovance in China — is to enter robotics from servo motion. It's a proven path, but the technology overlap between servo motion and robot is much less than between CNC and robot, and unlike robot control algorithm, servo motion is rarely, if at all, the source of significant differentiation of a robot.

Autonomous trajectory planning is the most exciting and dynamic area of robotic technology (see Exhibit 115). Robot makers (e.g., FANUC), third-party developers (e.g., Mech Mind, Mujin, Kindred Systems, Righthand Robotics, and Energid), and vision companies (e.g., Keyence) are collaborating and competing, all aiming to make robots intelligent and autonomous in order to push the boundary of their applications.

EXHIBIT 116: **The closest adjacency to robotics is not servo motion but CNC (similar hardware and software architecture)**



Source: "Toward Intelligent Machine Tool" and Bernstein analysis

ROBOTS AND CHIPS

Can the US-China tech war, currently anchored on semiconductors, engulf the industrial sector? We've shown previously that China's direct dependence on US industrial automation technologies is non-existent to limited, but the deeper question remains: How much do robot makers in China and elsewhere rely on US semiconductors? In this part, we go through a "virtual teardown" to examine the detailed variety of chips used in industrial robots, compare the chip supply chain of FANUC and Estun, analyze the chip specs required for robots, and assess the hypothetical impact if Chinese robot makers were denied access to US chips.

Semiconductor content of an industrial robot — a virtual teardown

Chips to a robot are what the nervous system is to the human body. They plan and control movement, and enable signal communication across the various parts of a robot and with the external world. One will find most of these chips in the control cabinet of the robot.

The robot nervous system works through important functional modules (see Exhibit 117), which at the high level include:

- **Robot controller —** the "brain" of a robot. It carries out general-purpose control such as communication, data processing, and task allocation. Most importantly, it performs *axis control*, i.e., planning the path of each axis, interpolating points into the paths, and setting the motion of each servo motor to follow the planned path based on inverse kinematics algorithms.

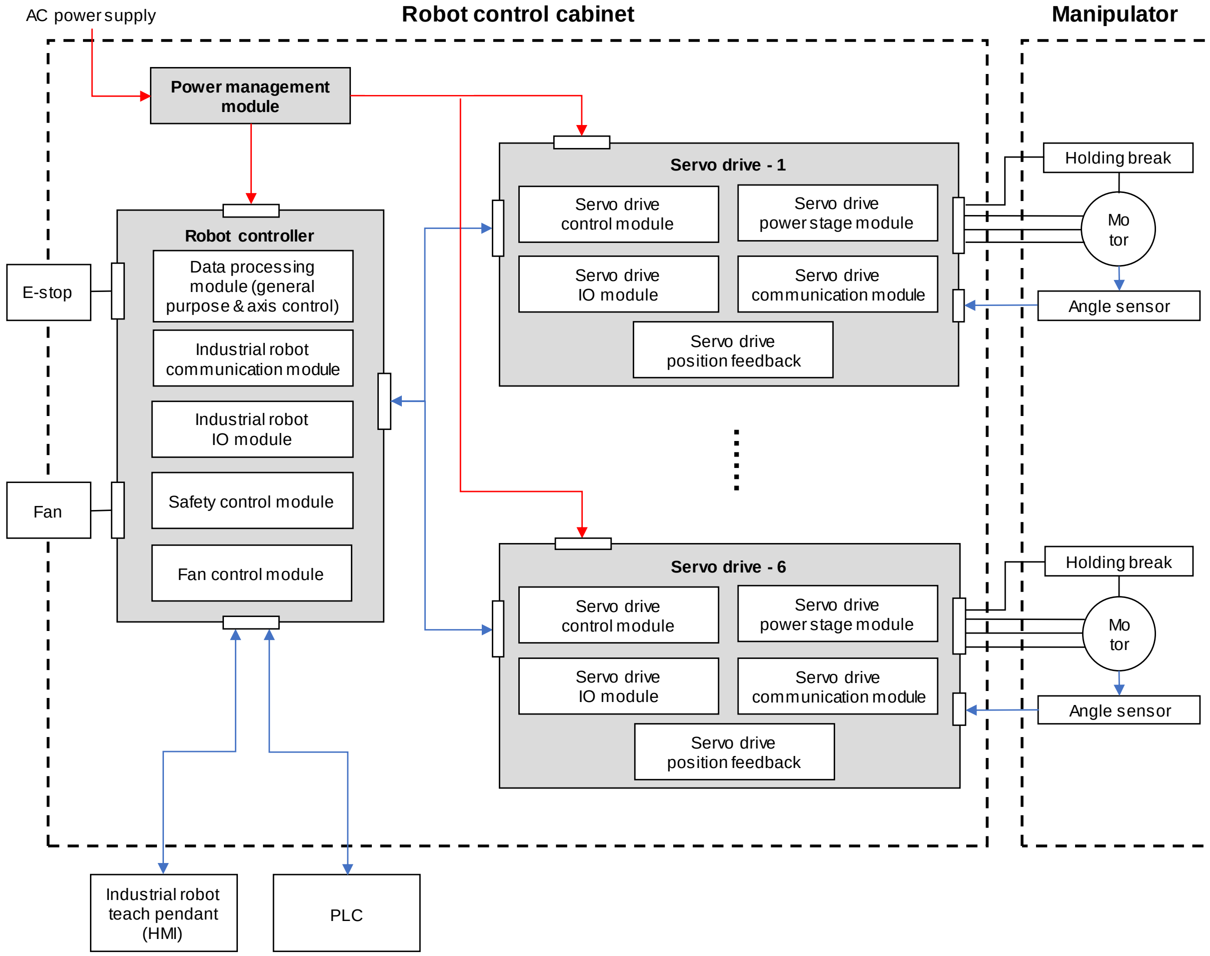
- **Servo drive —** the "field commander" of servo motion. It receives instruction from the robot controller, compares it with feedback signals from sensors, and translates the instruction to electrical current to provide power and motion for the servo motor to follow the setpoints in real time. Each robot axis has a motor and a corresponding drive, so in a six-axis articulated robot, there are six servo drives.

- **Power management module —** converts alternating current (AC) to direct current (DC) at various voltage levels (e.g., 5V and 3.3V) for the different chips. It also provides power protection and monitoring, and backup power to save parameters, motor position data, and latest sensor data during unexpected power loss.

Each of these modules include several submodules (see Exhibit 117). Following this modular structure, we present the detailed semiconductor content of a robot in Exhibit 118 and Exhibit 119,[38] along with estimated value in Exhibit 120.

[38] In addition to companies mentioned in the "Investment Implications" section, the Bernstein Global Memory & Consumer Electronics team covers Micron Technology (MU), Samsung Electronics (005930.KS, SMSN.LI), and SK Hynix (000660.KS); other companies in these two exhibits are not covered by Bernstein.

EXHIBIT 117: **Control modules and submodules of an industrial robot**



Note: Red/dark gray lines stand for power transmission; blue/light gray lines stand for signal transmission

Source: Texas Instruments, Analog Devices, and Bernstein analysis

EXHIBIT 118: **Chips used in a typical industrial robot (1/2)**

Modules	Sub-modules	Functions	Chips	Description	Overseas suppliers	Mainland Chinese suppliers	Suppliers to FANUC	Suppliers to Estun
Power supply	Power management module	Power conversion	AC-to-DC	To convert alternating current (AC) to direct current (DC)	***TI***, ***ADI***, Infineon, ***ON Semiconductor***, ***DIODES***, NXP, Renesas	Silan, SG Micro, Fine Made Elect, Bright Power Semiconductor, Chipown Micro, Belling	No info	***TI***, ***EXAR***, ***ON Semiconductor***, NXP, StarHope, MURATA, KINGCORE, TDK, ***Power Integrations***
			DC-to-DC	To convert a source of DC from one voltage level to another				
		Power management & protection	Input power protection	Over/under voltage, over current protection, miss-wire protection and inrush current protection				
			Voltage&current monitoring	Monitoring the voltage and current in real time				
			Backup power storage	To save system parameters, motor position data and latest sensor data in case of unexpected power loss				
			LDO (low-dropout)	To provide a stable power supply voltage independent of load impedance, input-voltage variations, temperature, and time				
			Power factor controller (PFC)	To control and monitor the cos φ (power factor) and the system power quality				
Robot controller	Data processing module	General purpose control + Axis control	CPU	**General purpose control** includes communication, data processing, task allocation, system operation, vision, etc. **Axis control** includes trajectory planning, interpolation, inverse kinematics, etc.	***Intel***, ***AMD***	Loongson, Phytium	FANUC (ASIC), etc	***Intel***
			MCU		Renesas, ***TI***, ***ADI***, ***Microchip***	GigaDevice, SinoWealth, Eastsoft		No info
			DSP		***TI***, ***ADI***, NXP	Advancechip, CETC,Vimicro	No info	
			FPGA		***Xilinx***, ***Intel (Altera)***, ***Lattice***	PangoMicro, Fudan Micro, GOWIN	***Xilinx***	
		Others	Memory	To support high data rates and save data like system configuration, robot tasks, etc.	Samsung, SK Hynix, **Micron Technology**, Toshiba, **Cypress**	Yangtze Memory, GigaDevice, Ingenic, ChangXin Memory	TDK, Renesas, ELPIDA	Samsung, Innodisk
			Clocking	To provide proper clock signal and timing information	***TI***, ***ADI***, ***Microsemi***, ***ON Semiconductor***	Dapu Telecom, Corebai, Saisi	No info	No info
			Temperature monitoring chip	To monitor system temperature in real time	***ADI***, ***TI***, ***ON Semiconductor***	Shandong Huake, Galaxy-CAS		
	Industrial robot communication module	Interfaces	Wired interface chip	To support communication standards like RS-485, RS-422, Ethernet and CAN	***ADI***, ***TI***, ***Intersil***, STMicroelectronics, Realtek	HGSEMI, Belling, Corebai, Motorcomm	FANUC (ASIC), etc	***ADI***, NXP
			Wireless interface chip	To support wireless communication standards like WiFi, Bluetooth and NFC	***Broadcom***, ***Qualcomm***, ***Marvell***, MediaTek	Telink, PHY, BlueX, Yichip (no Wi-Fi chips)		
		Signal IO protection	ESD/TVS chip	To protect electronics from damage by electromagnetic disturbances	***Littelfuse***, ***Bourns***, STMicroelectronics	JieJie, SuperESD, Will Semiconductor		
	Industrial robot IO module	Analog front-end	ADC + DAC + amplifier	Sampling and signal conditioning of incoming analog/digital signals	***ADI***, ***TI***, ***Microchip***, ***ON Semiconductor***	Belling, YunChip, AcelaMicro, SG Micro, 3Peak	FANUC (ASIC), TDK, Panasonic, OMRON, TOSHIBA	No info
		Signal isolation	Signal isolation chip	Isolation between a microcontroller and analog front end, i.e. ADC or DAC	***ADI***, ***TI***, ***Silcon Labs***	Novosense, Belling, 2Pai Semi		
		Signal IO protection	ESD/TVS chip	To protect electronics from damage by electromagnetic disturbances	***Littelfuse***, ***Bourns***, STMicroelectronics	JieJie, SuperESD, Will Semiconductor		
	Safety control module	Emergency stop	Comparator	Safety mechanism to shut off the system in an emergency	***TI***, ***ADI***, ***ON Semiconductor***	SG Micro, 3Peak, Richtek	No info	
	Fan control module	Fan control	Load switch + LDO	To cool the components in the robot cabinet	The same as power management chips			

Note: (1) American suppliers are in ***bold italics***. (2) Overseas/mainland Chinese suppliers provide corresponding chips for general purpose, not limited to industrial robot applications. (3) Acronym explanation: TI — Texas Instruments; ADI — Analog Devices; LDO — low-dropout; PFC — power factor controller; CPU — central processing unit; MCU — microcontroller unit; DSP — digital signal processors; FPGA — field-programmable gate array; IO — input and output; ESD — electrostatic discharge; TVS — transient voltage suppressor; ADC — analog-to-digital converter; DAC — digital-to-analog converter; ASIC — application-specific integrated circuit.

Source: Texas Instruments, Analog Devices, FANUC, Estun, company websites, and Bernstein analysis

EXHIBIT 119: **Chips used in a typical industrial robot (2/2)**

Modules	Sub-modules	Functions	Chips	Description	Overseas suppliers	Mainland Chinese suppliers	Suppliers to FANUC	Suppliers to Estun
Servo drive	Servo drive control module	Position loop control Speed loop control	MCU/DSP	To control position & speed loop in the servo drive and communicate with the robot controller	**MCU**: Renesas, ***TI***, ***ADI***, ***Microchip*** **DSP**: ***TI***, ***ADI***, NXP	**MCU**: GigaDevice, SinoWealth, Eastsoft **DSP**: Advancechip, CETC, Vimicro	FANUC (ASIC)	DSP from ***TI***
		Current loop control	FPGA	To control current loop in the servo drive and collect feedback data from both hall sensor and resolver/encoder	***Xilinx***, ***Intel (Altera)***, ***Lattice***	PangoMicro, Fudan Micro, GOWIN		***Lattice***, ***Xilinx***, domestic suppliers started from 2019
		Others	Temperature monitoring	To ensure the board working within temperature limit	***ADI***, ***TI***, ***ON Semiconductor***	Shandong Huake, Galaxy-CAS	No info	Shiheng
			Memory	To provide faster data transfer and overall higher system performance	Samsung, SK Hynix, ***Micron Technology***, Toshiba, ***Cypress***	Yangtze Memory, GigaDevice, Ingenic, ChangXin Memory		***Cypress***
			Clocking	To provide proper clock signal and timing information	***TI***, ***ADI***, ***Microsemi***, ***ON Semiconductor***	Dapu Telecom, Corebai, Saisi		HOSONIC
	Servo drive IO module	Digital IO interface	Input serializer + comparator	To communicate with external devices	***TI***, ***ADI***, ***ON Semiconductor***	SG Micro, 3Peak, Richtek		***TI***
		Analog IO interface	ADC + DAC + amplifier	To receive control reference setpoints and send back key drive parameters	***ADI***, ***TI***, ***Microchip***, ***ON Semiconductor***	Belling, YunChip, AcelaMicro, SG Micro, 3Peak		***ADI***
		Signal IO protection	ESD/TVS chips	To protect electronics from damage by electromagnetic disturbances	***Littelfuse***, ***Bourns***, STMicroelectronics	JieJie, SuperESD, Will Semiconductor		***ON Semiconductor***, ***Semtech***, Brightking
	Servo drive communication module	Interfaces	Ethernet interface chip	To communicate with external systems	***TI***, ***ADI***, Siemens, Renesas, Realtek	Motorcomm, Netforward, Corebai		TOSHIBA, ***AVAGO***
			Fieldbus interface chip	To support standards like RS-485, RS-422 and CAN	***ADI***, ***TI***, ***Intersil***, STMicroelectronics	HGSEMI, Belling, Corebai, Motorcomm		NXP, ***EXAR***, Nexperia, ***TI***
	Servo drive power stage module	Motor drive	Isolated gate driver	To provide electrical isolation and control over the IGBT	Infineon, ***ADI***, ***TI***, STMicroelectronics	Bronze, Jiangsu CAS-IGBT, LMY Electronics	FANUC (ASIC)	MITSUBISHI
			IGBT	To drive the motion of a motor	Infineon, ***ON Semiconductor***, Fuji Electric	Starpower,Yangjie, Sino-Microelectronics		Infineon, localization plan raised recently
		Current sensing	Hall sensor + ADC + amplifier	Current is sensed to implement the motor control algorithms and protect the inverter against over current conditions	***ADI***, ***TI***, ***Microchip***, ***ON Semiconductor***	Belling, YunChip, AcelaMicro, SG Micro, 3Peak	No info	***TI***
		Holding break	Isolation + high/low side switch + DC-to-DC chip	To hold the motor shaft to avoid unwanted movement after servo has stopped	The same as power management chips			
	Servo drive position feedback	Resolver or SIN/COS econder feedback	ADC + amplifier	To convert SIN/COS differential inputs from resolver or SIN/COS encoder to digital values	***ADI***, ***TI***, ***Microchip***, ***ON Semiconductor***	Belling, YunChip, AcelaMicro, SG Micro, 3Peak	No info	***ADI***, ***TI***
		Resolver excitation	DAC + amplifier	To generates sinusoidal excitation signal to drive the resolver primary winding				
		Absolute/ incremental encoder feedback	Transceiver + comparator	To catch the feedback from absolute/incremental encoder	***TI***, ***ADI***, ***ON Semiconductor***	SG Micro, 3Peak, Richtek Technology		
Industrial robot teach pendant	Human-machine interface (HMI)	Data processing	CPU/MCU	To generate a graphical content received from the general purpose control processor	**CPU**: ***Intel***, ***AMD***, ***Qualcomm*** **MCU**: Renesas, ***TI***, ***ADI***, ***Microchip***	**CPU**: Loongson, Phytium **MCU**: GigaDevice, SinoWealth, Eastsoft	Renesas	No info
		Interfaces	Data wired interface chip	Serial interfaces like Ethernet, USB and RS-232/422/485	***ADI***, ***TI***, ***Intersil***, STMicroelectronics, Realtek	HGSEMI, Belling, Corebai, Motorcomm	No info	
			Output user interface chip	Output user interfaces including LCD panel, speaker, etc.	LGD, SDC, INX, AUO, Sharp	BOE, CEC-Panda, HKC, CSOT		
			Input user interface chip	Input user interfaces including touch controller, buttons, etc.	***Synaptics***, ***Microchip***, ***Cypress***, Focaltech	Goodix, Silead		
		Others	Clocking	To generate multiple system clocks with the same clock domain	***TI***, ***ADI***, ***Microsemi***, ***ON Semiconductor***	Dapu Telecom, Corebai, Saisi		
			Memory	Extended memory or external removable memory such as a SD-Card	Samsung, SK Hynix, ***Micron Technology***, Toshiba, ***Cypress***	Yangtze Memory, GigaDevice, Ingenic, ChangXin Memory	SK Hynix	

Note: (1) American suppliers are in ***bold italics***. (2) Overseas/mainland Chinese suppliers provide corresponding chips for general purpose, not limited to industrial robot applications. (3) Acronym explanation: TI — Texas Instruments; ADI — Analog Devices; MCU — microcontroller unit; DSP — digital signal processors; FPGA — field-programmable gate array; IO — input and output; ESD — electrostatic discharge; TVS — transient voltage suppressor; ADC — analog-to-digital converter; DAC — digital-to-analog converter; IGBT — insulated-gate bipolar transistor; SIN/COS — sine and cosine; ASIC — application-specific integrated circuit.

Source: Texas Instruments, Analog Devices, FANUC, Estun, company websites, and Bernstein analysis

EXHIBIT 120: **Estimated value of semiconductor content in a six-axis industrial robot**

Modules	Sub-modules	Unit per robot	Chip expense per unit (USD)	Total chip expense per robot (USD)
Power supply	Power management module	1	15.3	15.3
Robot controller	Data processing module (assume an MCU and DSP used)	1	72.6	96.5
	Industrial robot communication module		10.4	
	Industrial robot IO module		12.7	
	Safety control module		0.1	
	Fan control module		0.7	
Servo drive	Servo drive control module (assume an MCU and FPGA used)	6	50.4	569.0
	Servo drive IO module		10.4	
	Servo drive communication module		3.7	
	Servo drive power stage module		29.3	
	Servo drive position feedback (assume an absolute/incremental encoder used)		1.0	
Industrial robot teach pendant	Human-machine interface (assume an MCU used)	1	13.0	13.0
Total		-	-	693.8

Source: Texas Instruments, Analog Devices, Mouser, DigiPart, WDL Systems, DigiKey, Cypress, GuestComponents, and Bernstein analysis

The most critical chips are processors. Four types of processors are used in industrial robots: central processing unit (CPU), microcontroller unit (MCU), digital signal processor (DSP), and field-programmable gate array (FPGA).

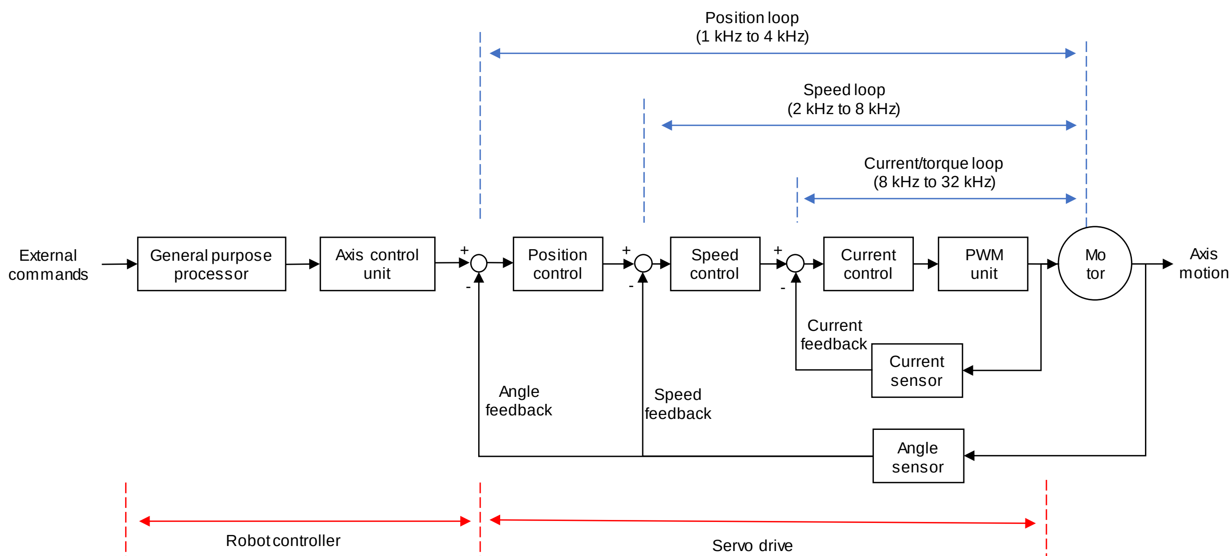
- In a robot controller, CPU or MCU is typically used for general-purpose control tasks. For axis control, DSP is the preferred choice, because of the intensive real-time calculation. FPGA is electively used to enhance performance in fine interpolation and communication. There is no universal standard for the selection/combination of processors. We've seen real-world examples of "CPU only," "CPU+DSP," and "MCU+DSP+FPGA." KUKA KR C4 robot controller, for instance, carries a dual-core processor, where one CPU core performs general-purpose control and the other executes the axis-control function.

- In the servo drive, a cascade control scheme is used to control the motor on three progressive levels, i.e., position, speed, and torque (see Exhibit 121). The torque (current) loop control requires much higher speed (8-32kHz) than position loop

(1-4kHz) and speed loop control (2-8kHz). Higher speeds allow for more sophisticated control algorithm and better performance.[39] Typically, MCU/DSP meets the requirements for position and speed loop control, and communication with the robot controller; FPGA, with its strengths in processing speed and I/O interfaces, is commonly used for the torque (current) loop control and for collecting feedback data from both hall sensors and resolvers/encoders. For example, we find an MCU (STMicroelectronics Arm®-based 32-bit MCU STM32F205) and an FPGA (Altera Cyclone IV EP4CE10F17) in Inovance's IS620P series servo drive, a high-performance model.

To the extent information is available, we also show in Exhibit 118 and Exhibit 119 the potential suppliers for each type of chip, and those used by FANUC and Estun. Many chips in a FANUC robot bear "FANUC" logos. These are application-specific integrated circuits (ASIC), exclusively developed and made (likely by Fujitsu and others) according to the spec FANUC provides.[40] Estun robot chips are mostly imported.

EXHIBIT 121: **Control diagram of a single axis in an industrial robot, and the three control loops of a servo drive**



Source: Texas Instruments, Analog Devices, and Bernstein analysis

How far is China from being self-sufficient in robotic chips?

In the chapter titled "The Playfield," we show that China's direct dependence on US industrial automation technologies is limited. It's quite different in the components upstream. Many Chinese industrial equipment companies accelerated their efforts to localize the semiconductor supply chain and develop new components suppliers as alternatives to their existing US-dependent supply chain. Raycus quickly brought its diode and fiber supply back home from II-VI and Nufern, respectively. In November 2020, the first

[39] See this vibration suppression demo (https://www.youtube.com/watch?v=eikPy2vJKyI).
[40] FANUC is quite unique in this regard. We find much lower chip customization ratios for ABB, Yaskawa, and KUKA robots.

100% Made-in-China DCS was successfully used in Huaneng's thermal power plant. Estun and Inovance are now both partly sourcing their FPGA and IGBT from Chinese companies.

The intention to localize is clear, but what about ability? To answer this question, we compare: (1) specs of key chips for industrial robots relative to other applications; and (2) the level of Chinese technology relative to required specs. We focus on processors (CPU, MCU, DSP, Fand PGA), analog/digital conversion (ADC/DAC), power semiconductors (IGBT), and Wi-Fi.

We find, in short, that if Chinese robot makers are denied access to US chips, the impact would be meaningful but far from fatal. Chinese robot makers can not only survive, but also largely retain their current level of robot performance by switching to domestic and regional chip suppliers. The key reason is that for robots, the specs of critical chips are orders of magnitude lower than, and generations behind, today's cutting edge. Among these chips, DSP has the highest risk, followed by CPU. For Wi-Fi, China does not have capable domestic suppliers, but MediaTek, Realtek (not covered), etc., are non-US suppliers that Chinese robot makers can work with. In perspective, the impact to robotics would be far smaller than that for telecom, smartphone, and industrial machine vision, and similar to that for video surveillance.

While there isn't an existential risk, there are uncertainties associated with consistency and long-term stability if Chinese robot makers switch to domestic chip suppliers. They would also need to redesign their robots. This takes time and is why many of them have chosen to start chip localization now.

For a CPU/MCU, clock frequency is a speed indicator (see Exhibit 122),[41] measuring how many cycles a processor can calculate per second. Applications such as PCs and smartphones require high-speed processing, and CPU clock frequency is typically 1-5GHz. Industrial applications generally require much lower processing speed but much higher reliability. For an industrial robot, the typical CPU clock frequency is 80-120MHz. This speed was first achieved in the mid-1990s (see Exhibit 123) and today Chinese products can meet this requirement.

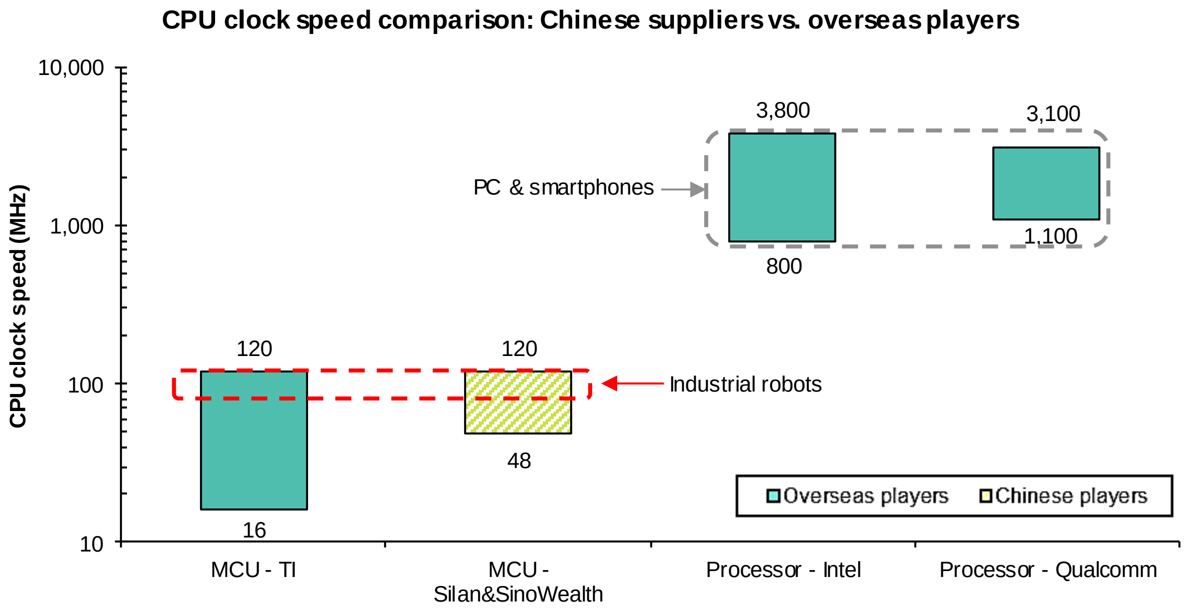
For DSP, the technology gap between Chinese and overseas suppliers is much more meaningful (see Exhibit 124). Although the speed spec for robotic applications (100-900MIPS) is meaningfully below that for smart cameras and machine vision, Chinese products barely reach the lower boundary. By comparison, Texas Instruments DSP chips are up to 9,000MIPS.

For FPGA, a LookUp Table (LUT) stores a predefined list of outputs for every combination of inputs, and the number of LUTs is a measure of FPGA performance. FPGAs used in industrial robots typically have 10,000-130,000 LUTs, compared to 100,000-1,000,000 LUTs for networking and machine vision, and up to 6,000,000 LUTs for 5G baseband and datacenter. There is a similar gap in node process: robotic FPGAs are usually produced with 28-55nm technologies, while the cutting edge is below 7nm. Chinese technology, although meaningfully behind industry leaders such as Xilinx, is largely adequate for industrial robots

[41] Because Exhibit 122 to Exhibit 128 are in logarithmic scale, in many cases the spec differences are more profound than they appear.

(see Exhibit 125). Inovance and Estun have both started to use domestic FPGAs in their servo drives.

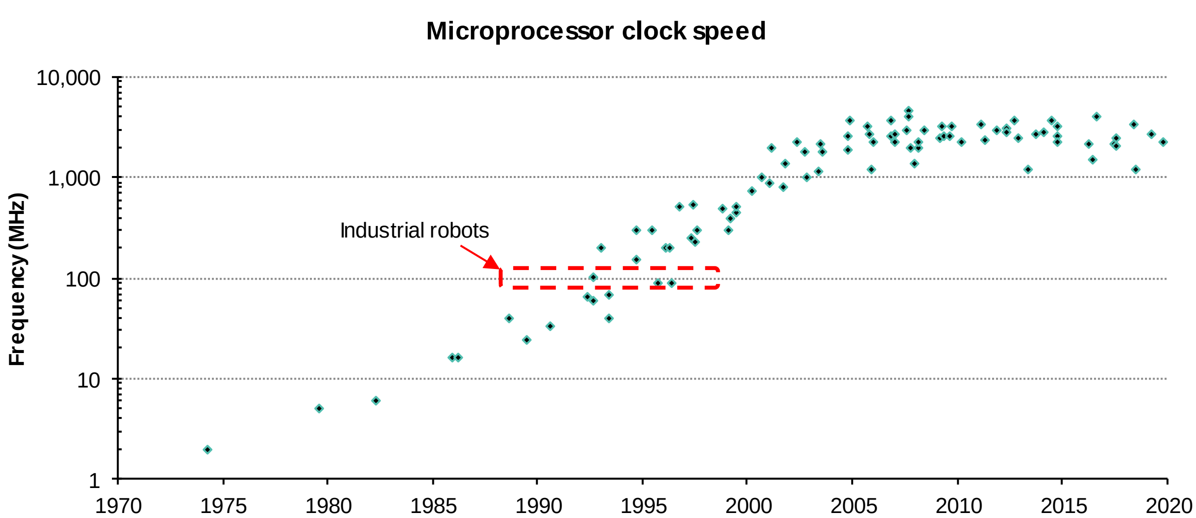
EXHIBIT 122: **CPU/MCU — specs for industrial robots and other applications, and where Chinese technology stands**



Note: Chinese MCU suppliers — Silan and SinoWealth

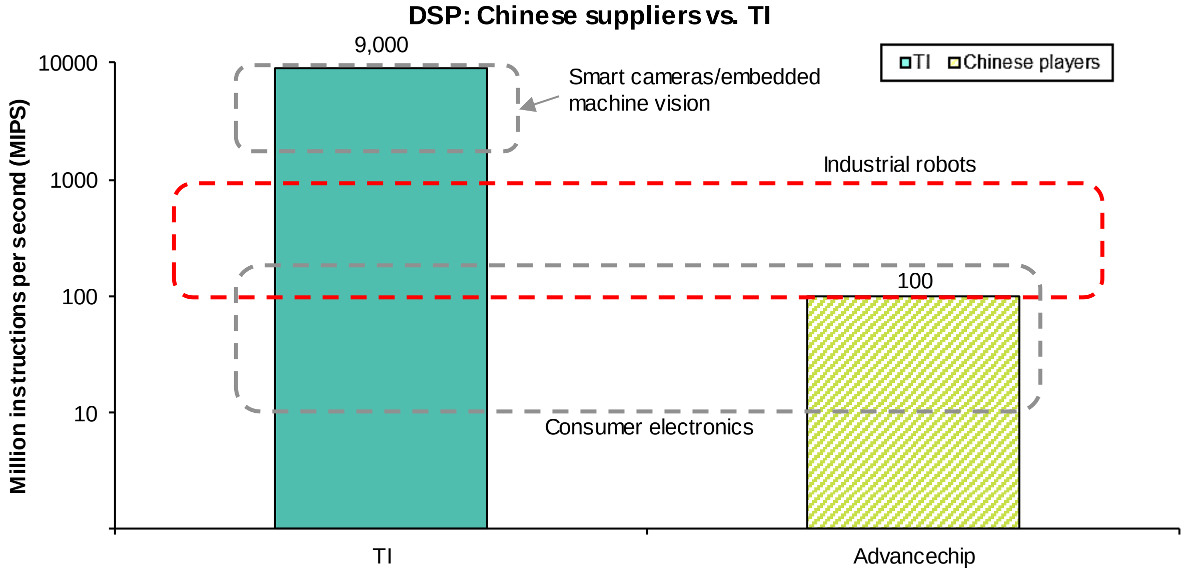
Source: Texas Instruments, Intel, Qualcomm, Silan, SinoWealth, and Bernstein analysis

EXHIBIT 123: **In terms of clock speed, processors for industrial robots use technologies introduced in the mid-1990s**



Source: K. Rupp, GitHub, and Bernstein analysis

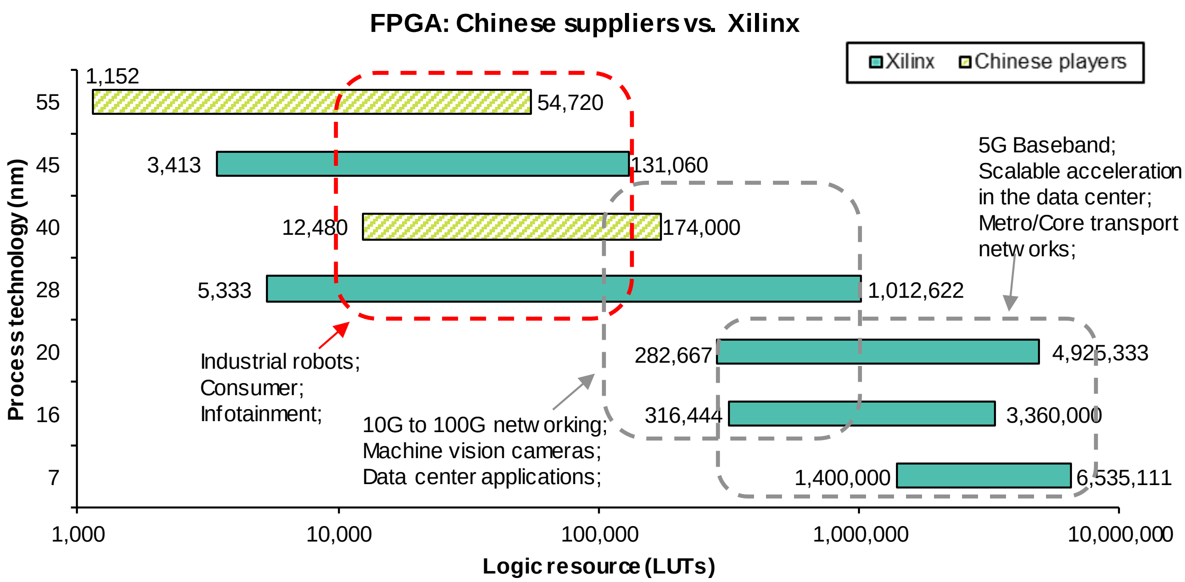
EXHIBIT 124: **DSP — specs for industrial robot and other applications, and where Chinese technology stands**



Note: Chinese DSP supplier — Advancechip

Source: Texas Instruments, Advancechip, and Bernstein analysis

EXHIBIT 125: **FPGA — specs for industrial robot and other applications, and where Chinese technology stands**



Note: Chinese FPGA suppliers — PangoMicro and GOWIN

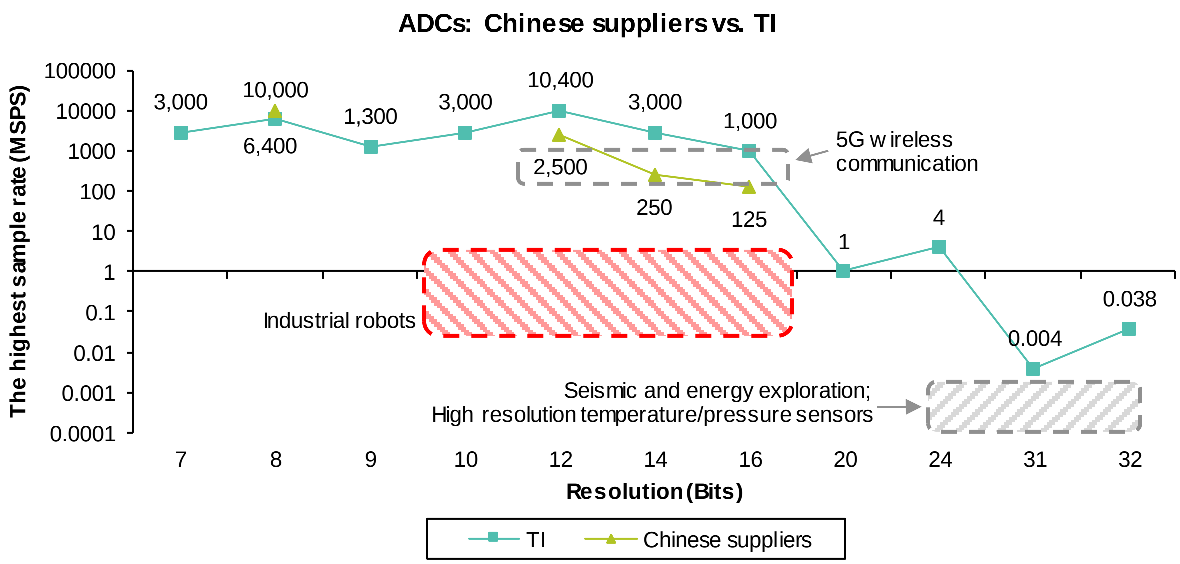
Source: Xilinx, PangoMicro, GOWIN, and Bernstein analysis

For connectivity, after the ban on Huawei, and specifically the semiconductor division HiSilicon, there is no alternative good Wi-Fi Chinese chip supplier. Fortunately, MediaTek and Realtek have Wi-Fi products. Because their products contain little US content, they will be able to legally supply these chips to Chinese robot makers when a sanction makes US Wi-Fi chips inaccessible. This is why broadly some non-US companies will benefit as it takes time for China to develop a domestic semiconductor supply chain for a wide variety of chips, and in the process these non-US suppliers can supply equivalent products to Chinese system companies if US chips become unavailable because of the US-China tech war.

For Analog-to-Digital converter (ADC) and Digital-to-Analog converter (DAC) chips, Chinese technology has exceeded the requirements for industrial robots, although still below the requirements for high-speed applications such as 5G communication, or high-resolution (18~32 bits) applications such as precision instrument, semiconductor test, and seismic and energy exploration (see Exhibit 126 and Exhibit 127).

For IGBT modules (see Exhibit 128), the industry leader, Infineon, offers the broadest choices and best performance, but Chinese products have also become adequate for applications such as industrial robots and servo motors.

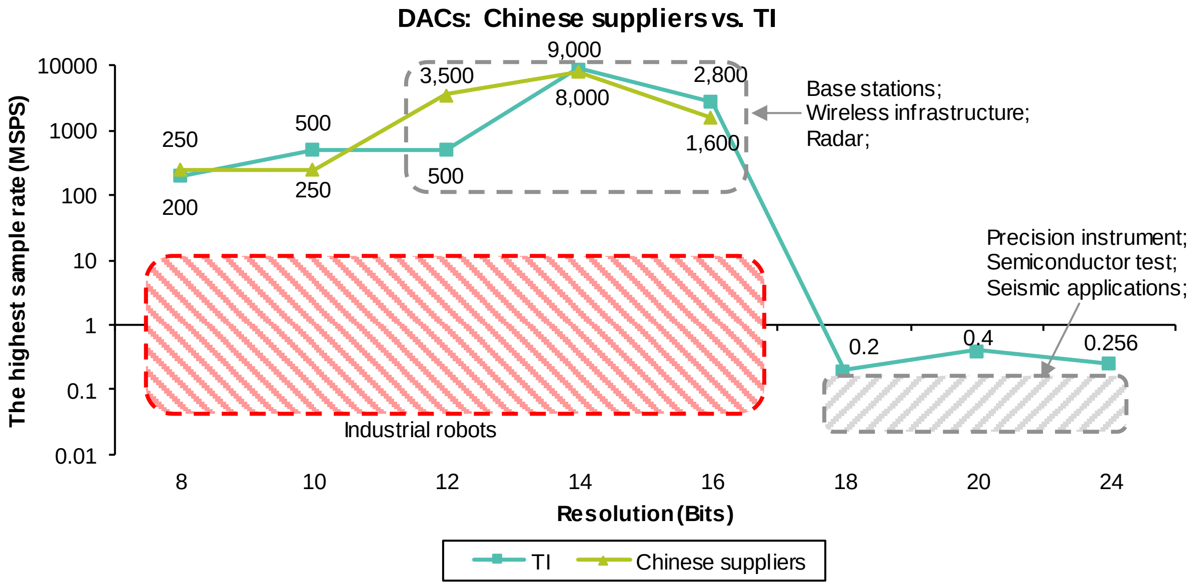
EXHIBIT 126: **ADC — specs for industrial robot and other applications, and where Chinese technology stands**



Note: MSPS — millions of samples per second; Chinese ADC suppliers — YunChip and AcelaMicro

Source: Texas Instruments and Bernstein analysis

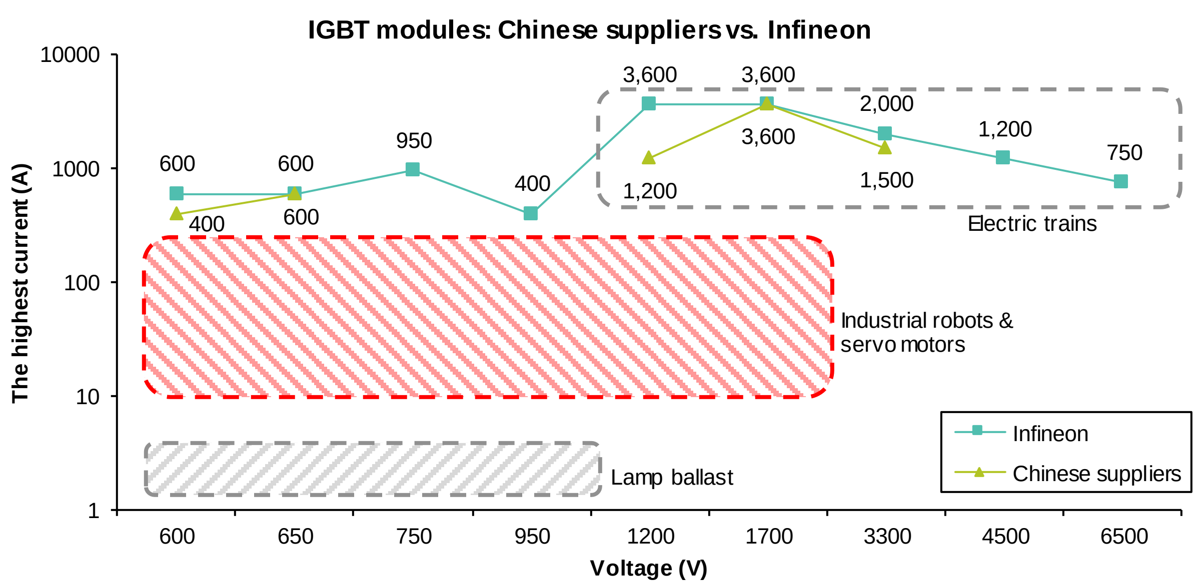
EXHIBIT 127: **DAC — specs for industrial robot and other applications, and where Chinese technology stands**



Note: MSPS — millions of samples per second; Chinese DAC suppliers — YunChip and AcelaMicro

Source: Texas Instruments and Bernstein analysis

EXHIBIT 128: **IGBT — specs for industrial robot and other applications, and where Chinese technology stands**



Note: Chinese IGBT suppliers — Starpower and Yangjie

Source: Infineon, Starpower, Yangjie, and Bernstein analysis

ESTUN: THE CHINESE ROBOTICS LOCAL CHAMPION

Look not only for local substitution but also for local consolidation. Estun is such a local champion in the Chinese industrial robot space. Already the domestic leader, its share can continue to increase from ~5% share in 2021 to 10% in 2025 and15% in 2030.

Estun's competitive advantage is a virtuous loop of: (1) relentless focus on robotic design, control, and components technology, rather than system integration; (2) careful choice of battlefields to develop deep domain expertise, then replicate; (3); synergic portfolio across robotics, motion, and industrial control to become the preferred partner to integrators; and (4) well-executed acquisitions of synergic technologies to strengthen the other three factors. The Cloos acquisition significantly expanded Estun's TAM in robotic welding and allowed its share gain to accelerate.

COMPANY INTRODUCTION

Having entered the industry in 2012, Estun is now a leading industrial robot player in China. Its development path (see Exhibit 132) was most similar to FANUC: starting from CNC and servo motor/drive, then building an industrial robot business from its expertise in motion and control.

The company's robot segment and automation components segment accounted for ~67% and ~33%, respectively, of its RMB2.5bn revenue in 2020 (see Exhibit 129 and Exhibit 131). They form the "dual cores" of Estun's growth strategy:

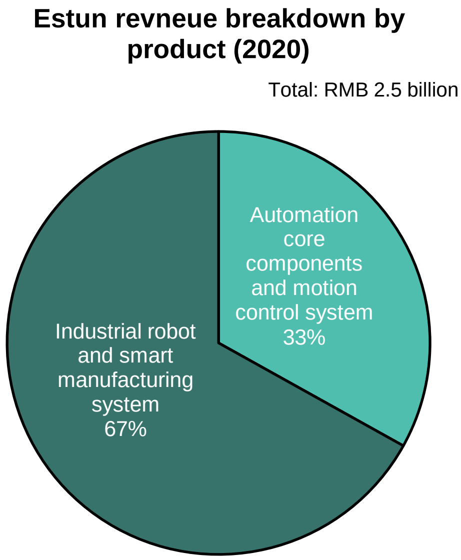
- **Automation core components and motion control system segment** is similar to FANUC's FA segment. Its main products are CNCs and servo systems (motors and drives), including CNCs for metal forming machine tools, electro-hydraulic servo systems, electric servo press and servo turret punch automation solutions, motion controllers and AC servo systems, robot controllers, robot servo systems, and robot machine vision products.

- **Industrial robot and smart manufacturing system segment** includes industrial robots and robot system integration. Estun and Cloos carries about 55 six-axis robot models and more than 20 standard robot cells.

Estun's overseas revenue increased from 4% in 2016 to 45% in 2020 (see Exhibit 130), with a number of overseas acquisitions including Euclid Labs (Italy), Trio (UK), Barrett (US), and M.A.I. (Germany). In 2020, Cloos (Germany) began to be consolidated (see Exhibit 133).

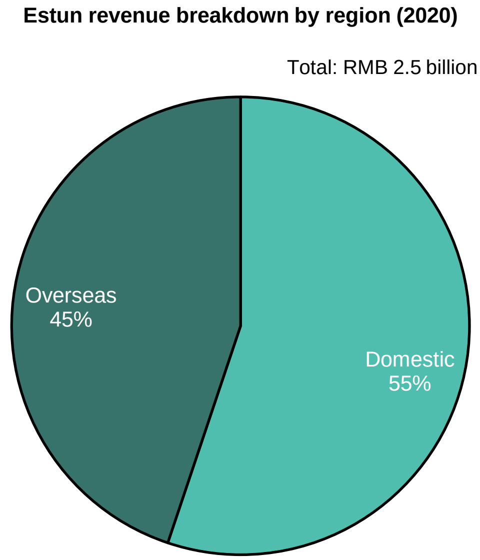
Estun was founded by Mr. Bo WU in 1993 and Estun's top team, Wu and the heads of the two segments, are technology savvy, with a deep engineering background. In 2020, Estun had 2,507 employees, 30% of whom were technical staff (see Exhibit 134).

EXHIBIT 129: **Estun revenue breakdown by business**



Source: Company reports and Bernstein analysis

EXHIBIT 130: **Estun revenue by region**



Source: Company reports and Bernstein analysis

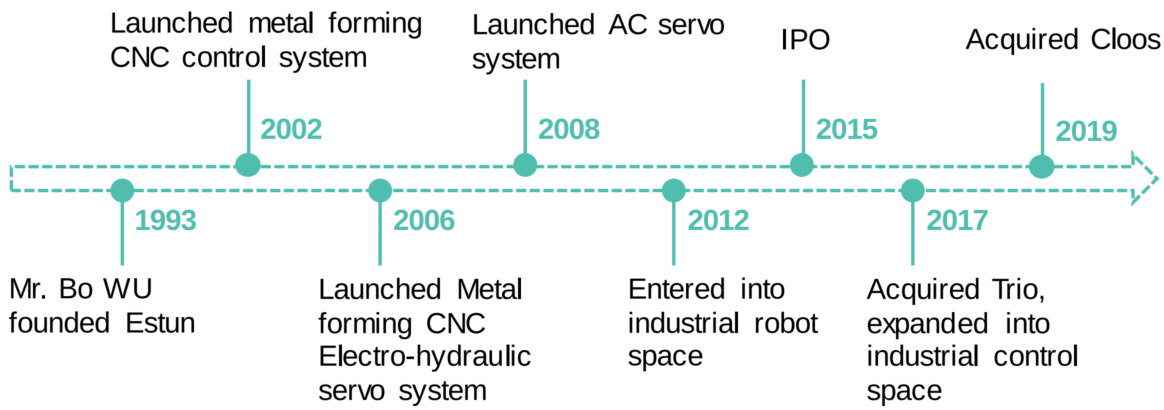
EXHIBIT 131: **Estun's product segments and key competitors**

Segment	Product	EM competitors	DM competitors
Automation core components and motion control system	Metal forming CNC control system	Nanjing Zeron ("南京泽荣"), Yangzhou DUCH ("大祺")	FANUC, ESA, Cybelec
	Electro-hydraulic servo system	Inovance, Modrol Electric, KEB	Voith, Hoerbiger, Atos
	AC servo system and other components	Inovance, INVT ("英威腾")	Panasonic, Yaskawa, Bosch Rexroth, Mitsubishi, Delta, Teco
Industrial robot and smart manufacturing system	Industrial robot and robot system integration	Shanghai Step, Siasun, Efort	FANUC, ABB, KUKA, Yaskawa, Epson, Yamaha, Denso
Cloos	Welding robots and welding power sources	CRP ("卡诺普"), Efort, Megmeet	ABB, KUKA, Yaskawa, Panasonic, Daihen (OTC), Lincoln Electric, ESAB, Fronius

Note: Cloos is shown separately here for explanation purposes. It is consolidated and reported in the first two segments; besides Estun, we cover FANUC and Inovance, the rest are not covered by Bernstein.

Source: Company reports and Bernstein analysis

EXHIBIT 132: **Estun started in metal forming CNC, and then expanded into servo and robotics**



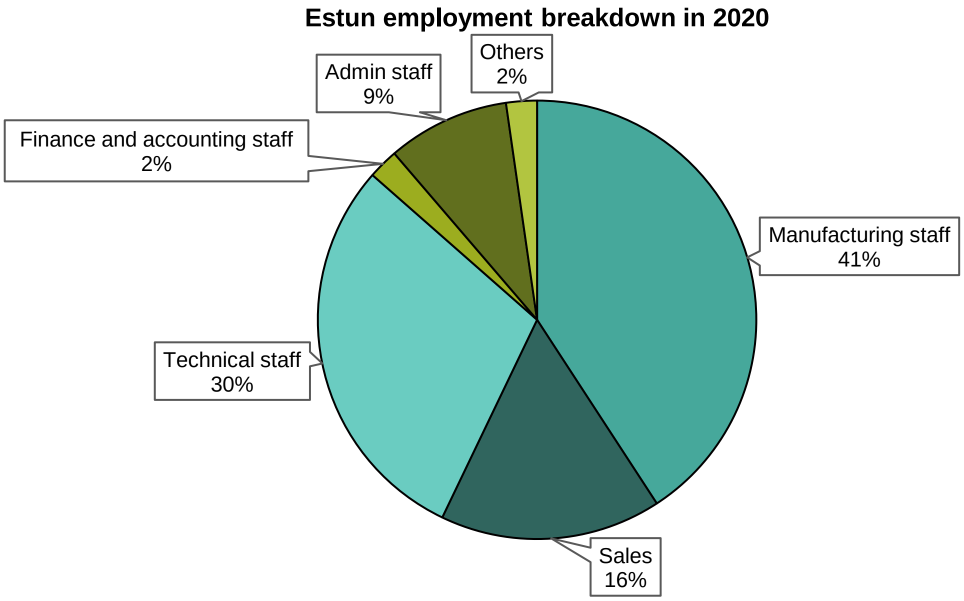
Source: Company reports and Bernstein analysis

EXHIBIT 133: **Estun's subsidiaries and important associates and JVs**

Entity name	Estun's share	Business scope	Note
Euclid Labs	20%	Bin picking software, 3D vision applications for robots	Investment into Italian company
Euclid Labs (Nanjing) (埃克里得)	60%	Bin picking software, 3D vision applications for robots	Newly setup entity in China after investment in Euclid Labs
Shanghai Prex	100%	Manufacturing peripheral automation equipment for die-casting machines	Acquisition of Chinese company
Fengyuan Automation	100%	Design, development and manufacturing of automation equipment for automotive, appliances, etc.	Acquisition of Chinese company
Trio	100%	Industrial control: Motion controller, robot controller, HMI, etc.	Acquisition of UK company
Barrett	30%	Medical robot	Investment into US company
Estun Medical Technology (Nanjing) Co. Ltd	20%	Medical robot	Newly setup entity in China after investment in Barrett
M.A.I	50%	Robot integration for verticals including auto engines, semiconductors, aerospace components and medical equipment	Acquisition of German company
Yangzhou Dawn	68%	Laser machine equipment, CNC, AC servo system, etc.	Acquisition of Chinese company
Cloos	89%	Robotic welding	Acquisition of German company
Carl Cloos Robotic Technology (Nanjing) Co. Ltd 卡尔克鲁斯机器人科技（南京）有限公司	100%	Robotic welding	Newly setup entity in China after acquiring Cloos
南信科技	90%	Development of robot, intelligent system technology, software	Direct setup
南京鼎通	100%	Development and production of mechatronics products, automation control products and systems, robots, intelligent equipment and computer application software	Direct setup
航鼎智能	51%	Development of robotics technology in aerospace	Direct setup
南京鼎控	100%	Development of mechanical and electrical products	Acquisition
松乐智能装备（深圳）有限公司	22%	Painting robot	Investment into Chinese company

Source: Company reports and Bernstein analysis

EXHIBIT 134: **30% of Estun employees are technical staff (mostly R&D)**



Source: Company reports and Bernstein analysis

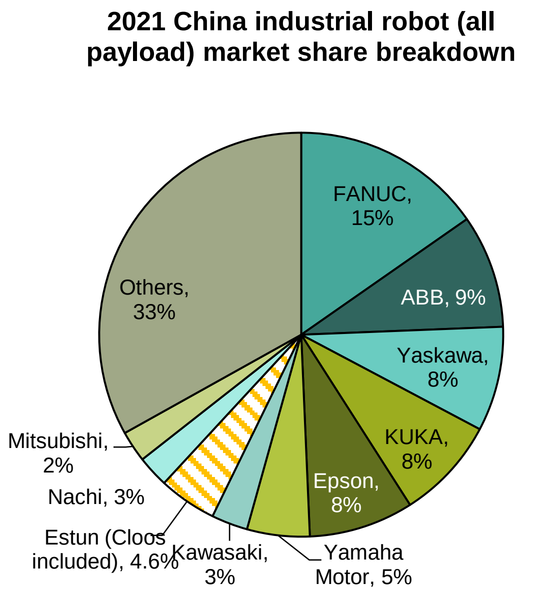
TO DOUBLE AND TRIPLE ROBOT MARKET SHARE IN CHINA

By volume share, Estun ranks #7 in the Chinese robotic market, but is already the #1 local robot maker (see Exhibit 135). Our Estun thesis is that it has a clear path to 10%+ market share in 2025 and 15% in 2030, up from 5% in 2021.

While investors very much focus on the "local substitution" story, we think Estun's journey to 10%+ share is as much about replacing foreign brands as consolidating shares from local peers. The latter is an easier path and a more convincing story already unfolding; the former is accelerated by the Cloos acquisition. In the last four years, Chinese companies' collective share only modestly increased (see Exhibit 137), while Estun's share gain was the fastest across all key segments (see Exhibit 138 to Exhibit 142). Meanwhile, the global robot leader, FANUC, moderately grew its share in China (see Exhibit 143).

We recognize there is still a substantial technology gap vs. the Big 4, and it is unrealistic to assume the gap will fully close. Fortunately, what supports the "local consolidator" story is not a fully closed gap vs. the global Big 4, but an expanding technology edge against local peers. As Estun's edge expands, a clear price ladder has formed, and Estun is enjoying price advantage and good margins. Our primary goal is to explain how this technology edge formed and evolves.

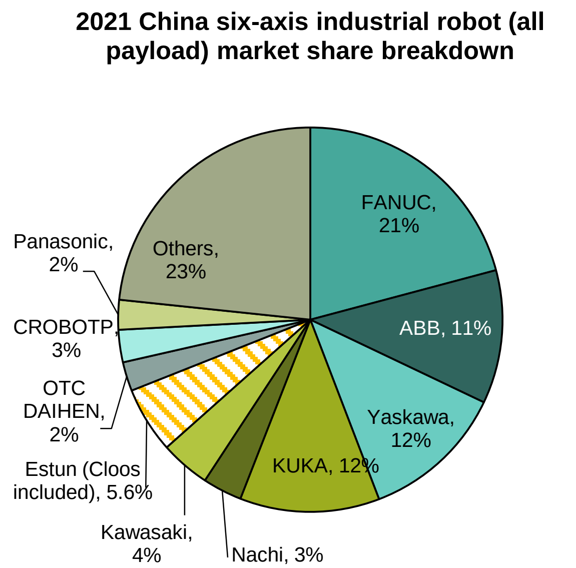
EXHIBIT 135: **Estun is the only local company within the top 10 robot players in China...**



Note: Cloos China is included in Estun in the exhibit.

Source: MIR Databank and Bernstein analysis

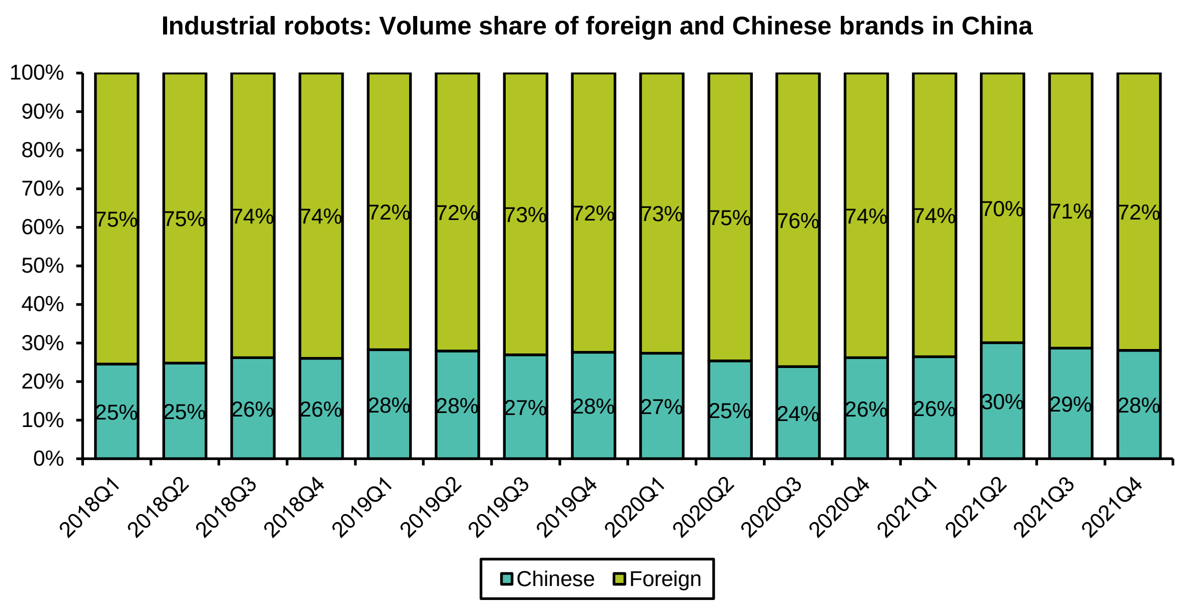
EXHIBIT 136: **...and also the #1 local player in six-axis industrial robots**



Note: Cloos China is included in Estun in the exhibit.

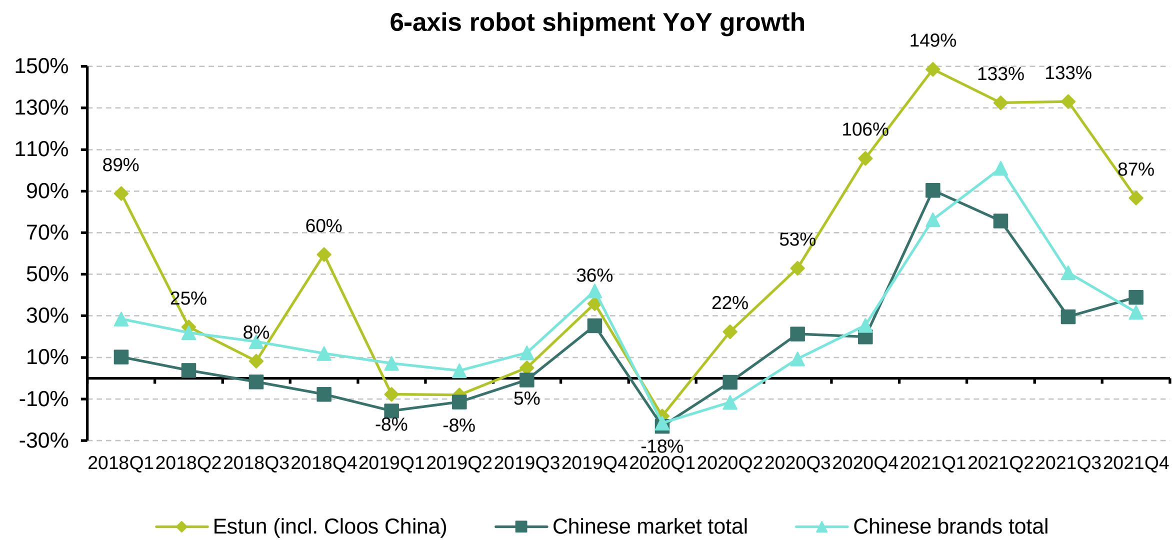
Source: MIR Databank and Bernstein analysis

EXHIBIT 137: **Chinese robot brands' collective share has only increased modestly since 2018**



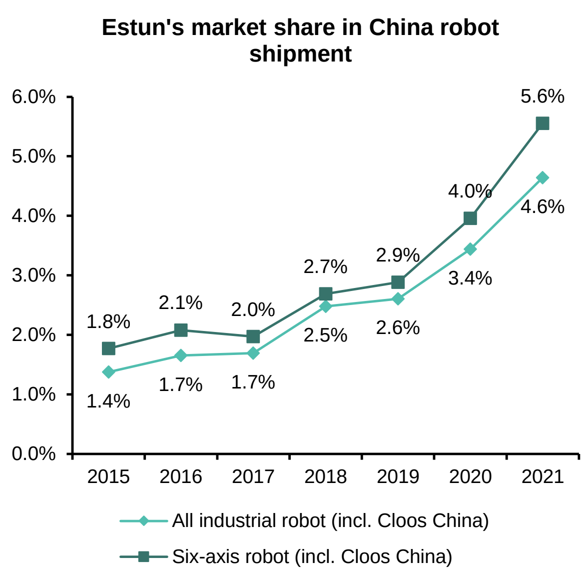
Source: MIR databank and Bernstein analysis

EXHIBIT 138: **Estun's six-axis robot shipment has consistently outgrown the market and Chinese brands overall**



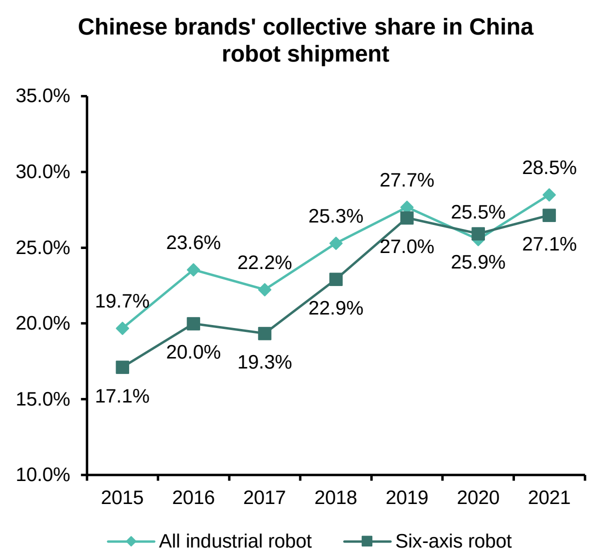
Source: MIR Databank and Bernstein analysis

EXHIBIT 139: **Estun's share gain accelerated in 2021**



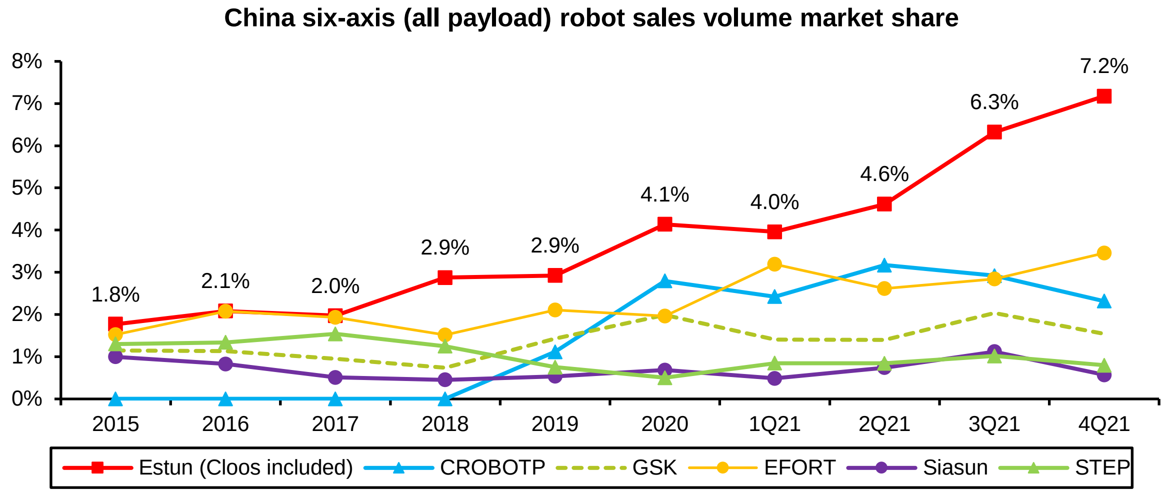
Source: MIR Databank and Bernstein analysis

EXHIBIT 140: **Chinese brands' collective share remained flat in the last three years**



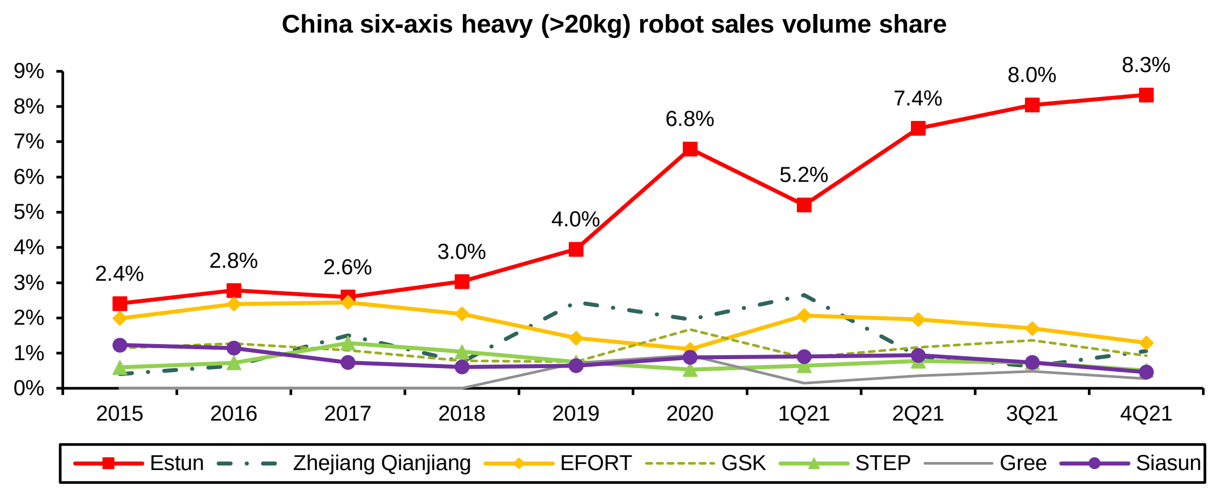
Source: MIR Databank and Bernstein analysis

EXHIBIT 141: **Estun's market share in six-axis robots keeps increasing**



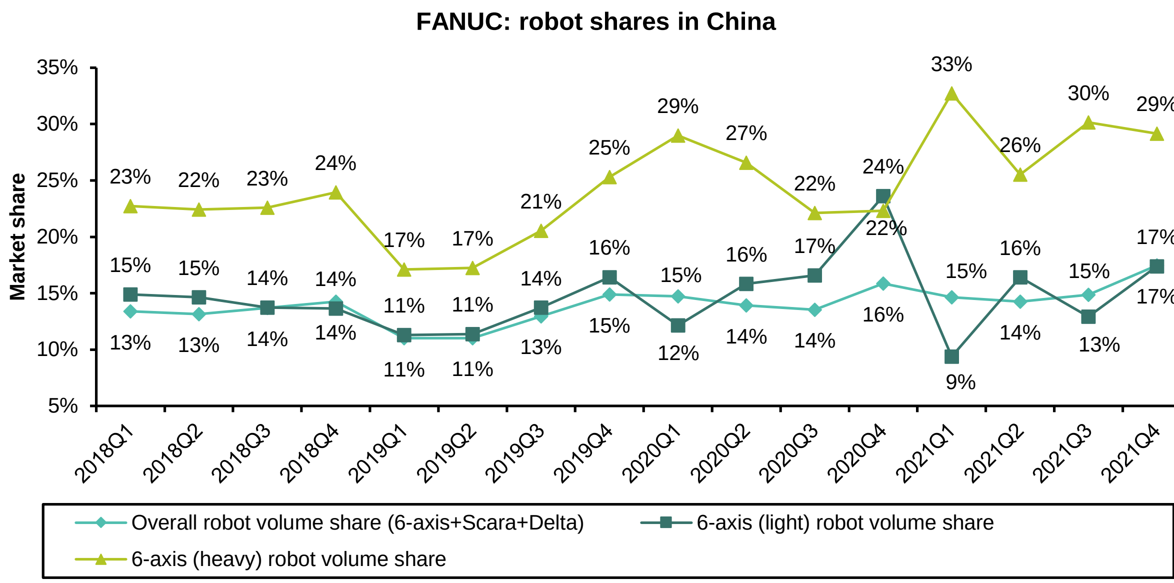
Source: MIR Databank and Bernstein analysis

EXHIBIT 142: **Estun's share gain is the most prominent in heavy six-axis robots; proof of the company's technical strength vs. local peers**



Source: MIR Databank and Bernstein analysis

EXHIBIT 143: **FANUC's robot market share in China increased between 2018 and 2021**



Source: MIR Databank and Bernstein analysis

Best technology and strongest portfolio among Chinese robot makers

Estun's robot portfolio is the broadest in China in terms of number of SKUs and payload coverage (significantly broader than Efort, STEP, and CROBOTP, similar to Siasun). Its portfolio shows a clear focus on sophisticated six-axis articulated robots, rather than relatively simpler SCARA robots (see Exhibit 144).

EXHIBIT 144: **Estun has the most comprehensive portfolio of articulated robots among Chinese companies**

Robot Portfolio		Estun		Inovance	Siasun Robot	Efort	Step	CROBOTP	FANUC	ABB
		Estun China	Cloos							
Articulated (six-axis) robots	Models	38	17	6	27	15	10	7	77	58
	Payload range	6-500kg	4-15kg	3-20kg	4-500kg	3-210kg	3-200kg	6-20kg	4-2,300kg	3-800kg
Parallel robots	Models				6				16	5
	Payload range				3-15kg				0.5-12kg	1-8kg
SCARA robots	Models	10		21	3		14	1	5	5
	Payload range	3-50kg		3-50kg	5-10kg		3-20kg	3/6 kg	3-12kg	3-6kg
Others (cobots, etc.)	Models								12	10
	Payload range								4-45kg	0.5-13kg
Total	Models	48	17	27	36	15	24	8	110	78
	Payload range	3-500kg	4-15kg	3-50kg	4-500kg	3-210kg	3-200kg	3-20kg	0.5-2,300kg	0.5-800kg

Source: Company websites, company reports, and Bernstein analysis

A more profound difference between Estun and other Chinese robot companies is the former's focus on products and restraint participation in system integration. About 25% of Estun's robot segment is system integration in 2021, a ratio lower than most robot makers in China (see Exhibit 146) and globally except FANUC. System integration is an easier path to boost scale (see Exhibit 145). But when a company is carried away by integration, it loses focus on product technology. Behind Estun's choice is a clear goal and relentless effort to improve its robot design, key components, and control technologies.

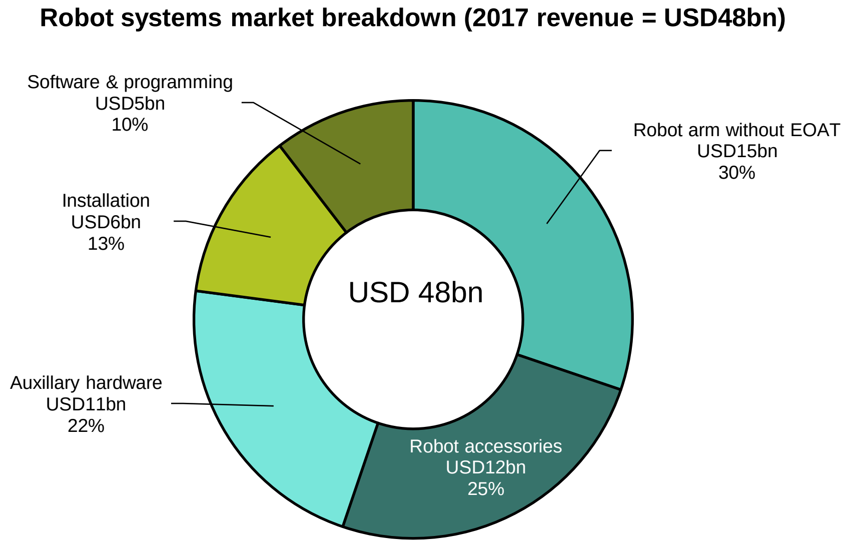
Following the FANUC model, Estun pursues an "All Made by Estun" strategy. It designs and produces most components in-house and only procures reducers externally. For small producers, vertical integration is usually not the most cost effective, as third-party component suppliers have significant scale advantage and are more mature in technology. Despite that, Estun management has decided that in-house components technology is critical for product innovation and long-term competitiveness. It has purposefully chosen the harder but more rewarding path for the long term.

The vertical integration ratio alone does not fully reflect Estun's technical strength. Almost all robot companies make the robot controller in-house. Yet, for this part of the robot, the real differentiator is the embedded control algorithm, not the controller box, and better control algorithm is in turn the result of deep hardware and application know-how, as discussed in the "Robotic Technology Deep Dive" section of this chapter. On the hardware side, when two robot companies are using exactly the same servo motors and reducers, there can nevertheless be substantial performance difference due to product design (e.g., how weight is distributed along the robot arm; how payload and speed of motors in each axis is optimized) and manufacturing recipe (e.g., how motors and reducers are assembled in each axis).

It is in these areas that years of R&D pay off. Estun robot performance is superior to local peers. This manifests directly in the company's fastest share gain in the technically most challenging heavy payload (>20kg) six-axis robot segment (see Exhibit 142). Comparing robot speed, FANUC is again the best. Among Chinese brands, Inovance and Estun are better than the rest (see Exhibit 147). Across the payload range, Estun robots usually have the best weight-to-payload ratio (see Exhibit 148 and Exhibit 149), which is evidence of better product design and control technology.

Besides product technologies, Estun has also developed deep process know-how in the areas it focuses on. Its software packages control robots and related equipment to achieve better performance, higher efficiency, and unlock advanced functions.

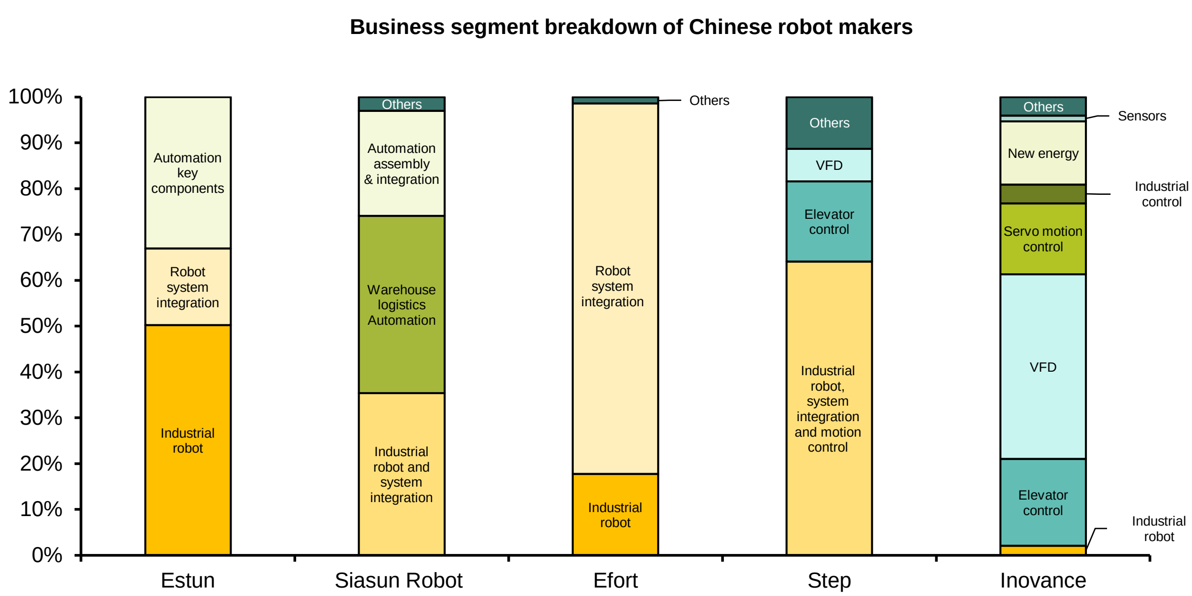
EXHIBIT 145: **Robot is ~30% of the total robotic integration market**



Note: EOAT stands of End of Arm Tooling

Source: McKinsey, IFR World Robotics, and Bernstein analysis

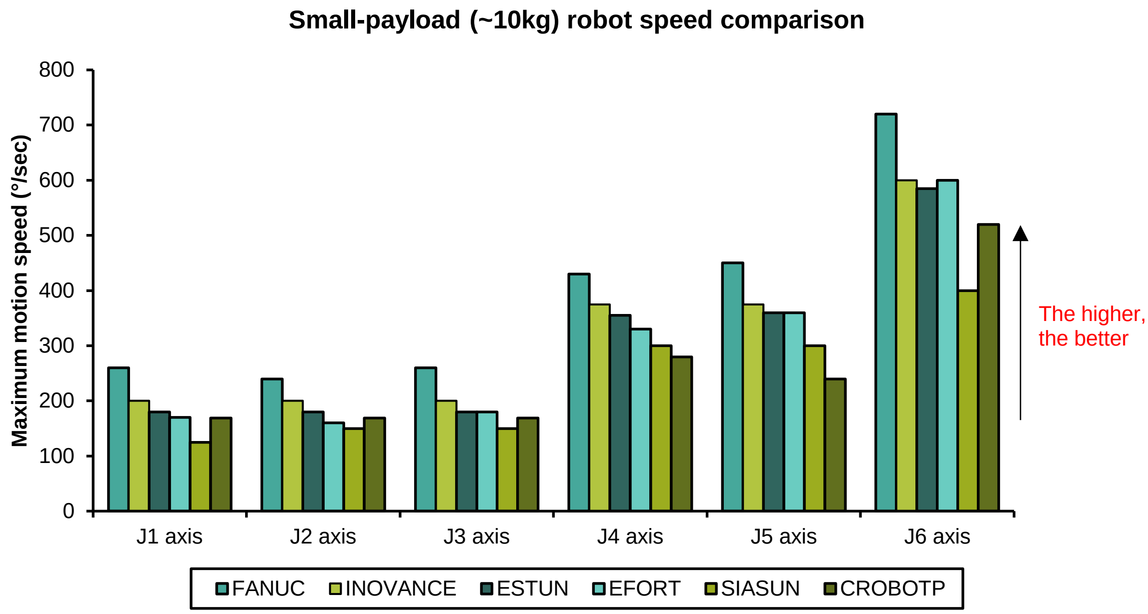
EXHIBIT 146: **Among major Chinese robot companies, Estun is the most focused on robot technology, instead of system integration**



Note: Inovance 2019 robot revenue is estimated based on its 1H20 robot revenue.

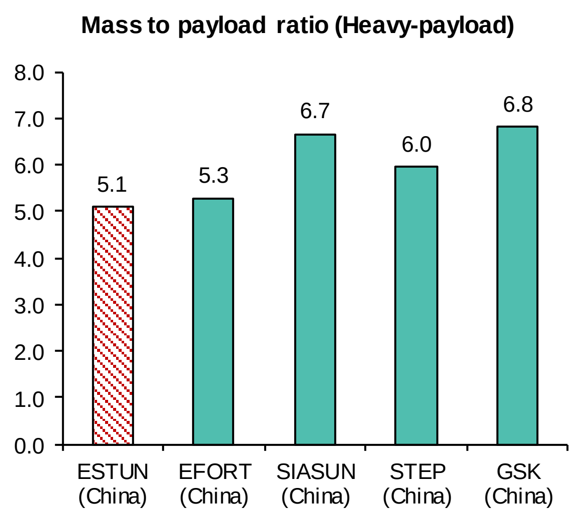
Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 147: **Robot speed comparison: FANUC is fastest; Estun and Inovance better than other Chinese brands**



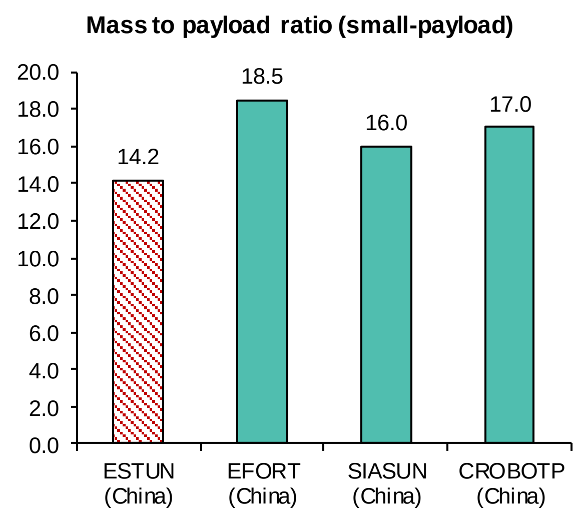
Source: Product datasheets and Bernstein analysis

EXHIBIT 148: **Estun robots are superior to other local brands in weight-to-payload ratio (heavy-payload robot)**



Source: Company websites and Bernstein analysis

EXHIBIT 149: **Estun robots are superior to other local brands in weight-to-payload ratio (small-payload robot)**



Source: Company websites and Bernstein analysis

Well-chosen battlefields, expanding TAM, Cloos

Many Chinese rising stars took a common path to success — they identified niche areas not dominated by industry leaders or packed by low-end competitors, went all in with R&D and sales/marketing, became the segment leader and saturated the opportunity in that niche, and moved on to replicate the success many times. By doing so, they are able to compete with deep domain expertise and differentiated products, instead of merely on lower price, even when they still lag the global leaders in overall technology level. Inovance, Hollysys, Hikvision, and Han's Laser have all chosen this path early on in their rise to the status of national champions.

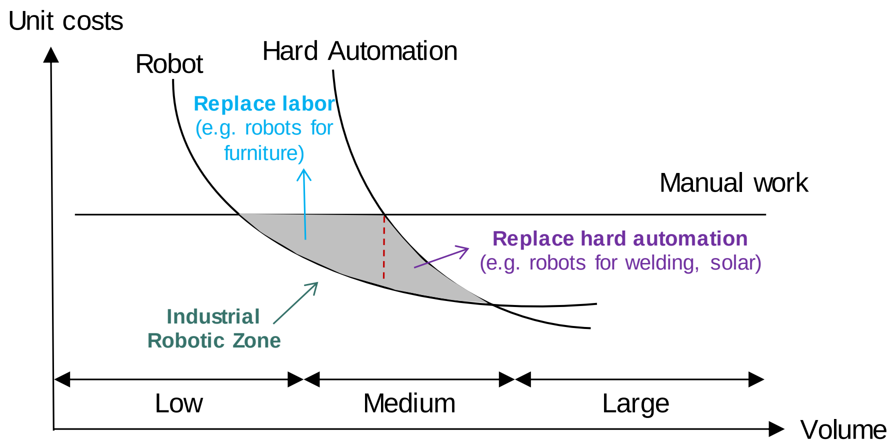
The most challenging step along this journey is achieving scalability. If a company's technology and products are too "general purposed," they would not be able to differentiate from incumbents and dominate the niche. If, on the other hand, they are too customized, their success would be confined to niches. It is this leap from tailored products to common underlying technology that makes the best companies stand out.

Estun is demonstrating this leap. The company initially focused on niche customer verticals such as solar panel and furniture production, where no robotic solutions were readily available. Estun developed innovative solutions and robots with optimized specs and dominated those niches. For example, Estun's robotic assembly cells (see Exhibit 151) continue to replace traditional panel assembly machines (see Exhibit 152). The robotic approach not only increases assembly speed from 16s/string to 6s/string, but also improves process flexibility to better handle panels of different sizes. This is one example where robots are primarily replacing other machines, instead of labor. Estun's focus areas address both opportunities (see Exhibit 150).

The company has recently expanded its focus to cover robotic applications in electronics, battery, metal processing, rehabilitation, etc., and met considerable success (see Exhibit 155). Estun, recognizing the technical and branding barriers, stated that in the near term it does not intend to compete head-to-head with the Big 4 for automotive OEM customers. That segment is only 7% of all robot shipment in China (see Exhibit 153), or 31% for heavy load (>20kg) six-axis robots (see Exhibit 154). We think Estun can afford to not enter that segment but still achieve 10%+ overall market share in China.

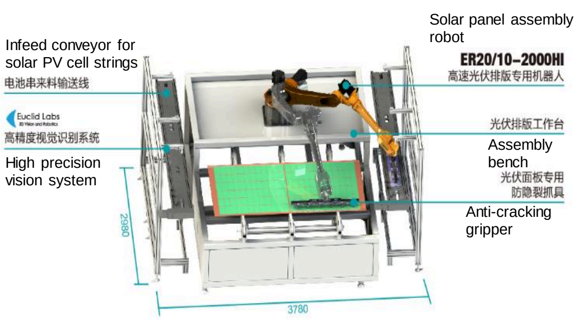
Estun's robot portfolio is balanced with general-purpose products and industry/application-specialized products (see Exhibit 156). This ties to the point discussed earlier — by focusing on robotic design, control, and components technology instead of system integration, Estun was able to grasp important common technologies and leverage its know-how beyond the initial niches. This is an important reason for us to believe that it can become a local consolidator. We think the balance between common technology and application-optimized products will increasingly prove Estun's competitive strength going forward.

EXHIBIT 150: **Industrial robots replace manual work and other machines; Estun's chosen areas of focus address both opportunities**



Source: https://www.researchgate.net/publication/285951267_Robotic_Welding_Technology and Bernstein analysis

EXHIBIT 151: **Estun solar panel assembly workstation**

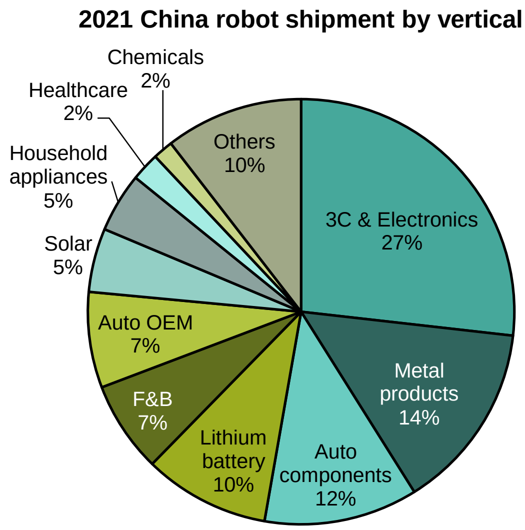


Source: Company website and Bernstein analysis

EXHIBIT 152: **Traditional solar panel assembly machine**

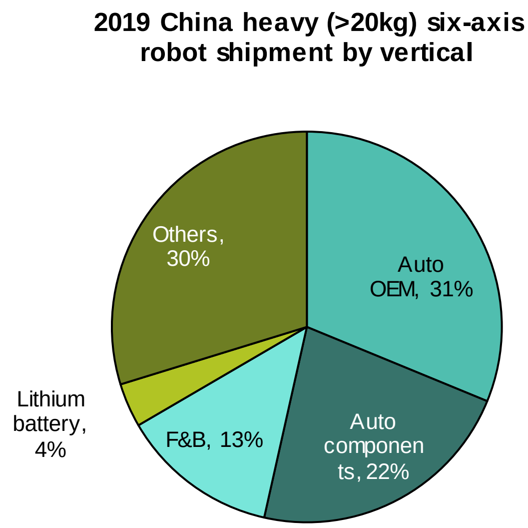
Source: Wikimedia and Bernstein analysis

EXHIBIT 153: **In China, automotive OEMs only account for a small part of overall robot demand**



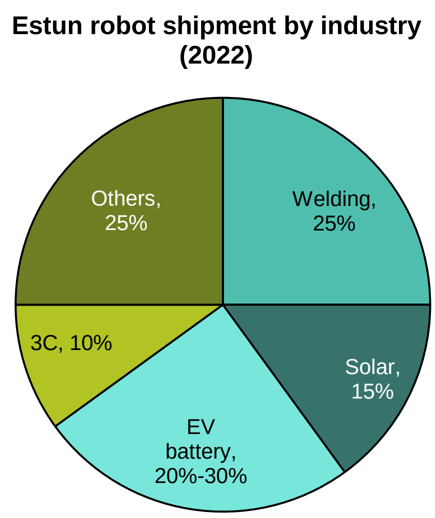
Source: MIR Databank and Bernstein analysis

EXHIBIT 154: **Even for heavy six-axis robots, auto OEMs only account for 31% of shipment**



Source: MIR Databank and Bernstein analysis

EXHIBIT 155: **Estun's focus started with solar and furniture, but expanded to other critical verticals and general manufacturing**



Source: Company presentation, and Bernstein estimates and analysis

EXHIBIT 156: **Estun's robot portfolio shows good balance between general-purpose and customized SKUs**

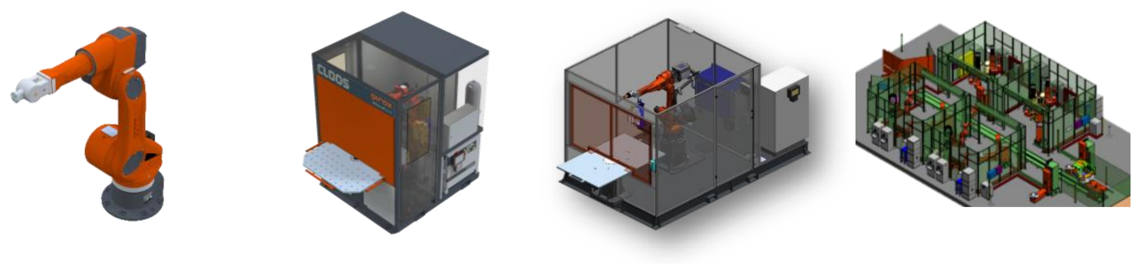
Category	Payload range	Model	Type	Payload	Max working radius	Positon repeat accuracy	Industry applications	Functions
Articulated	>=20kg	ER500-2800	6-axis	500kg	2800mm	±0.2mm		
		ER500-2850-5	5-axis	500kg	2800mm	±0.3mm		
		ER350-3300	6-axis	350kg	3300mm	±0.3mm		
		ER350-3300-5	5-axis	350kg	3300mm	±0.3mm		
		ER220-2650	6-axis	220kg	2650mm	±0.2mm		
		ER180-3100-PL	4-axis	180kg	3060mm	±0.2mm		Palletizing
		ER170-2650	6-axis	170kg	2650mm	±0.2mm		
		ER130-2865-BD	6-axis	130kg	2865mm	±0.2mm		Bending
		ER120-2400-PL	4-axis	120kg	2400mm	±0.2mm		Palletizing
		ER100-3000	6-axis	100kg	3000mm	±0.2mm		
		ER80-2565-BD	6-axis	80kg	2565mm	±0.2mm		Bending
		ER-60-2000-PL	4-axis	60kg	2000mm	±0.2mm		Palletizing
		ER50-2100	6-axis	50kg	2100mm	±0.15mm		
		ER50-2100F	6-axis	50kg	2100mm	±0.15mm	Metal forming	
		ER30-1880	6-axis	30kg	1880mm	±0.08mm		
		ER20-1780F	6-axis	20kg	1780mm	±0.06mm	Metal forming	
		ER20-1780	6-axis	20kg	1780mm	±0.06mm	Loading and unloading / gluing	
	<20kg	ER12-1510	6-axis	12kg	1510mm	±0.05mm	Wood riveting and auto parts gluing	
		ER12-1510-H5	5-axis	12kg	1510mm	±0.05mm	Wood drilling	
		ER20/10-2000-HI	6-axis	10kg	2000mm	±0.07mm	Solar	
		ER50B-2100	6-axis	10kg	2100mm	±0.08mm	Auto parts Loading and unloading	
		ER10-900-MI	6-axis	10kg	900mm	±0.05mm		
		ER10-900-MI/4	4-axis	10kg	900mm	±0.05mm	PCB loading/unloading	
		ER10-900-MI/3	3-axis	10kg	900mm	±0.05mm	PCB loading/unloading	
		ER6-1600	6-axis	6kg	1600mm	±0.08mm		Welding
		ER6-1450-H	6-axis	6kg	1450mm	±0.08mm		Welding
		ER6-730-MI	6-axis	6kg	730mm	±0.02mm		
SCARA	All	ER20-1000-SR	SCARA	20kg	1000mm	J1+J2: ±0.025mm J3: ±0.015mm J4: ±0.01°		
		ER20-800-SR	SCARA	20kg	800mm	J1+J2: ±0.025mm J3: ±0.015mm J4: ±0.01°		
		ER6-700-SR	SCARA	6kg	700mm	J1+J2: ±0.025mm J3: ±0.015mm J4: ±0.01°	Lithium battery handling	
		ER6-600-SR	SCARA	6kg	600mm	J1+J2: ±0.025mm J3: ±0.015mm J4: ±0.01°		
		ER6-500-SR	SCARA	6kg	500mm	J1+J2: ±0.025mm J3: ±0.015mm J4: ±0.01°	Lithium battery handling	
		ER3-400-SR	SCARA	3kg	400mm	J1+J2: ±0.02mm J3: ±0.015mm J4: ±0.01°		

Source: Company website and Bernstein analysis

Cloos is a technology leader in robotic welding. It began to develop welding robots in 1981. Cloos offerings include welding robots, welding power sources, welding guns, work piece positioning apparatus, software, and system solutions ranging from cells to complex lines (see Exhibit 157). Its welding power sources are under the "QINEO" brand and welding robots and related equipment are under the "QIROX" brand.

Estun's share gain was greatly expedited with its acquisition of Cloos. The robotic welding opportunity is very substantial and there are important synergies between the two companies. Welding accounts for over 20% of global robot shipment. Cloos' robotic technologies mainly address arc and laser welding. Arc welding alone was about 33,000 units globally in 2019, increasing at a ~7% CAGR since 2012. Laser welding is growing even faster. In China, arc welding robots were 13,500-14,000 units in 2019 and growing rapidly.

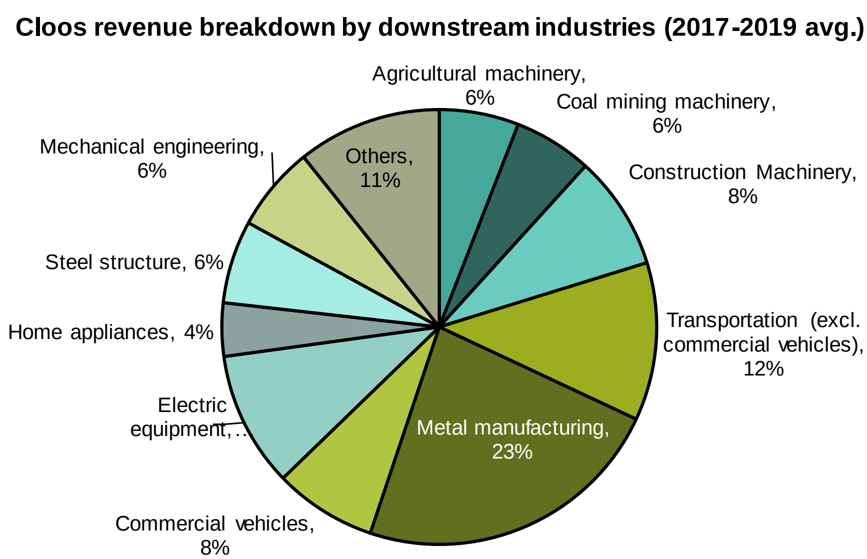
EXHIBIT 157: **Cloos offerings include welding robots, power sources, and system solutions ranging from welding cells to complex welding lines**



QRC-320/350/410
Classic wrist welding robot | Micro Cell MC-1.1 S / M | Compact Cell QR-CC-1.1 | Complex welding lines

Source: Cloos and Bernstein analysis

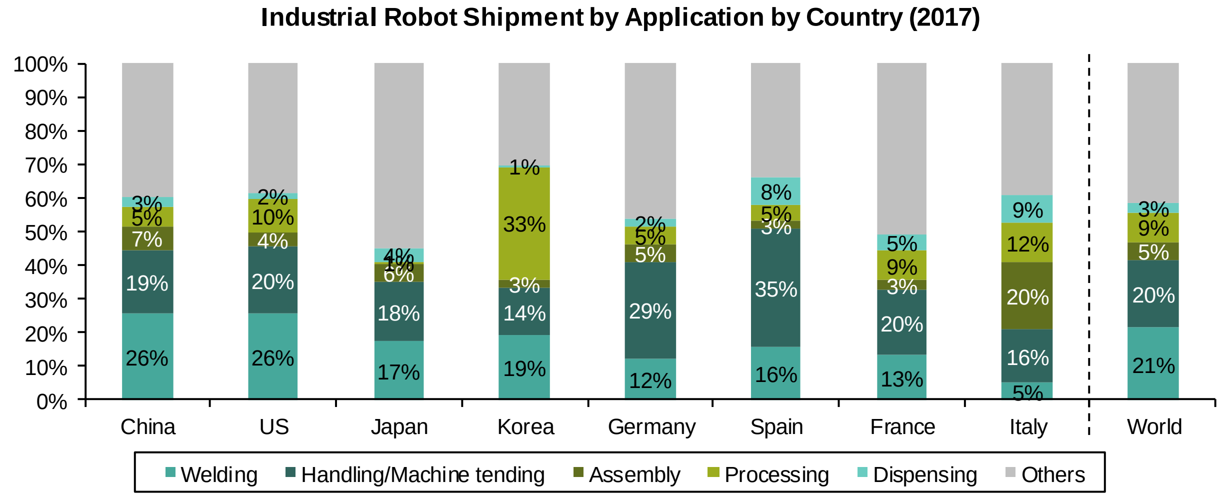
EXHIBIT 158: **Cloos revenue by downstream industry**



Note: We averaged industry breakdown revenue from January 2017 to October 2019 to calculate percentages.

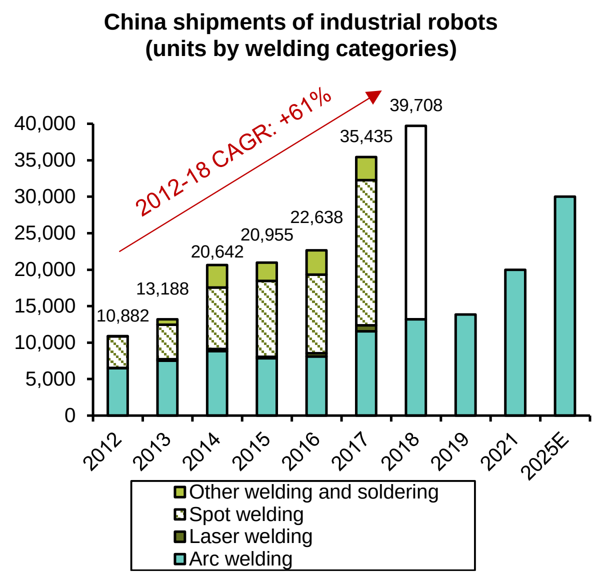
Source: Company reports and Bernstein analysis

EXHIBIT 159: **Welding is the largest robot segment by application**



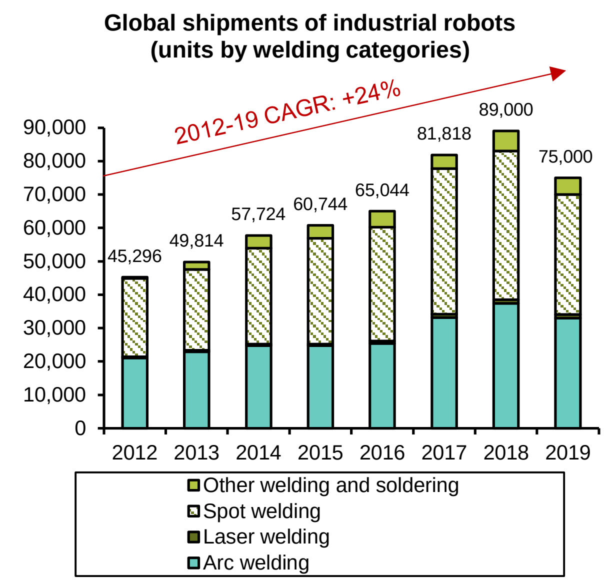
Source: IFR and Bernstein analysis

EXHIBIT 160: **China shipments of arc welding robots will likely reach 30k units in 2025**



Source: IFR, and Bernstein estimates and analysis

EXHIBIT 161: **Global shipments of arc and laser welding robots were about 34k units in 2019**



Source: IFR, and Bernstein estimates and analysis

Compared to spot welding, which is mainly used in automotive manufacturing, arc welding has far broader applications. A robotic arc welding system includes wire feeder, torch, welding power source, industrial robot, and work piece positioning apparatus. The welding power source is critical and one of the most differentiating elements of the entire system. It is through sophisticated modulation of voltage/current output that one develops innovative welding processes for different materials and achieves higher productivity and better quality. For example, to weld thin metal plates without distorting the pieces with excessive heat, Cloos developed a "Cold Weld" technique by precisely controlling the power source output to the curve shown in Exhibit 162.

Another important technology barrier in arc welding is the integrated control of the power curve, robot movement, wire feeding, and work piece positioning. The robot path needs to be not only accurate in space, but also perfectly synchronized to the critical points of the sophisticated power curve (see Exhibit 162). For this reason, many players in the arc welding market carry both welding robots and welding power sources. Others, such as FANUC and Lincoln Electric, closely cooperate to optimize programming interfaces and other specs in their respective products, in order to allow integrated control. Estun, however, has found it difficult to achieve good welding performance with third-party welding power sources, as they are designed to the specs of other major robot brands.

Cloos is the leading expert for arc welding. Its differentiation includes premium welding power sources, unique robots and piece positioning hardware, advanced robotic control and path planning technology (e.g., to allow multiple-robot collaboration and autonomous path correction), complete system know-how, and process expertise. It covers the broadest range of plate thickness from 0.3mm to 450mm and has the most strength in 0.3-0.8mm thin plate and >20mm thick plate, the two challenging ends. By contrast, most robot companies' welding capability is limited to 0.8-20mm (see Exhibit 163).

Before acquiring Cloos, Estun's welding robots were only for thin plate. We identify the following synergies between Estun and Cloos to capture additional opportunities in China and globally (see Exhibit 164):

- In thin plate welding (0.3-3mm), Estun integrates Cloos power sources (replacing generic third-party sources it currently uses) to enhance Estun's competitiveness in China against other robot makers (started in 1H20). In fact, CROBOTP, the other Chinese robot company that quickly gained share in six-axis robots (see Exhibit 141), focused on thin-plate welding, and we believe with Cloos power sources, Estun now has a much better opportunity here.

- In medium- and thick-plate welding (3-60mm), Estun and Cloos co-develop cost-competitive robotic solutions tailored for the China market. This would be based on Cloos technology but leverage Estun's lower cost.

- In ultra-thin-plate (<0.3mm) welding, the two companies co-develop innovative solutions to replace incumbents. These solutions may include arc and laser welding.

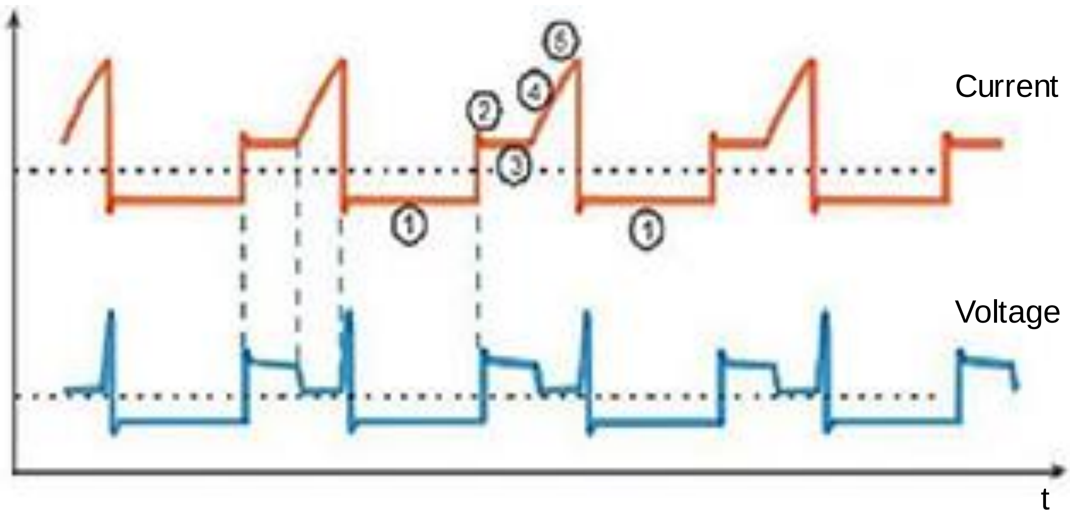
- In ultra-thick-plate (>60mm) welding, Estun cross-sells existing Cloos solutions to its customers and strategic investors in China.

- Robotic components, design, and control technology transfer from Cloos to Estun.

- Cloos cross-sells Estun robots in Europe for welding and non-welding applications. Cloos' customers are mainly machinery makers (e.g., agricultural, industrial, construction, and transportation machinery) (see Exhibit 158), for whom Estun's metal forming CNC, servo motor/drive, and robots for certain applications (e.g., machine tending and palletizing) are good enough in technology but lack an entry ticket. Cloos' broad distribution network and existing customer relations can be of great help (future potential).

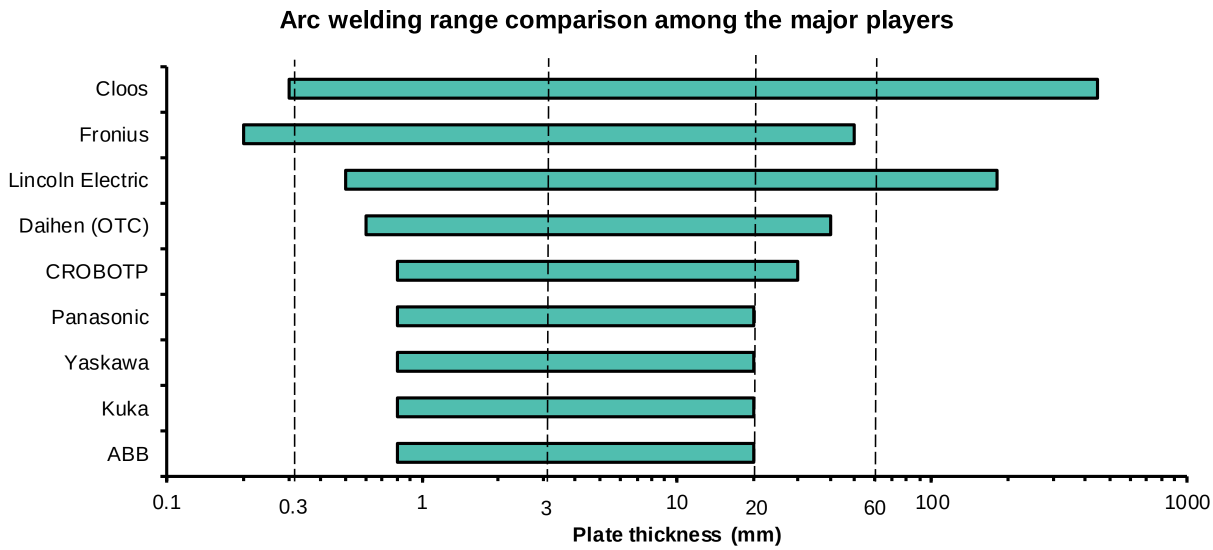
On October 26, 2021, Estun launched new welding robots and welding power sources, indicating a step forward of co-development between Estun and Cloos. In 2021, Estun and Cloos launched 12 models of welding robots (QWAS series and EWAS series) specially for the Chinese market (see Exhibit 165) and targeted to take share in thin- and medium-plate welding from leading foreign players (see Exhibit 167). New EWAS robots' performance has improved significantly vs. the previous series (see Exhibit 168).

EXHIBIT 162: **Complex voltage/current control by the welding power source is critical for arc welding performance and new processes (Cloos "Cold Weld" process example)**



Source: Cloos and Bernstein analysis

EXHIBIT 163: **Cloos welding technology covers broadest range of plate thickness; it's the strongest in thick plate (>20mm) welding**



Note: Assumes robot makers use in-house welding power sources; CROBOTP uses welding power source from Megmeet.

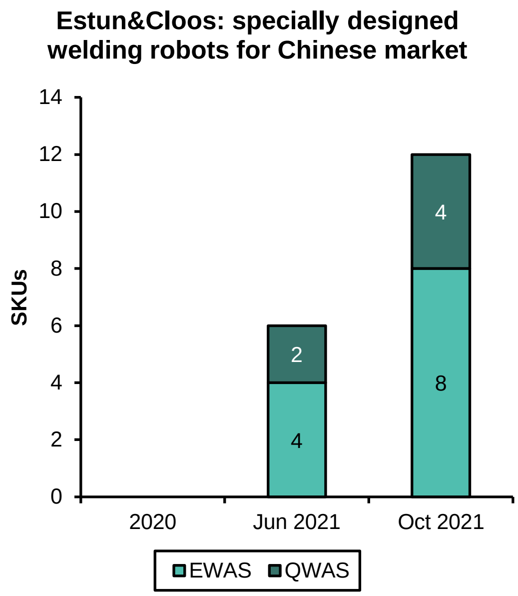
Source: Company websites, company reports, and Bernstein analysis

EXHIBIT 164: **Synergies between Estun and Cloos**

Arc welding categories	Thickness	Major applications	Cloos	Estun	Synergy
Ultra thin plate	< 0.3 mm	3C, auto parts, white goods, aerospace	√ (Cloos has relevant techniques)		Estun and Cloos will co-develop ultra thin plate welding system based on Cloos' techniques
Thin plate	0.3-3 mm		√	√	Estun is able to integrate Cloos' power sources in Estun's robots to improve welding performance
Medium plate	3-20 mm	Pipeline, shipping, railway, transporation, aerospace	√		Estun can take advantage of Cloos' expertise in thick plate welding to develop cost-effective new robots targeting at Chinese customers
Thick plate	20-60 mm	Heavy manufacturing, military products, bridges	√		
Ultra thick plate	> 60 mm		√		Estun can cross sell Cloos' products

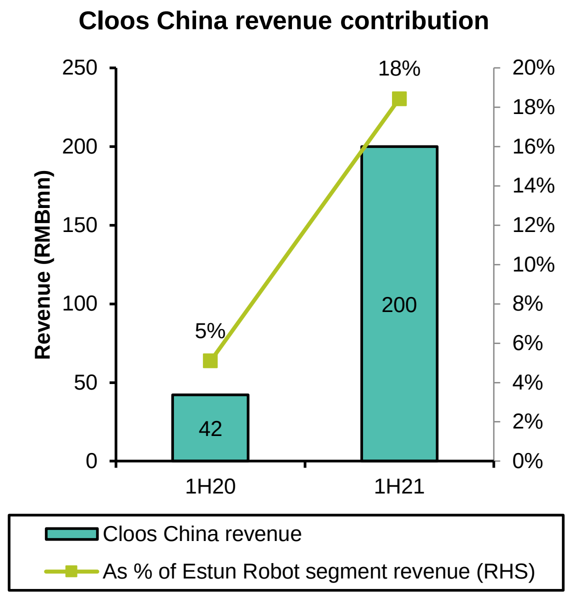
Source: Gongkong, CISA, company websites, and Bernstein analysis

EXHIBIT 165: **Estun & Cloos co-developed welding robots for Chinese market**



Source: Estun and Bernstein analysis

EXHIBIT 166: **Increasing contribution from new products**



Source: Estun and Bernstein analysis

EXHIBIT 167: **Welding robot portfolio of Estun and Cloos brands (plate thickness defined by Estun & Cloos)**

Estun&Cloos welding robots		Brands	Welding range	Major pplications	Major competitors	Average price	Robot production
Copper series	EWAS	Estun	Thin plate (0.6-4 mm)	3C, auto parts, white goods, aerospace	FANUC, ABB, Yaskawa, KUKA, OTC, Panasonic, CROBOTP	< RMB500k	In China
	QWAS	Cloos	Thin&medium plate (0.6-12 mm)	3C, auto parts, white goods,pipeline, shipping, railway, transporation, aerospace	FANUC, ABB, Yaskawa, KUKA, OTC, Panasonic		Some components in China
Silver series	QIROX-E		Medium plate (4-12 mm)	Pipeline, shipping, railway, transporation, aerospace	FANUC	RMB300~800k	In Europe
Gold series	QIROX-P		Medium&thick plate (4-300 mm)	Pipeline, shipping, railway, transporation, aerospace, heavy manufacturing, military products, bridges	-	RMB600~1,300k	

Source: Estun and Bernstein analysis

EXHIBIT 168: **Performance improvement: New EWAS vs. Old EWAS**

New EWAS robots	Compared to old EWAS models
Speed	Up 15%
Real production capacity	Up 10-15%
Maintenance cost	Down 50%
Payload	Up 30%
New EWAS robots	**New capabilities**
Point accuracy	0.5mm
Thin plate welding	Down to 0.6mm thickness
Circular welding	Down to 12mm diameter

Source: Estun and Bernstein analysis

Synergy with non-robotic business

The industrial automation space is very broad and companies' scope of business falls into a few categories (see Exhibit 169):

- **One-stop shops.** Companies such as Mitsubishi and Omron have purposely built a portfolio to meet the broadest possible automation needs of factories. Their products range from discrete components to various machines and control products at production line and plant levels.

- **Specialists.** These are leading experts of one or a few technology areas, e.g., Keyence and Cognex in vision, IPG in fiber laser, FANUC in robotics and CNC, Harmonic Drive in SW reducers, and SMC in pneumatic components. Although they may carry limited other products, those are meant to be accessories in the technical solutions they specialize in.

- **Line integrators' partners.** Their scope of business falls between the first two — broader than the specialists, but not so broad as to cover every corner of a factory. Their model customers are production line integrators with a focus on specific factory processes. They often have an internal integration business as well. Examples include ABB, Schneider, and Inovance.

The "specialist" model is the best, but not every company has that choice. For emerging market automation rising stars, we think the most sensible choice is to become line integrators' preferred partners, and it fits best with the growth strategy of "saturate (a niche) then replicate" that is based on deep domain expertise and process know-how, as discussed earlier.

In addition to robots, Estun has built expertise around *motion and control* for system integrators. Its robot, CNC, servo motor/drive, and IPC products have natural synergies. A typical production line consists of robots and other machines, each of which may have multiple servo motors. The tens of motors in a typical line are interconnected through robot controllers, CNCs, and PLCs at the individual equipment level, then through PLCs or IPCs across different equipment. A system integrator's job is to build the line so that each motor and equipment works in a synchronized and efficient way to complete a multi-step task (e.g., welding/assembly/packaging). There is incentive for an integrator to procure all motors and control instruments from one vendor, because: (1) it is more likely to get products customized for the specific process, and (2) these components are the data links of a line, and getting them from one vendor ensures smooth data flow, easier integration, and higher control stability. Therefore, most motion companies carry control products (CNC/PLC/IPC), but the synergy does not go much further to other product categories.

Estun's journey is one that increasingly covers this synergic group of motion and control products (see Exhibit 132). After it built capabilities in CNC, servo, and robots, the expansion to industrial control was achieved with the acquisition of Trio, a global leader in industrial control instruments (see Exhibit 171). Trio's IPC integrates the functions of PLCs and some robot controllers and can control up to 128 axes (i.e., number of servo motors) in a production line (see Exhibit 170). This level of integration enhances data communication speed, improves stability, saves hardware cost, and simplifies the programming of multiple equipment. It allows Estun to develop more sophisticated vertical solutions and makes Estun a better partner to system integrators.

Estun has demonstrated strength in M&A. Besides Cloos and Trio, which we already discussed, the company's other acquisitions also had clear strategic rationales to either complement Estun's product and application know-how, or bring important cross-selling opportunities (see Exhibit 172).

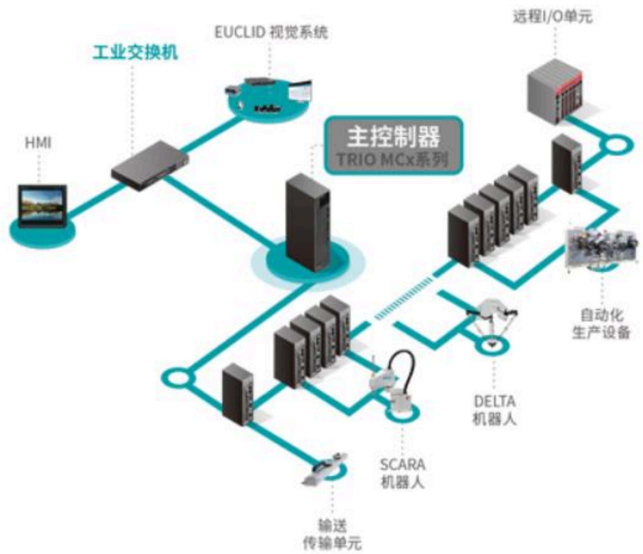
EXHIBIT 169: **Business scope of global and Chinese automation players — Estun aims to become the preferred choice of system integrators for motion and control**

Layer	Product	FANUC	ABB	KUKA	Yaskawa	Universal Robots	Keyence	Siemens	Rockwell	Schneider	Omron	Mitsubishi	Beckoff	Estun	Inovance	Siasun	Efort	Step	SMC
Layer 1 System control and software	MES		✓					✓	✓	✓		✓		✓	✓	✓			
	PLM/ CAD							✓	✓							✓			
Layer 2 Control Instrument	CNC	✓						✓	✓		✓	✓	✓	✓	○				
	PLC / IPC / PAC		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
Layer 3 Automation Equipment	Robotics	✓	✓	✓	✓	✓					✓	✓		✓	✓	✓	✓	✓	
	Machine vision	✓	✓	○	○		✓			✓	✓			✓	✓				
	Machine Tool	✓										✓							
	Laser material processing	○										✓							
	AGV		✓	✓	✓			✓			✓					✓			
Layer 4 Discrete Component	Inverter		✓		✓			✓	✓	✓	✓	✓			✓			✓	
	Servo	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
	Linear motion			○	✓			✓	✓	✓	✓	✓	✓						
	Sensor						✓			✓	✓			✓	✓	✓			
	Pneumatic Valve							✓		✓		✓							✓

Note: Except for FANUC, Keyence, and Estun, companies named here are not covered by Bernstein.

Source: Company reports and Bernstein analysis

EXHIBIT 170: **Acquiring Trio allowed Estun to provide premium control to integrate robotic and motion control products**



Source: Company website and Bernstein analysis

EXHIBIT 171: **Trio controllers are in the high end with the ability to control robots and motors up to 128 axes**

Company	Control scope	Max axis	Type	Communication
Trio	Robot + Motor	128	IPC	EtherCAT
ABB	Robot + Motor	n.a.	IPC	EtherCAT
Adventech	Robot + Motor	128	IPC	EtherCAT
Siemens	Motor	128	Integrate PLC into the servo driver	Profibus, Profinet, EtherNet
Yaskawa	Motor	62	PLC	Mechatrolink, Modbus, EtherNet

Source: Company reports and Bernstein analysis

EXHIBIT 172: **Estun's previous acquisitions all had clear strategic rationales**

Date	Target company	Country	Shareholding %	Investment amount (USD million)	Acquisition purpose					
					Complementary technology				Application know-how	Cross-selling opportunity
					Robot	Motion control	Industrial control	CNC		
Feb-16	Euclid Labs	Italy	20%	1.6	√					
Jun-16	Shanghai Prex (上海普莱克斯)	China	100%	10.9					√	
Jul-16	Fengyuan Automation (南京锋远自动化)	China	100%	5.5					√	
Mar-17	Trio	U.K.	100%	17.5			√			
Apr-17	Barrett	U.S.	30%	9.0	√	√			√	√
Oct-17	M.A.I	Germany	50%	9.9					√	
Dec-17	Yangzhou Dawn (扬州曙光)	China	68%	47.2		√			√	√
Nov-19	Cloos	Germany	89%	221.6					√	√

Source: Company reports and Bernstein analysis

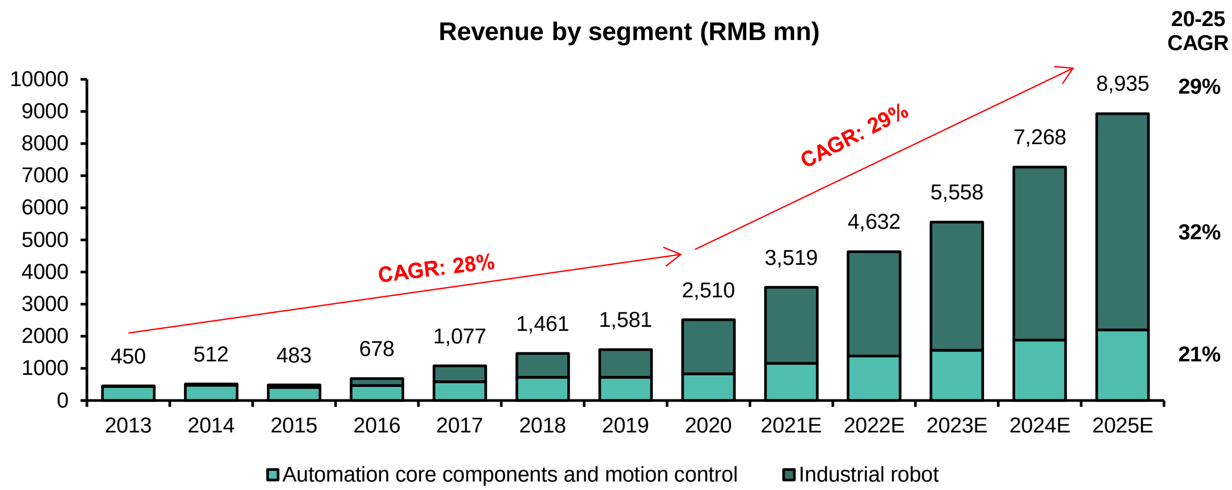
PATH TO STRONGER FINANCIALS

We forecast the company's top line to grow at a robust organic CAGR of 29% from 2020 to 2025 (see Exhibit 173). Estun's robot business will likely continue to be the main growth driver.

Estun is already the most profitable robot maker in China, at the company level (see Exhibit 174) as well as for the robot segment (see Exhibit 175). We believe this is due to Estun's vertical integrated strategy: in-house components (motors, etc.) are usually not the most cost competitive until the business reaches a certain scale and the component technology improves to a certain level. The data shows that Estun has reached that point and the power of vertical integration is gradually manifesting.

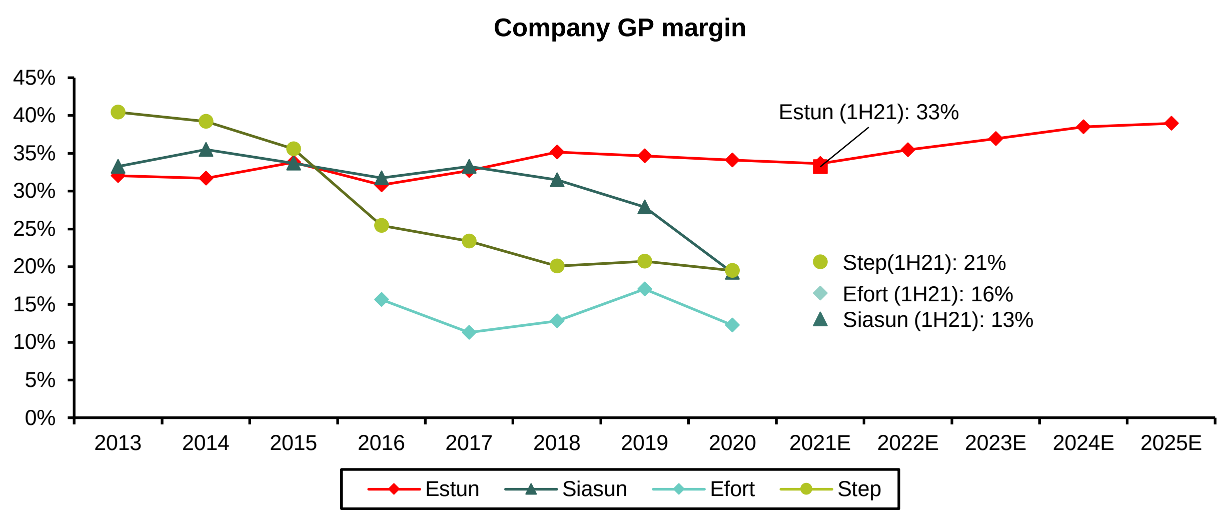
Furthermore, thanks to its better technology, Estun is able to price its robots at 20-30% premium vs. most local peers, but still maintain a 15-20% discount vs. FANUC and Yaskawa (see Exhibit 176). It uniquely occupies the mid-segment of the price ladder.

EXHIBIT 173: **Estun's revenue by segment — its robot business will likely continue to drive the most growth**



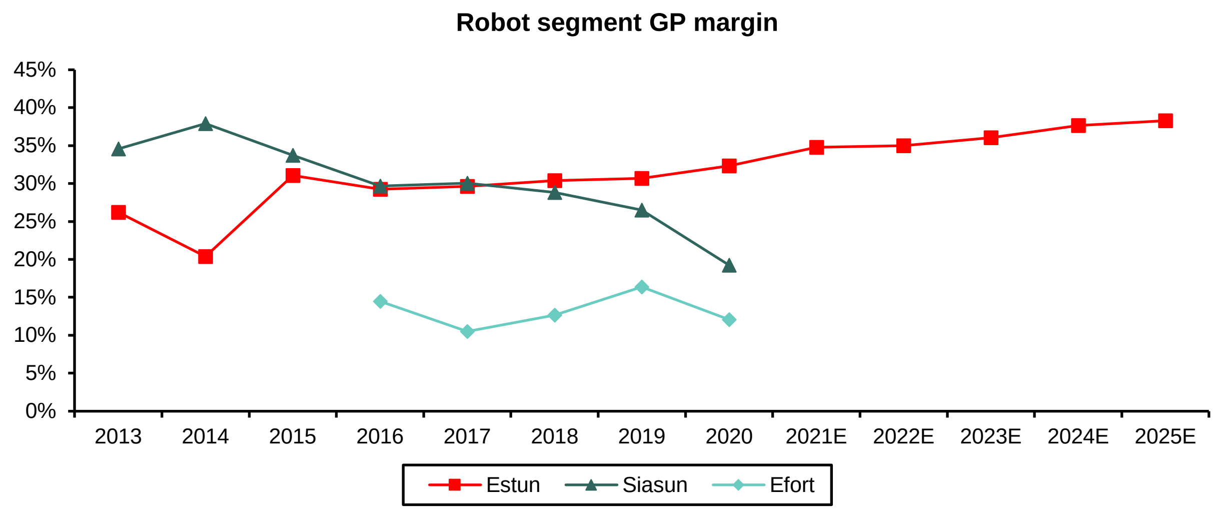
Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 174: **Estun's GP margin is the highest among Chinese robot players, and will likely keep improving with increasing scale**



Source: Company reports, and Bernstein estimates and analysis

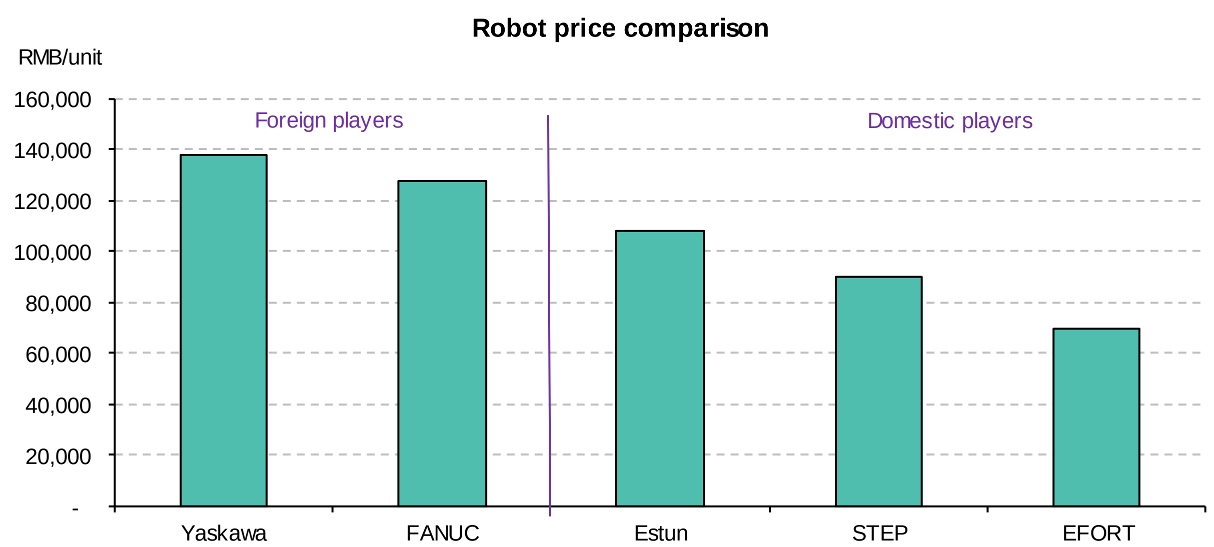
EXHIBIT 175: **Estun's robot segment GP margin is also the highest among Chinese robot players**



Note: Step is not included as it reported robot and motion control in the same segment, so it's not comparable; Efort does not report segmental gross profit in interim results.

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 176: **Estun occupies the mid-segment of a price ladder in the Chinese robot market; the result of the company's superior technology vs. local peers**



Note: Price includes a robot, a controller, a teach pendant, and cables; we compare prices of robot models with 6-8kg payload and range between 911mm and 1,600mm.

Source: MIR Databank and Bernstein analysis

Estun's robotic gross margin will likely further expand going forward and stabilize in the high 30s, helped by:

- Product design and production optimization as Estun's robotic and manufacturing technologies continue to improve.
- Product scalability. Estun's robot portfolio is relatively broad (see Exhibit 144 and Exhibit 156) and each model can drive more sales as the company expands from the initial niches and broadens its vertical and customer coverage. This new formula for growth is much more cost efficient than the initial phase when growth was in line with expansion of SKUs.
- Procurement. At 2-3x its current scale, Estun will see immediate cost saving in the robot segment from the highest value component, the reducers. Our previous research showed that between large and small customers, the same reducer from the same company can have a 40% difference in price.[42] We estimate that reducers account for ~35% of Estun's robot BoM, or ~25% in price. In addition to economy of scale, Estun is also expediting the process of local procurement for both SW and RV reducers.

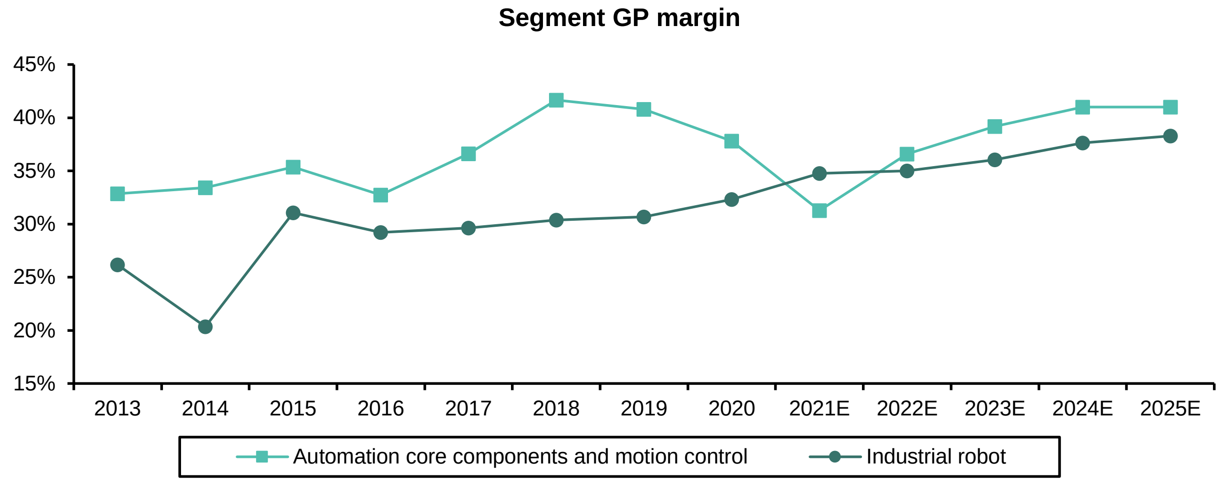
At steady state, we think Estun's automation components and motion control segment GP margin will be around 42%, similar to the 2018 level; its robotic segment GP margin will be 38-39%, up from the low 30s in 2020 and similar across Estun and Cloos (see Exhibit 177).

As GP margin expands, Estun's OP margin and NP margin are also expected to reach double digits in 2023-24 and further expand to stabilize in the mid-teen range in the long term (see Exhibit 178). We forecast R&D intensity to remain 8-10% of revenue in the forecasting period, but operating leverage in other SG&A and finance expenses.

Comparing Estun to FANUC, two companies with the most similar product scope, we forecast both will have a similar long-term GP margin close to 40%. Estun's technology gap and lower price are offset by its lower costs. Because of its much bigger scale, stronger brand, and established customer relationships, FANUC will likely still enjoy higher normalized OP margin of 25-30% compared to ~15% for Estun.

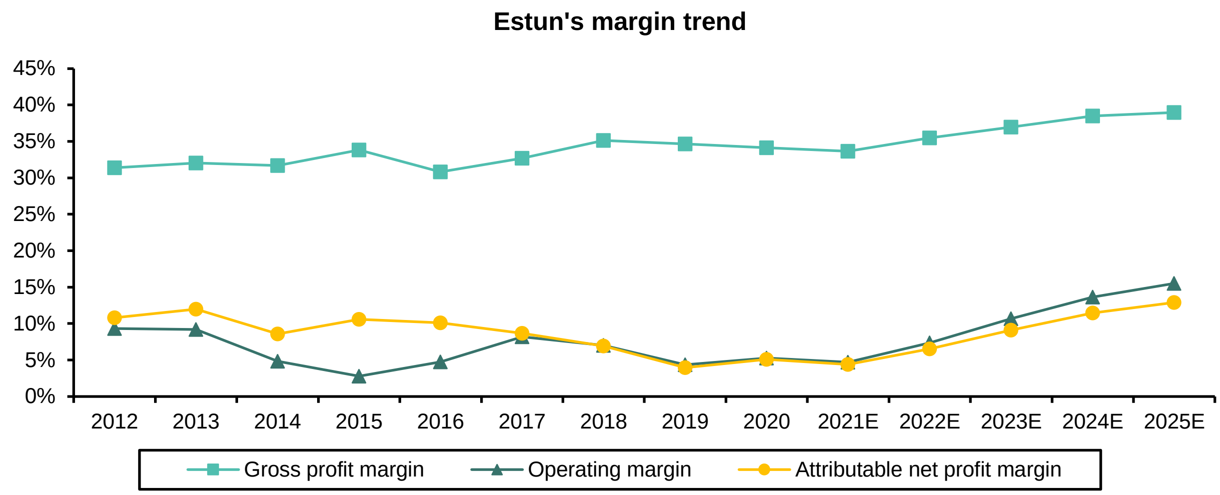
[42] See Global Automation: Baby shark, doo, doo ... Leader Drive IPO and read-across to Harmonic Drive.

EXHIBIT 177: **Estun's segment GP margin trend**



Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 178: **Following GP margin expansion, we also project company's OP and NP margins to gradually improve**



Note: Government subsidies are classified as non-operating income and added after operating profit and before net profit.

Source: Company reports, and Bernstein estimates and analysis

LASERS

A migrating battlefield, a duel, and a new rising star

FIBERS AND CHIPS

In the laser supply chain, China's progress has been the most impressive in the upstream: diodes and chips, where the gap between Chinese and global components supply has all but diminished.

ANATOMY OF A FIBER LASER

Like all lasers, a fiber laser consists of: (1) a pump as the energy source; (2) a gain medium to convert other forms (electrical or optical) of energy to the desired output; and (3) an optical resonator with a pair of reflectors at the ends to amplify the desired output.[43] In a fiber laser, these three major components are:

- Pump laser diodes (PLDs): Fiber lasers are typically pumped by semiconductor laser diodes, which convert electrical energy to low-quality laser. Multiple PLDs are required in each fiber laser.
- Active fiber: An optical fiber doped with rare-earth elements, e.g., ytterbium and erbium. The low-quality input light from PLDs triggers stimulated emission corresponding to the energy levels of these elements and is converted to high-quality laser.
- A pair of fiber Bragg gratings (FBGs) functions like a pair of mirrors. Together with the active fiber, it forms an optical resonator. FBGs selectively reflect and transmit certain wavelengths, allowing the maximum conversion of low-quality laser from PLDs to high-quality laser before it is emitted as output.

The above description, however, is too simplified a picture if one were to understand fiber laser technology, supply chain, and competition. Industrial fiber lasers use a cascade modular architecture (see Exhibit 179), generating light in tens of watts in a single-diode chip, combining them to around 100 watts in each PLD, outputting 2-5kW high-quality laser in a single module, and finally combining multiple modules to reach the desired output up to hundreds of kW. In this architecture, tens of different components are critical for performance. These components and their open-market suppliers are summarized in Exhibit 181, and the business scopes of major laser companies in Exhibit 182.

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[43] See The Laser Primer: Products, industrial applications, key trends and players - the rise of laser in automation.

For interested readers, some details on the anatomy of a fiber laser follow:

- Inside the PLD: A laser is first generated by individual *single-diode chips*, which are mounted on a *heat sink* (see Exhibit 180, left-hand side). The light from these chips is collimated and combined via a variety *of microlenses and mirrors*, and coupled into the output fiber of the PLD (see Exhibit 180, right-hand side). With a dimension of just ~1 mm, a single-diode chip continuously emits 20-30W. This makes temperature control crucial for the chip and the PLD, as temperature fluctuations would result in a shift in the laser's wavelength and instability of the entire system. The shape and material of the heat sink need to be carefully designed/selected to fit the thermal expansion of the chip to dissipate heat most efficiently.

- Coupling light into active fiber: Light from multiple PLDs is combined by a *pump combiner* and coupled into a *passive fiber*. The energy then needs to be "pumped" from the passive fiber into an active fiber. There are two categories of pumping technologies: end-pumping, in which light goes into the active fiber from the ends (see Exhibit 206), and side pumping, in which the passive and active fibers merge and energy propagates gradually from the former to the latter (see Exhibit 207). End-pumping is used widely because it is easier to fabricate. IPG uses a proprietary side-pumping process, which we discuss later in this chapter (see Exhibit 207).

- Single-module output: After light conversion in the active fiber, a *mode field adaptor* allows the laser to go through fibers of different diameters without energy loss or beam quality deterioration, and a *cladding light stripper* removes the unwanted light in the fiber cladding. The final output from an individual fiber laser module is typically 1.5-12kW.

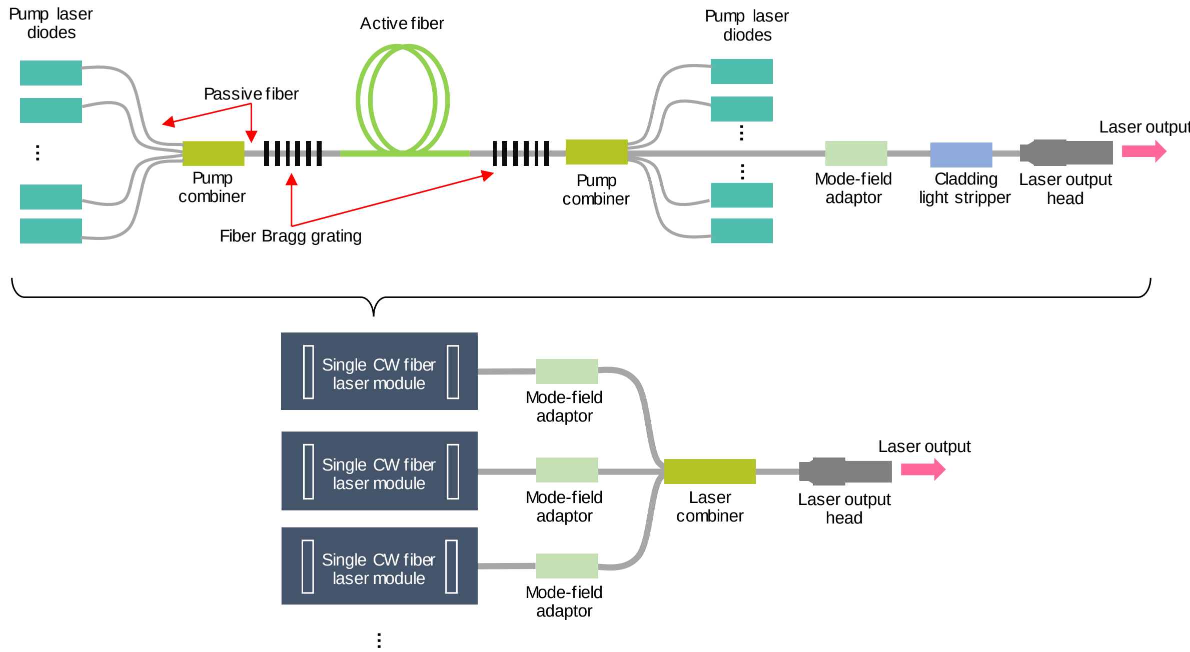
- Multi-module energy combining and output: Energy from individual modules is combined by a *laser combiner* to reach much higher powers.[44] The laser combiner, output fiber, and output head optics all need to be able to handle the higher powers. Currently, cutting and welding applications in volume have reached 20-40kW, and much higher levels (up to 500kW) in niche applications. Although the working principle of a laser combiner is similar to the pump combiner discussed earlier, the former needs to handle much higher power levels.

- Beam delivery: As fiber laser accessories, laser *cutting/welding heads* deliver energy from the laser source to workpieces with sophisticated optics and motion control. Heat, dust, and incorrect operation can damage components. Many functions may be integrated in the heads, e.g., height sensing, focusing adjustment, real-time monitoring, and wireless communication.

In the next sections, we follow this structure and the list of components to discuss the level of vertical integration, the progress of the Chinese fiber laser industry, and product differentiation from the industry leader, IPG Photonics.

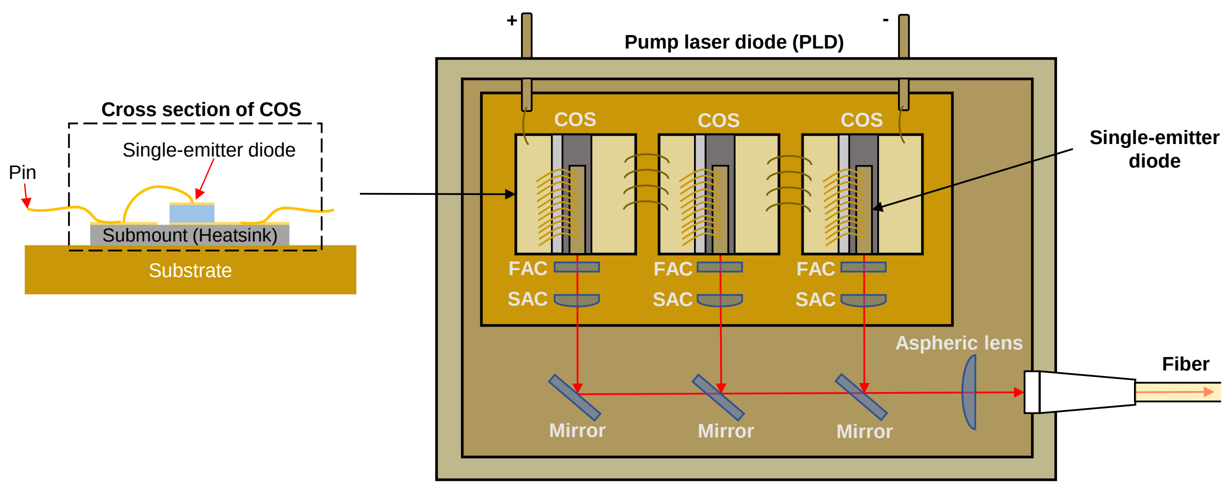
[44] Beam quality inevitably worsens during beam combining, and the single-mode output from an individual module becomes multi-mode. This is usually not an issue for material processing applications. To achieve ultra-high-power single-mode output, however, a different architecture, multi-stage Master Oscillator Power Amplifier (MOPA), is usually used.

EXHIBIT 179: **Illustrative structure of an industrial fiber laser**



Source: Bernstein analysis

EXHIBIT 180: **Inner structure of a pump laser diode (PLD)**



Note: COS — chip on submount, FAC — fast-axis collimation, SAC — slow-axis collimation

Source: IPG Photonics (CoS structure) and Bernstein analysis

EXHIBIT 181: **Fiber laser components and supply chain**

Components for high power CW fiber laser	Functions	Chinese suppliers	Overseas suppliers
Pump laser diodes (PLDs)	To emit laser into passive fiber. A PLD is a package mainly including sub components listed below	Everbright Photonics, BWT	nLight, II-VI, IPG, Lumentum
- Single laser diode chip(s)	To directly convert electrical energy into light	Everbright Photonics, BDL	II-VI, Dilas (acquired by Coherent), OSRAM
- Micro optics (e.g. fast-axis collimation and slow-axis collimation)	To shape the beam into the fiber	Optowide, LIMO (acquired by Focuslight), C.F. technology	FISBA, Edmund, Sigma Koki, Ingeneric, Alps Alpine
- Heat sink	To absorb and transfer heat generated by single laser diode chip(s)	No. 43 Research Institute of CETC	MARUWA, Kyocera
Pump combiner	To combine the light from multiple PLDs into one	Juhere, Comcore, Optizone, Xunhong Photonics, DK Photonics	ITF Technologies, Lightel
Fiber Bragg grating (FBG)	To reflect particular wavelengths of light and transmit all others; A pair of FBGs form the laser cavity	RSYF, AFR, YOFC	ITF Technologies, TeraXion
Active fiber	It is the fiber doped with rare-earth elements, serving as active gain medium	Brightcore, YOFC	Nufern (acquired by Coherent), nLight
Passive fiber	It is the fiber without dopant, which is used to deliver light	Brightcore, YOFC	Nufern (acquired by Coherent), nLight
Cladding light stripper	To remove light from a fiber cladding, so that only light in the fiber core remains	Juhere, Optizone, Xunhong Photonics, DK Photonics	Lightel, Neptec
Mode-field adaptors	To expand or compress the mode field between two fibers	Juhere, Rayzer, Xunhong Photonics	ITF Technologies, Lightel, Thorlabs
Laser output head	It is the output component of the fiber laser	Xunhong Photonics, OSCOM, DK Photonics	Coherent, Lightel, II-VI
Laser combiner	To combine laser from modules into a single fiber	Juhere, Comcore, Optizone, Xunhong Photonics, DK Photonics	ITF Technologies, Lightel
Additional components for ultrafast pulsed laser			
Kerr medium / Semiconductor saturable absorber mirror (SESAM)	They are used for laser mode-locking in ultrafast pulsed lasers	-	BATOP
Gratings / Chirped volume Bragg grating (CVBG)	They are used for pulse width compression	SIOM, Newopto	OptiGrate (acquired by IPG), LuxxMaster, Ultrafast Innovations
Polarization-Maintaining Fiber (PMF) / Chirped fiber Bragg grating (CFBG)	They are used for pulse width expansion	Optounion	TeraXion, Technica
Additional components for wavelength conversion			
Nonlinear crystals	To convert laser wavelength from near-infrared to visible/ultraviolet ranges	Castech	Raicol, Eksma, Cristal Laser

Source: Prospectus of Maxphotonics (2019.11 version), Prospectus of Raycus, Annual Report on Chinese Laser Industry 2020 (published by Wuhan Library, Chinese Academy of Sciences), company websites, and Bernstein analysis

EXHIBIT 182: **Who plays where in industrial lasers**

Supply chain segment	Product		Lumentum	II-VI	Castech	Optowide	Gooch & Housego	MKS	IPG	Coherent	nLight	Raycus	Maxphotonics	Trumpf	Han's Laser
			LITE US	IIVI US	002222 CH		GHH LN	MKSI US	IPGP US	COHR US	LASR US	300147 CH			002008 CH
Fiber laser components	Pump	Single laser dipde chip	S	S					P	(S) (Dilas)	P			P	
		Micro-optics				S			(P)						
		Pump packaging	S	S			S		P	(S) (Dilas)	S	P	P	P	S (planning)
	Fiber-related	Active fiber							P	(S) (Nufern)	(S) (Liekki)	(P)	(P)		(S) (CorActive)
		Passive fiber		S					P	(S) (Nufern)	(S) (Liekki)	P	P		(S) (CorActive)
		Pump/laser combiner		S		S	S		P	S	P	P	P		(S) (CorActive)
		Cladding light stripper							P		P	P	(S)		
		Mode-field adaptors							P		P	P	P		
		Laser output head							P	S	P	P	(S)		
		Fiber bragg grating		S	S				P	S	P	(P)	(P)		(P)
	Crystal	Nonlinear crystal		S	S		S	S	(P)	S					
		Volume bragg grating							(S) (OptiGrate)						
		Saturable absorber		S				P	P	P					
	Electronics & optics	Acouso-optic modulator		S	S	S	S	S (Newport)	(P)	S		(P)	(S)		
		Electro-optic modulator		S	S		S	S (Newport)	P					S	
		Isolator		S	S	S	S	S (Newport)	P		P	(P)	(S)	S	
		Filter		S	S	S	S	S (Newport)	P	P	P				
		Lens/mirrors		S	S	S	S	S (Newport)	P	S				S	
	Beam delivery accessories	Laser cutting heads		S					S	S				P	S (planning)
		Laser welding heads		S					S	S				P	
Lasers	Fiber laser		S					S (Spectra-Physics)	S	S (Rofin)	S	S		S (SPI)	S (planning)
	Diode laser		S	S				S (EO Technics)	(S)	S	S	S		S	S (planning)
	Ultra-fast laser							S (Spectra-Physics)	S	S		(S) (Gauss laser)		S	S (planning)

S	External sales
(S)	Minor external sales
P	Production in-house
(P)	Minor production in-house

Source: Company websites and Bernstein research

PROGRESS OF CHINESE FIBER LASER TECHNOLOGY

The Chinese fiber laser industry progressed faster than expected in 2017-21. Not only has the share of Chinese companies steadily increased (see Exhibit 183), the two leading local players, Raycus and Maxphotonics, have also become more vertically integrated. External supply is mostly limited to components within the PLD (the packaging of PLD is now in-house), FBGs, some active fibers, and specialty crystals for ultrafast lasers and frequency conversion (see Exhibit 184).

The more impressive progress took place in the upstream. While there was a huge gap in 2016, Chinese fiber laser components have largely closed that gap vs. global open market supply (see Exhibit 185). As a result, the outsourced part of Raycus' and Maxphotonics' supply chain is moving back to China, e.g., diode chips from II-VI and Lumentum to

Everbright, micro-optics from FISBA to Optowide, and active fibers from Nufern to YOFC.[45] Key areas of improvement include:

- For single-diode chips, output power is one of the most important specs (see Exhibit 186), because higher output per chip means fewer chips to achieve a given total output and, hence, lower cost. Leading Chinese suppliers such as Everbright Photonics improved more than 100% from 2016 to 2020 and show no gap in power level compared with overseas suppliers today. It is worth noting that Raycus and one of its chip suppliers, Bright Diode Laser (BDL), are affiliated to the same owner, China Aerospace Science and Industry Corporation (see Exhibit 187).

- For micro-optics, some critical parameters, including damage threshold and frequency transmission curves,[46] are not disclosed. However, Optowide, the Chinese company, supplies practically all major global and Chinese fiber laser companies, including IPG. For microlenses, an important parameter is focal length, as a shorter focal length allows more compact design. Chinese products show no meaningful gap (see Exhibit 188).

- For pump combiners, the handling power of each port limits the highest output power of the component. Chinese products improved more than 50% from 2016 to 2020, and the gap is now minimal compared with overseas products (see Exhibit 189).

Gaps are shrinking, but still meaningful for the following components:

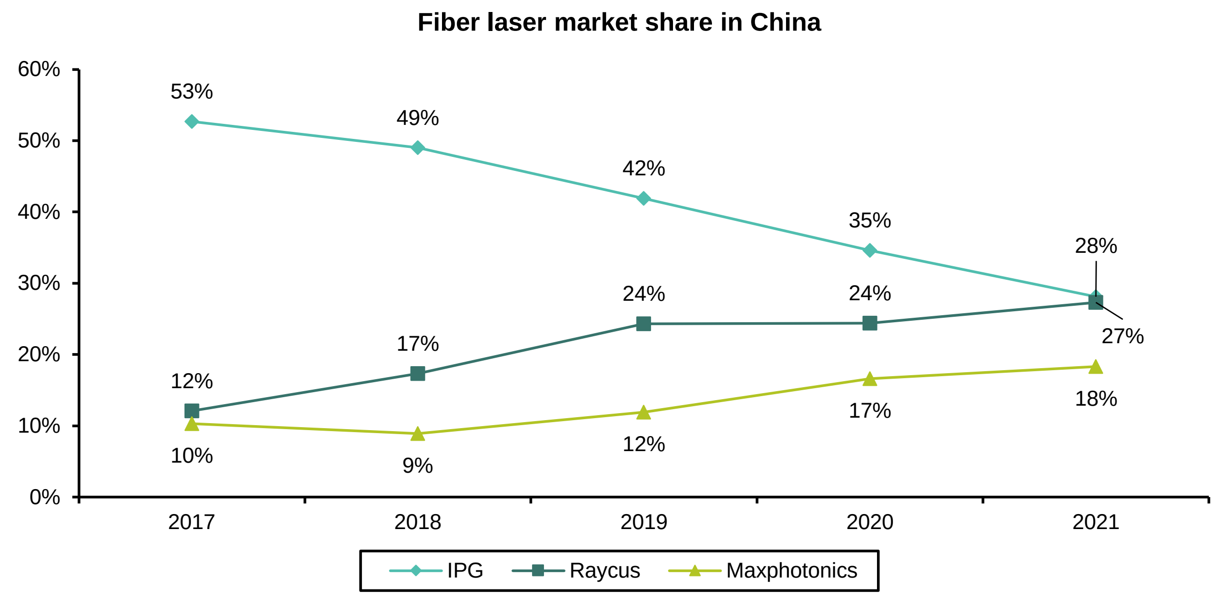
- For active fiber, absorption coefficient is an important indicator for measuring the effectiveness of absorbing the pump energy from PLDs. The remaining difference is negligible (see Exhibit 190). However, in other aspects, e.g., the recipe and uniformity of dopant, there likely remain some gaps. A nonuniform dopant leads to the photodarkening effect, which leads to power degradation and shorter life of the laser. In 2019, the localization rate of active fiber in Maxphotonics reached 75% for pulsed fiber lasers (generally lower power) and 52.5% for continuous wave (CW) fiber laser.

- For FBGs, the handling power of Chinese products barely reach the lower boundary required by a CW fiber laser module. Raycus and Maxphotonics have started using some domestically produced FBGs, but still rely on imports for most of their high-power products.

- For beam delivery heads, which are important accessories to a fiber laser in cutting and welding applications, the technology gap between Chinese and overseas is significant (see Exhibit 192 and Exhibit 193). While some Chinese companies, such as Han's Laser, claimed to have reached higher power, their products are neither trusted nor broadly used. Beam delivery at 12kW or above for cutting and 6kW or above for welding still relies on imports. IPG felt it necessary to introduce its 25kW laser cutting heads and 100kW laser welding heads to debottleneck ultra-high-power applications.

[45] In 2019, YOFC became the largest fiber suppler of Maxphotonics.
[46] Both are related to sophisticated coating technologies.

EXHIBIT 183: **Fiber laser market share in China (all power levels)**



Source: Annual report on Chinese Laser Industry (published by Wuhan Library, Chinese Academy of Sciences), and Bernstein analysis

EXHIBIT 184: **Vertical integration and external supply of leading fiber laser makers**

	Mainly inhouse? (with additional external suppliers)			
Components for high power CW fiber lasers	**Raycus**	**Maxphotonics**	**IPG**	**nLIGHT**
Pump laser diodes (PLDs)	✓	✓	✓	✓
- Single diode chips	✗ (Everbright, BDL, ***Dilas, II-VI, OSRAM***)	✗ (Everbright, ***Lumentum, II-VI***)	✓	✓
- Micro-optics	✗ (Optowide, ***FISBA, SvetWheel***)	✗ (Optowide, etc)	✓ (Optowide, etc)	✗ (Optowide, etc)
- Heat sink	✗ (***MARUWA***)	✗ (***Kyocera***)	✓	Unknown
Pump combiner	✓	✓	✓	✓
Fiber Bragg grating (FBG)	✗ (RSYF, ***TeraXion***)	✓ (RSYF, ***ITF Technologies, TeraXion***)	✓	✓
Active fiber	✓ (***Nufern***)	✗ (YOFC, ***Nufern, nLight***)	✓	✓
Passive fiber	✓	✓	✓	✓
Cladding light stripper	✓	✓	✓	✓
Mode-field adaptors	✓	✓	✓	✓
Laser output head	✓	✓	✓	✓
Laser combiner	✓	✓	✓	✓
Additional components for ultrafast lasers				
Kerr medium / Semiconductor saturable absorber mirror (SESAM)			✓	
Gratings / Chirped volume Bragg grating (CVBG)	Unknown	NA	✓	NA
Polarization-Maintaining Fiber (PMF) / Chirped fiber Bragg grating (CFBG)			✓	
Additional components for wavelength conversion				
Nonlinear crystals	Unknown	NA	✗ (Castech)	NA

Note: Overseas suppliers are in bold italic.

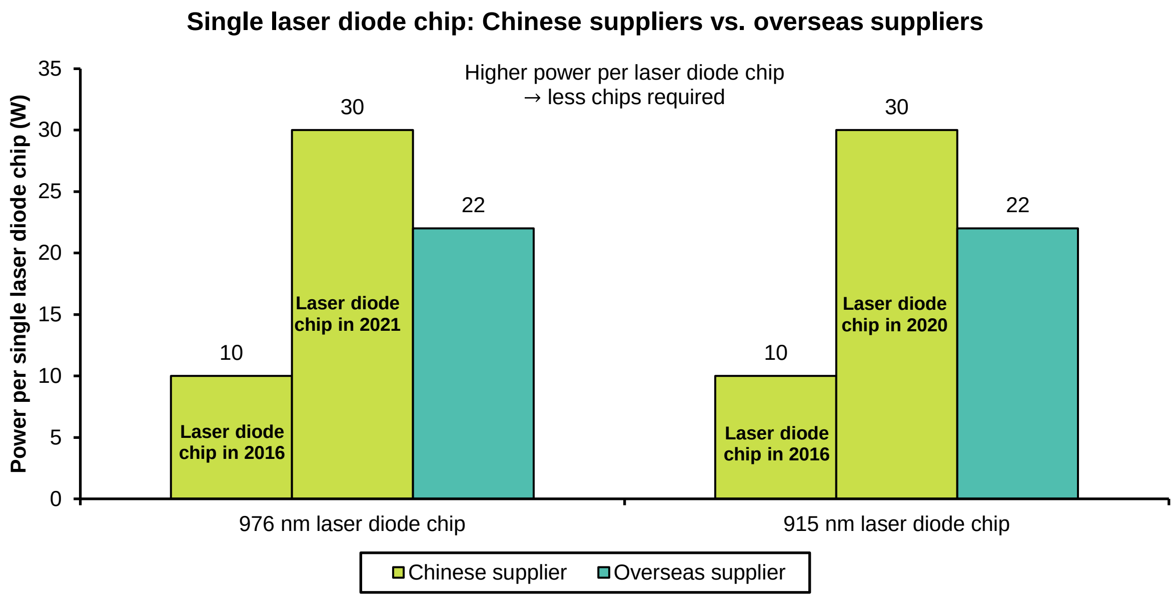
Source: Prospectus of Maxphotonics (2019.11 version), prospectus of Raycus, prospectus of Everbright, Annual Report on Chinese Laser Industry 2020 (published by Wuhan Library, Chinese Academy of Sciences), IPG, nLight, company websites, and Bernstein analysis

EXHIBIT 185: **Gap between Chinese and global fiber laser components supply all but diminished**

Power (kW)	Chinese tech in 2016	Chinese tech in 2020	Global best products / highest requirements
Lasers			
Single-mode CW fiber laser	1.5	12 (in 2021)	20
Multi-mode CW fiber laser	10	100 (in 2021)	500
Components			
Single laser diode chip (W)	10	30	>30
Pump combiner (per pump port)	1.2	1.85	2.0
Fiber Bragg grating (FBG)	1.0	2.0	3.0
Cladding light stripper	0.8	1.5	1.0
Laser combiner (per port)	0.4	5.0	2.1
Laser output head	4	35	20
Beam delivery			
Laser cutting head	2	12	25
Laser welding head	-	6	100

Source: Research advance on the key technology of high-power fiber laser materials and components (2017) (Changsheng Yang, et al., Scientia Sinica Techologica), High-power fiber laser materials and components (2020) (Zhongwei Fan, Aerospace Information Research Institute under the Chinese Academy of Sciences), news reports, Maxphotonics, company websites, and Bernstein analysis

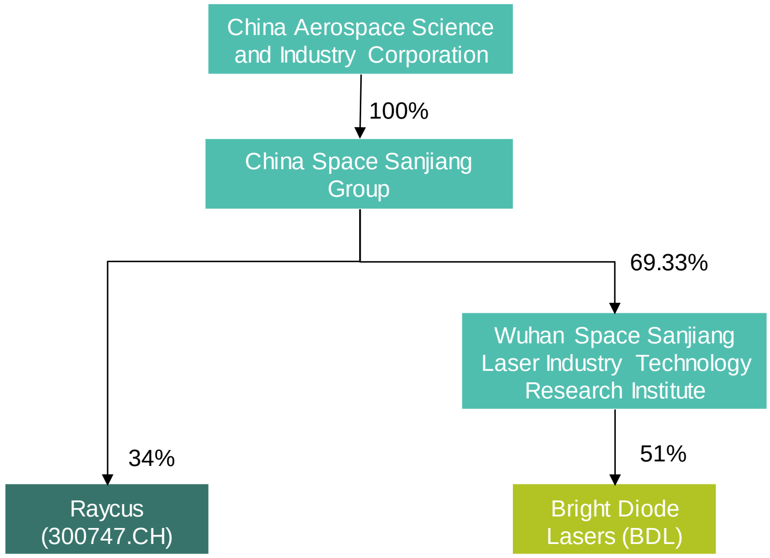
EXHIBIT 186: **Spec comparison of single-diode chip**



Note: Overseas supplier— II- VI; Chinese supplier — Everbright Photonics

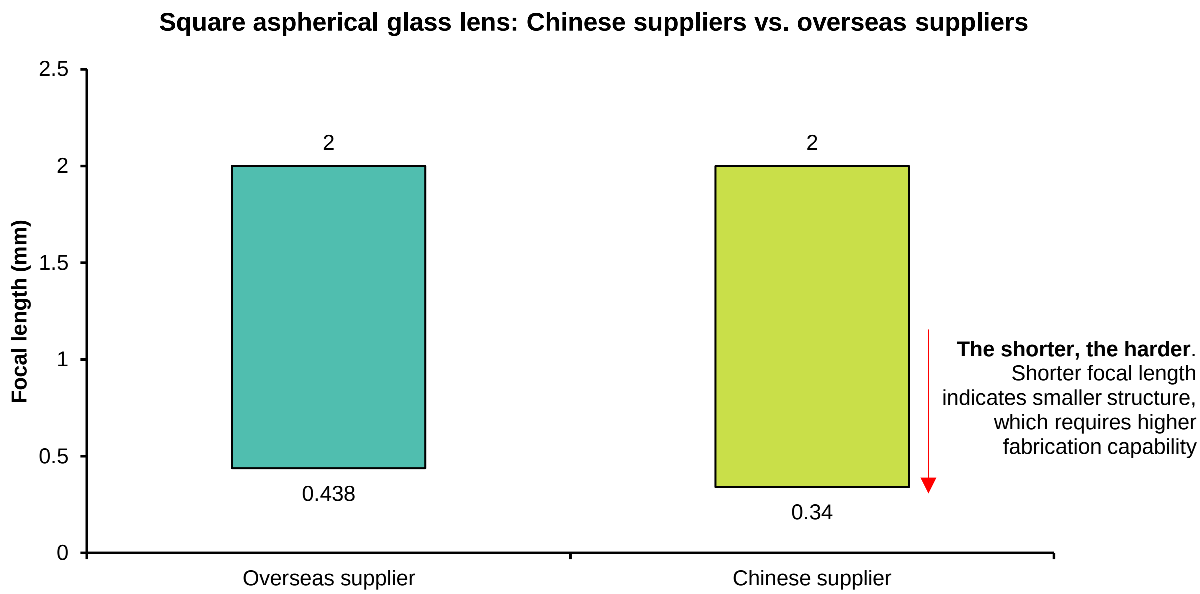
Source: II-VI, Everbright Photonics, media news, and Bernstein analysis

EXHIBIT 187: **Raycus and its diode chip supplier, Bright Diode Lasers (BDL), are related entities**



Source: Wind and Bernstein analysis

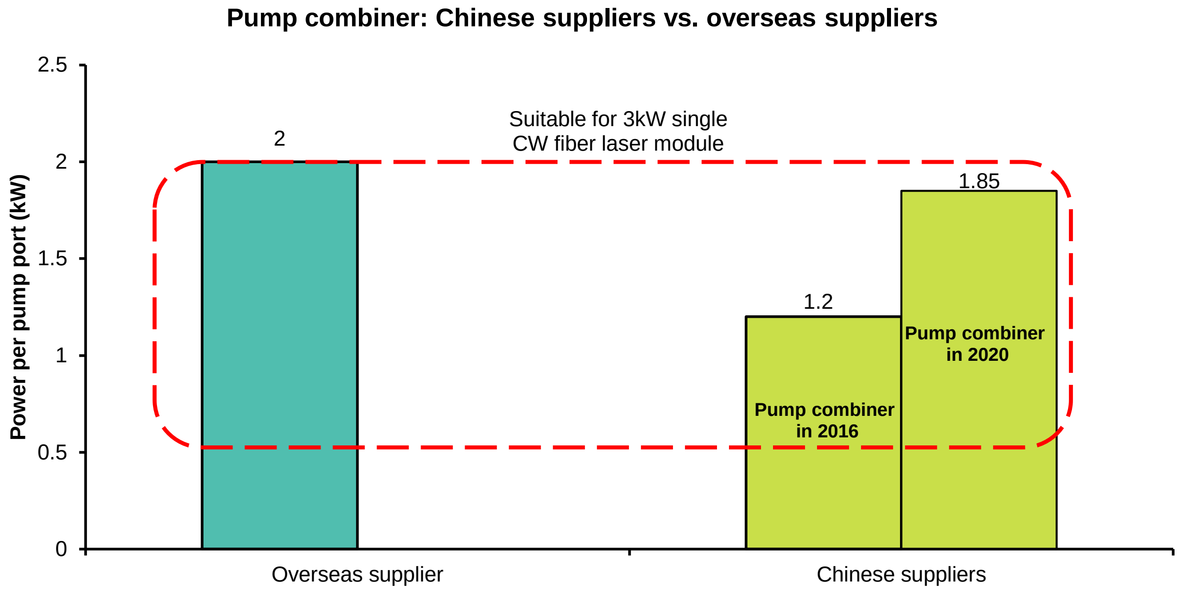
EXHIBIT 188: **Spec comparison of square aspherical glass lens (used in pump laser diodes)**



Note: Overseas supplier — Alps Alpine; Chinese supplier — Optowide

Source: Optowide, Alps Alpine, and Bernstein analysis

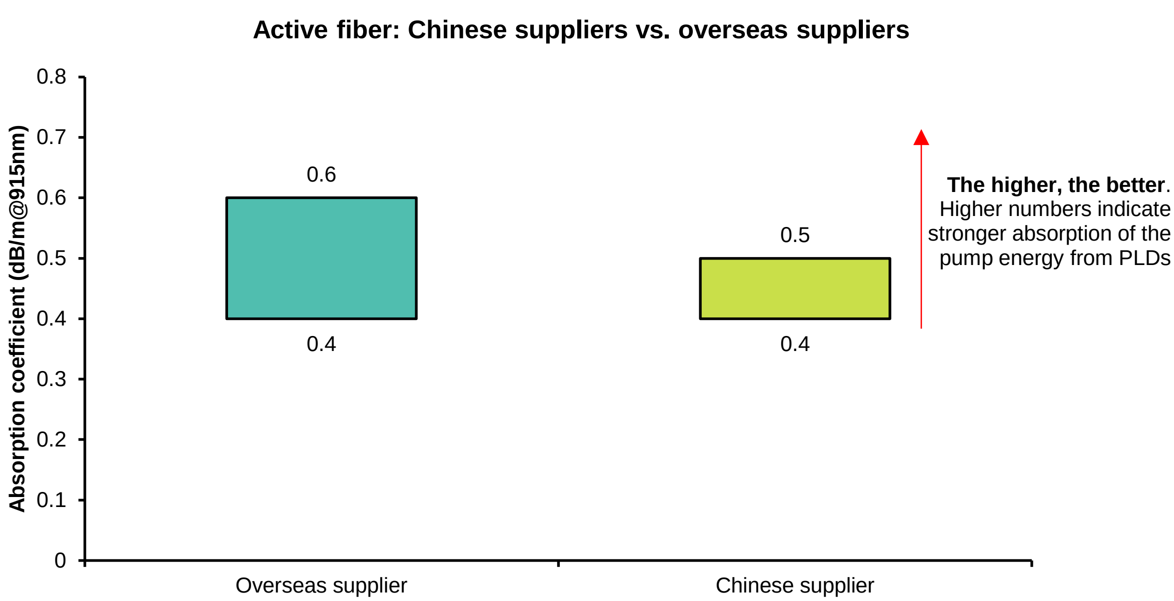
EXHIBIT 189: **Spec comparison of pump combiners**



Note: Overseas supplier — Laser Component; Chinese supplier — AFR

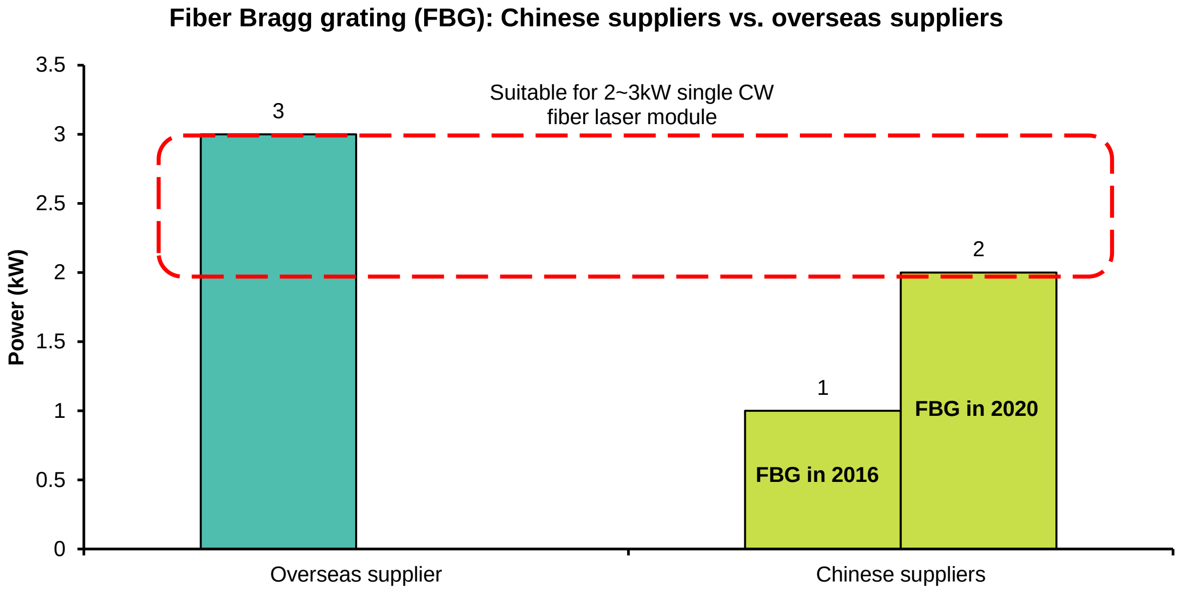
Source: Laser Component, High-power fiber laser materials and components (2020) (Zhongwei Fan, Aerospace Information Research Institute under the Chinese Academy of Sciences), and Bernstein analysis

EXHIBIT 190: **Spec comparison of active fibers**



Source: Prospectus of Maxphotonics (2019.11 version) and Bernstein analysis

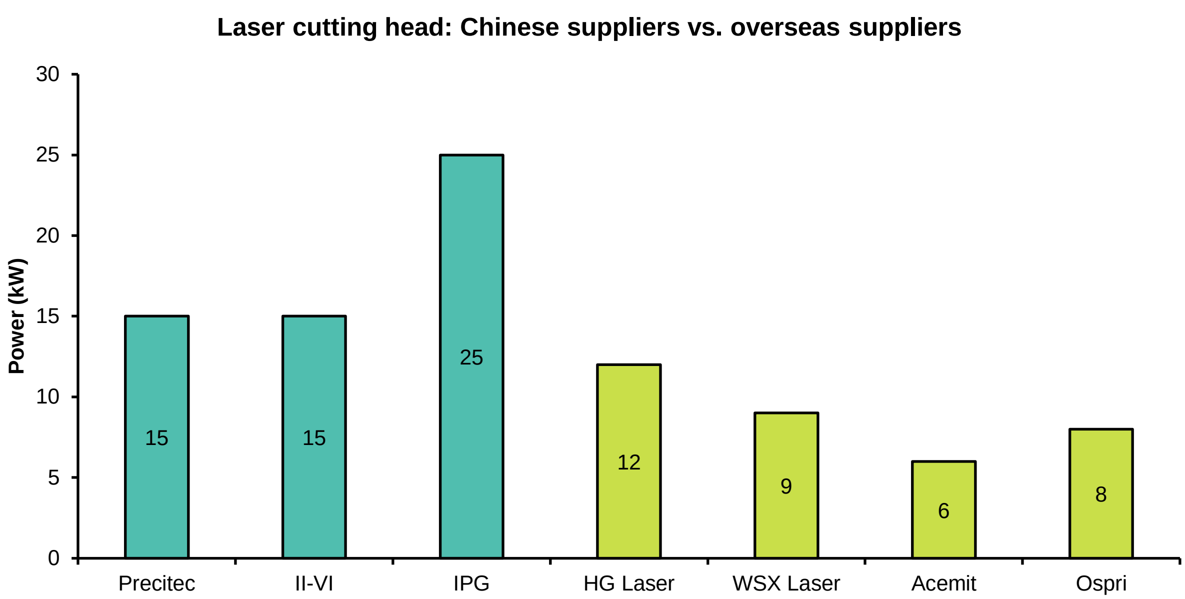
EXHIBIT 191: **Spec comparison of fiber Bragg gratings (FBGs)**



Note: Overseas supplier — TeraXion; Chinese supplier in 2020 — AFR; Chinese supplier in 2016 — SIOM

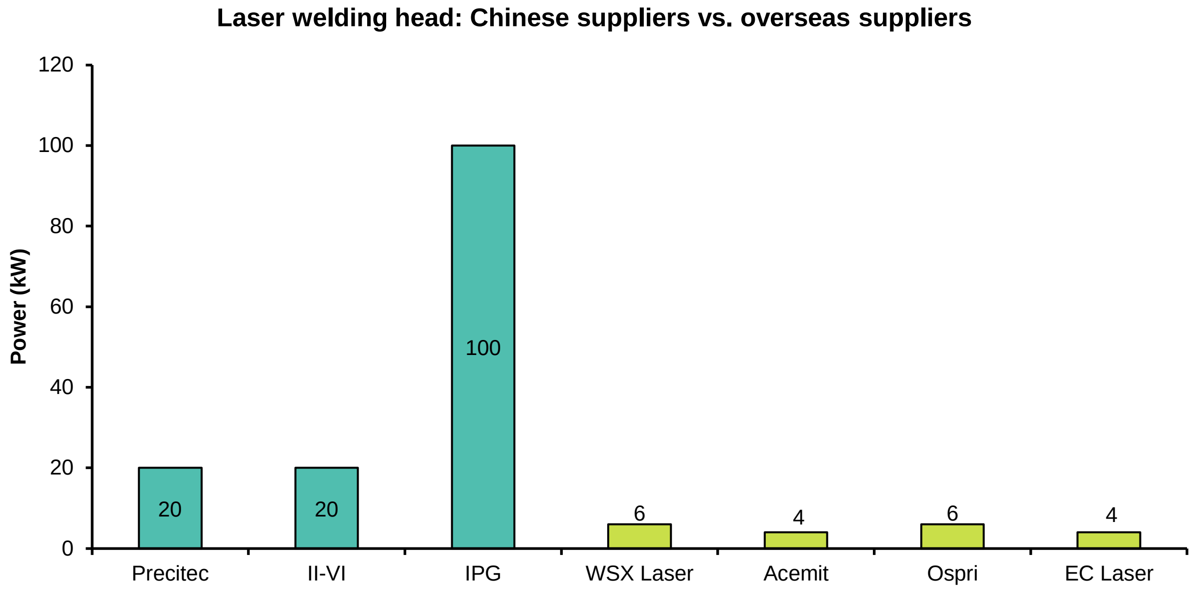
Source: TeraXion, AFR, Research advance on the key technology of high-power fiber laser materials and components (2017) (Changsheng Yang, et al., Scientia Sinica Techologica), and Bernstein analysis

EXHIBIT 192: **Spec comparison of laser cutting heads (1/2)**



Source: Company websites and Bernstein analysis

EXHIBIT 193: **Spec comparison of laser welding heads (2/2)**



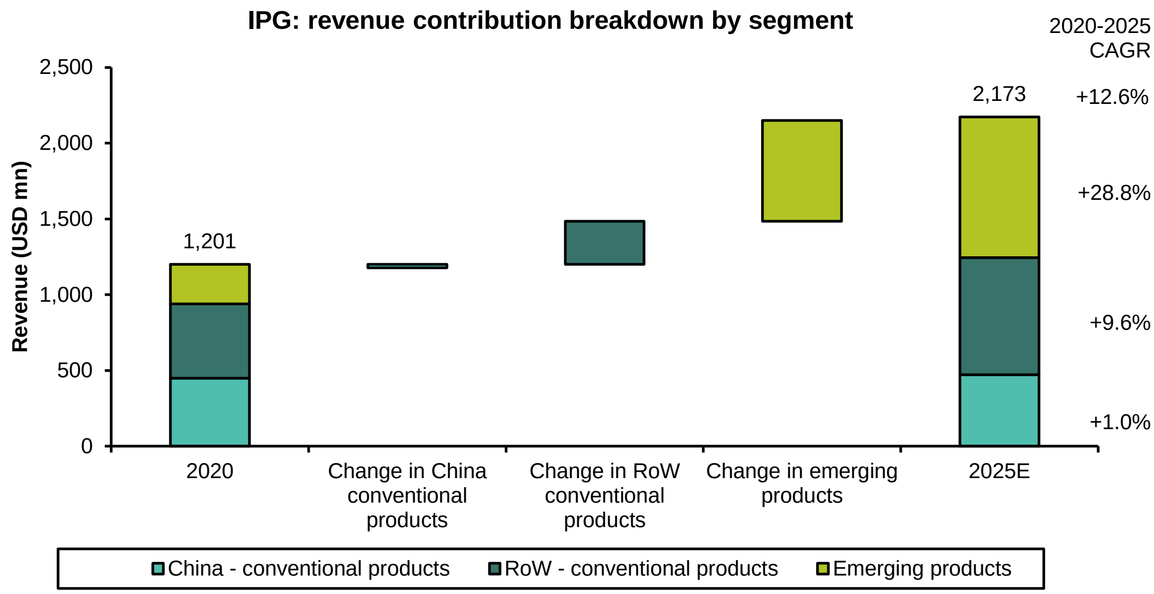
Source: Company websites and Bernstein analysis

FIBER LASER: A GLOBAL LEADER AND THE LOCAL "DUEL"

IPG PHOTONICS: THE GLOBAL LEADER

People have traditionally associated high-end demand with higher power levels, but that is no longer so. In China, even cutting demand exceeding 10kW comes mostly from metal workshops, a large portion of which can tolerate significantly lower laser performance. As a result, even when IPG's technology remains superior and retains >50% market share in performance-demanding applications such as welding, local players such as Raycus and Maxphotonics have firmly established themselves as "good enough" in most cutting applications. We believe IPG's overall share in China will further decline from ~35% in 2020 to 24% by 2025. Despite this competitive headwind, we believe IPG can still deliver 12% five-year CAGR globally (see Exhibit 194), because its emerging products address multiple secular trends, including EV, battery, and microelectronics, more than double its TAM, have already shown strong traction, and can contribute 40-45% of revenue (~30% in 2021) in 2025.

EXHIBIT 194: **IPG can continue to expand at double-digit CAGR despite competitive headwinds in China**



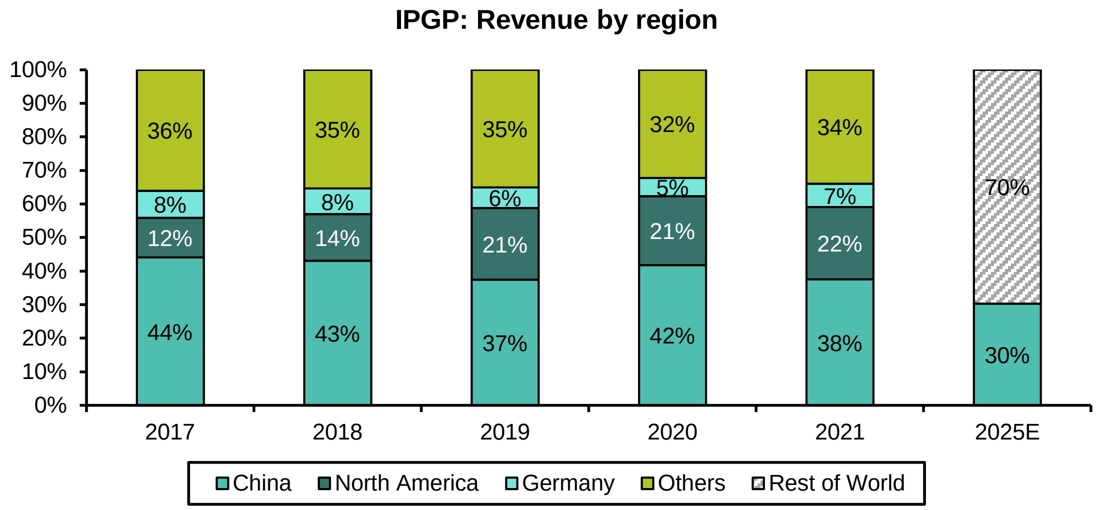
Note: Shows regional revenue excluding emerging products and so it differs from company's reporting. For emerging products, we assume 20% are in China for modeling purpose.

Source: IPG, and Bernstein estimates and analysis

Cyclical headwind in China

As China remains the most important market for IPG (see Exhibit 195), IPG's stock price has a strong correlation to the automation cycle in the country. In the 2020-1H2021 upcycle, fiber laser demand was helped disproportionately by the unique high-power to ultra-high-power upgrade in China — laser cutting customers adopted 10-30kW systems much faster than expected and ahead of all other regions. The upgrade picked up momentum in 4Q19 and reached peak contribution to IPG in 2H20 (see Exhibit 196). While the long-term TAM of these 10-30KW units is at least an order of magnitude bigger from today, in this early phase of adoption, demand is mostly associated with construction, heavy industrial equipment, and shipbuilding, and near-term capex seems to be tapering off.

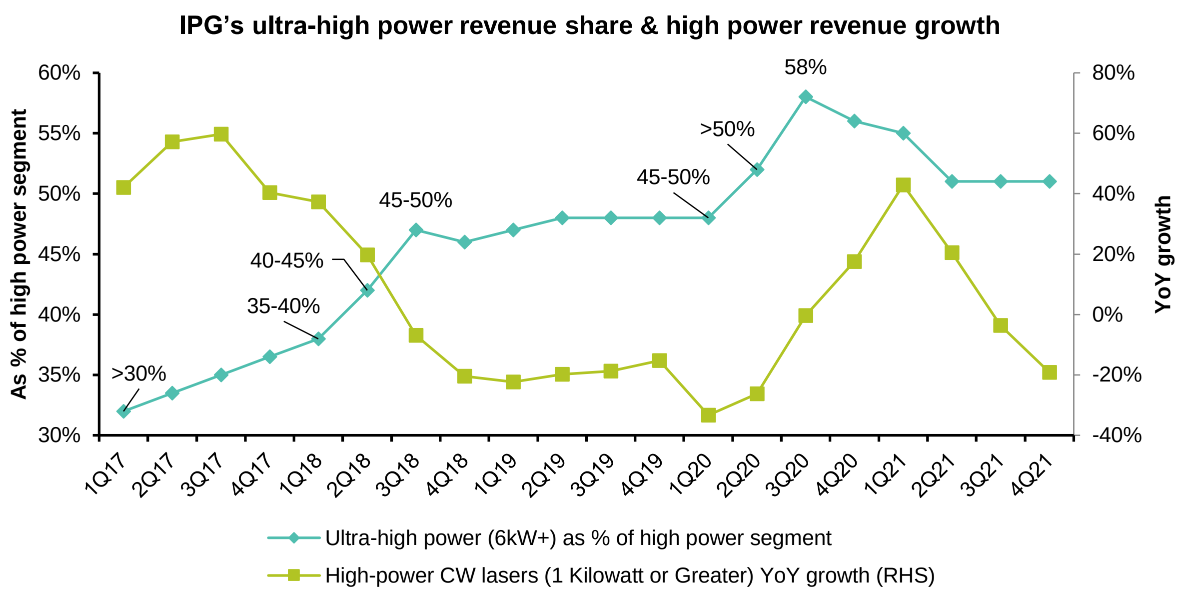
EXHIBIT 195: **China remains the most important market for IPG**



Note: Regional revenue includes conventional and emerging products.

Source: IPGP, and Bernstein estimates and analysis

EXHIBIT 196: **Near-term demand for ultra-high-power upgrade (mostly from China) already tapering off**



Source: Company reports, and Bernstein estimates and analysis

Persisting competitive pressure

When a downcycle hits, the best defense is market share gain. It certainly does not help that IPG is facing persistent competitive pressure and will likely see its share in China further decline to 24% in 2025 (see Exhibit 197). This rate of share loss in a market that expands at mid-teen CAGR means that IPG's conventional fiber laser product revenue[47] will remain largely flat during 2020-25 (see Exhibit 194).

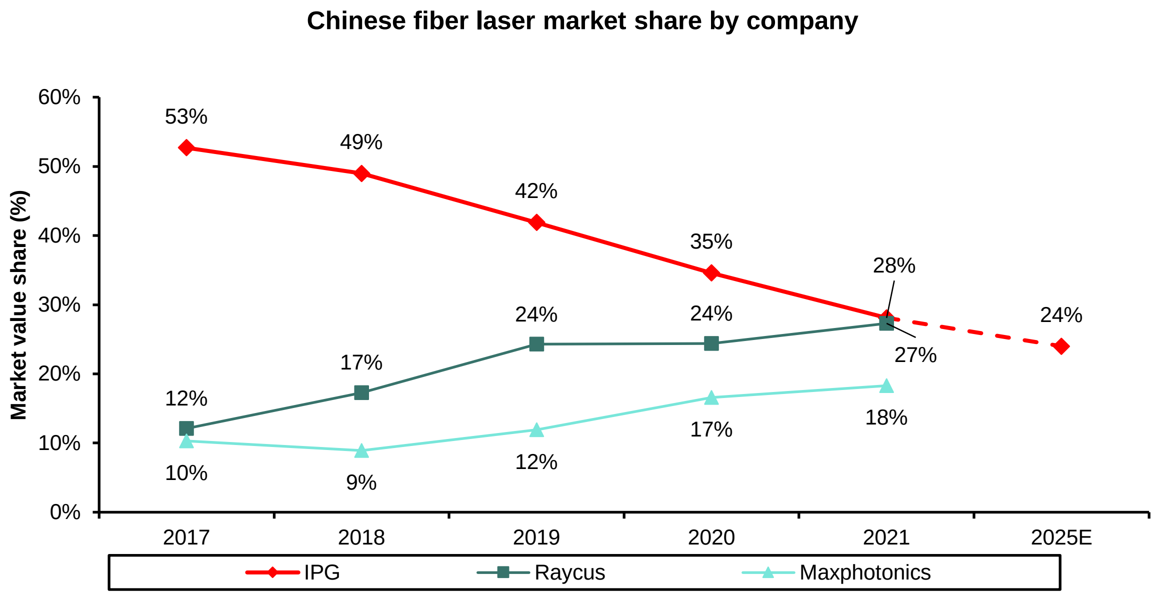
From a technical point of view, IPG is still superior and remains a moving target for Chinese competition. The tangible product performance differences include short-term stability (in power and beam mode), long-term durability, energy efficiency, and controllability.[48] However, with faster-than-expected progress of Chinese laser components upstream (diodes, fibers, etc.), leading Chinese fiber laser makers such as Raycus and Maxphotonics (both not covered by Bernstein) have established themselves as good enough in most cutting applications, with the apparent specs (e.g., highest power, beam quality parameter, and output fiber diameter) of their products becoming very similar to IPG's.

The painful realization to IPG and to us is that there are many low-end customers in ultra-high-power cutting. In China, even cutting demand exceeding 10kW comes mostly from metal workshops. Since the machines are standalone and not integrated in production lines, a large portion of these customers can tolerate significantly lower laser reliability. Raycus' and Maxphotontics' traction in 10kW+ fiber lasers in the last 12 months is strong evidence of it (see Exhibit 198 and Exhibit 199). IPG's share loss (see Exhibit 197) is largely due to the quick expansion of the cutting segment in China. In contrast, it still retains >50% market share in performance-demanding applications such as general welding, and automotive and battery manufacturing.

Because of IPG's product superiority, it is able to hold the 30-40% price premium, a gap largely unchanged from 2017, even though overall ASP has gone down significantly for all players (see Exhibit 200). In 2021, the fierce competition between the two leading local players, Raycus and Maxphotonics, led to 30-40% ASP decline, but IPG maintained price discipline and did not follow the price war (see Exhibit 200). The different choices manifested as diverging revenue trends (see Exhibit 201) and margin trends (see Exhibit 202) between IPG and Raycus. We applaud IPG's price discipline, but also see the domestic competition between Raycus and Maxphotonics, and the resulting expansion of price gap as an ongoing risk to IPG's China business. It will have to walk a very fine line between maintaining price and slowing down market share loss.

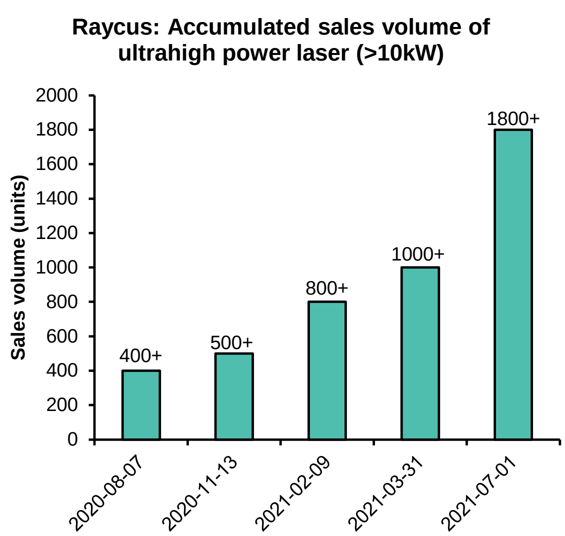
[47] This excludes emerging products from IPG; see later in this chapter for details.
[48] See Global Automation: The hurdles to becoming "the next Keyence, IPG, and Harmonic Drive" from China.

EXHIBIT 197: **We believe IPG's share in China will continue to decline because of a quickly growing low-end segment**



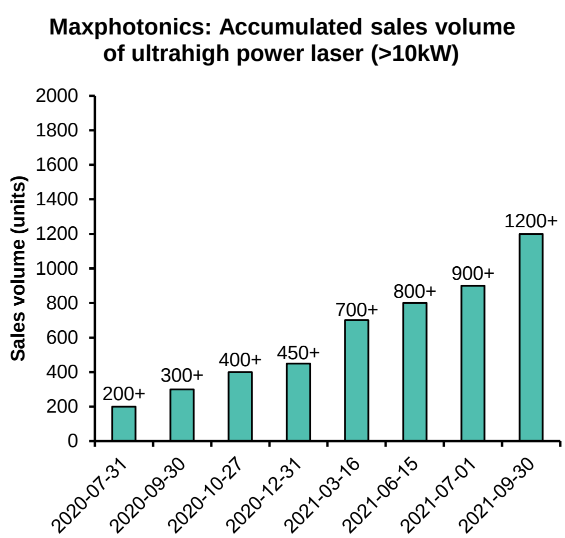
Source: Annual report on Chinese Laser Industry (published by Wuhan Library, Chinese Academy of Sciences), and Bernstein estimates and analysis

EXHIBIT 198: **There is enough low-end demand in ultra-high-power cutting (1/2)**



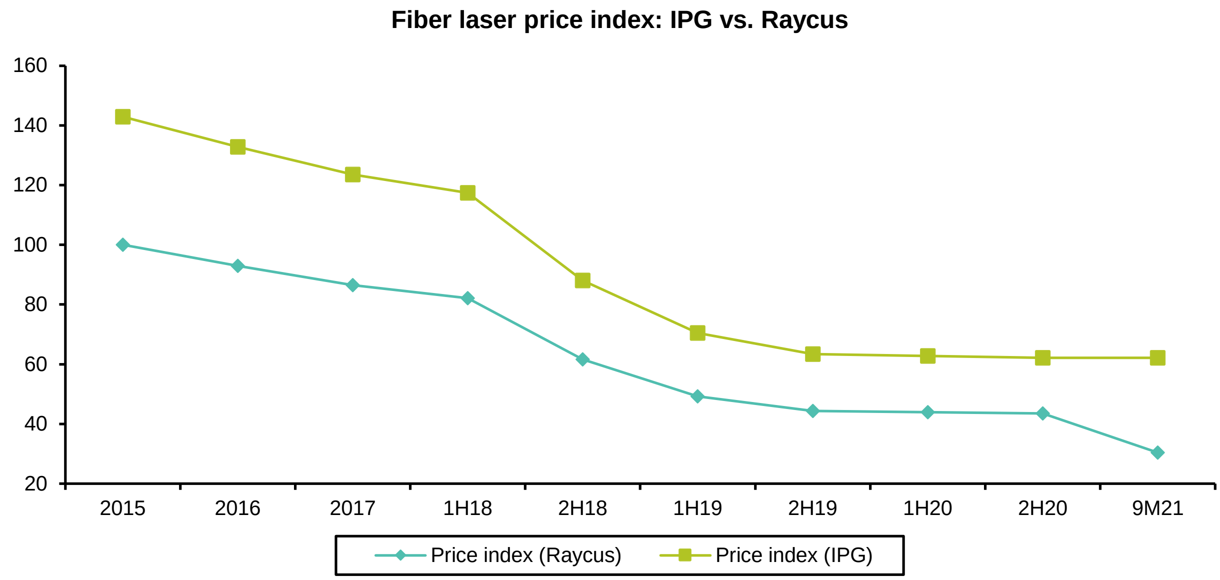
Source: Raycus and Bernstein analysis

EXHIBIT 199: **There is enough low-end demand in ultra-high-power cutting (2/2)**



Source: Maxphotonics and Bernstein analysis

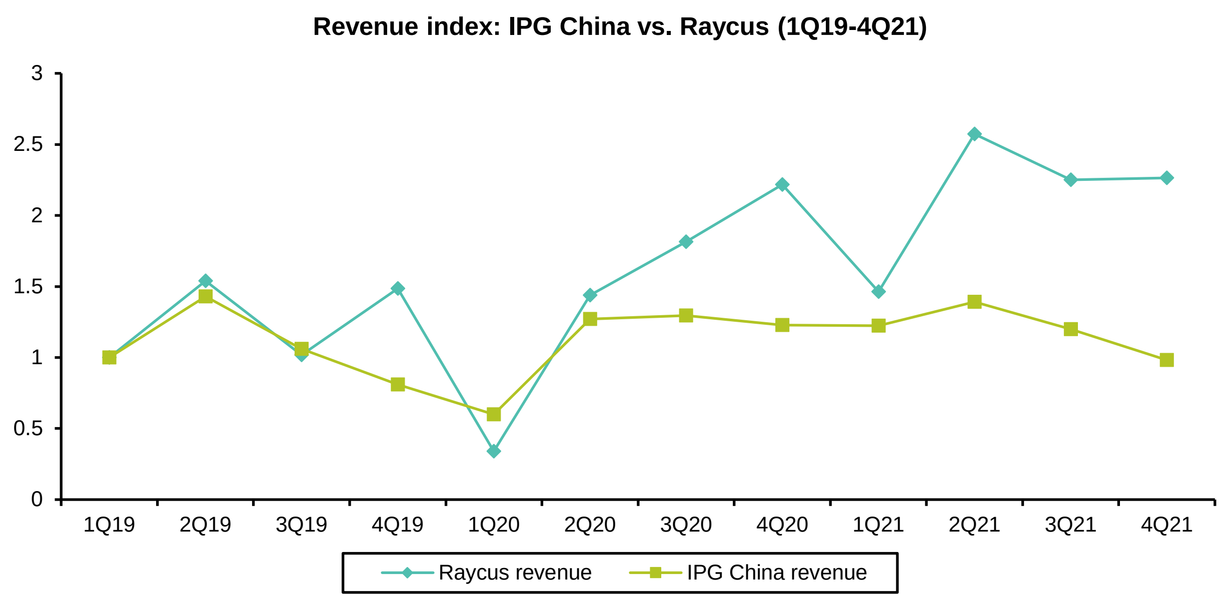
EXHIBIT 200: **IPG held a 30%+ price premium vs. Chinese competition; the gap expanded in 2021 due to IPG's price discipline and Raycus' price war against Maxphonotics**



Note: Price indexes based on per unit laser power.

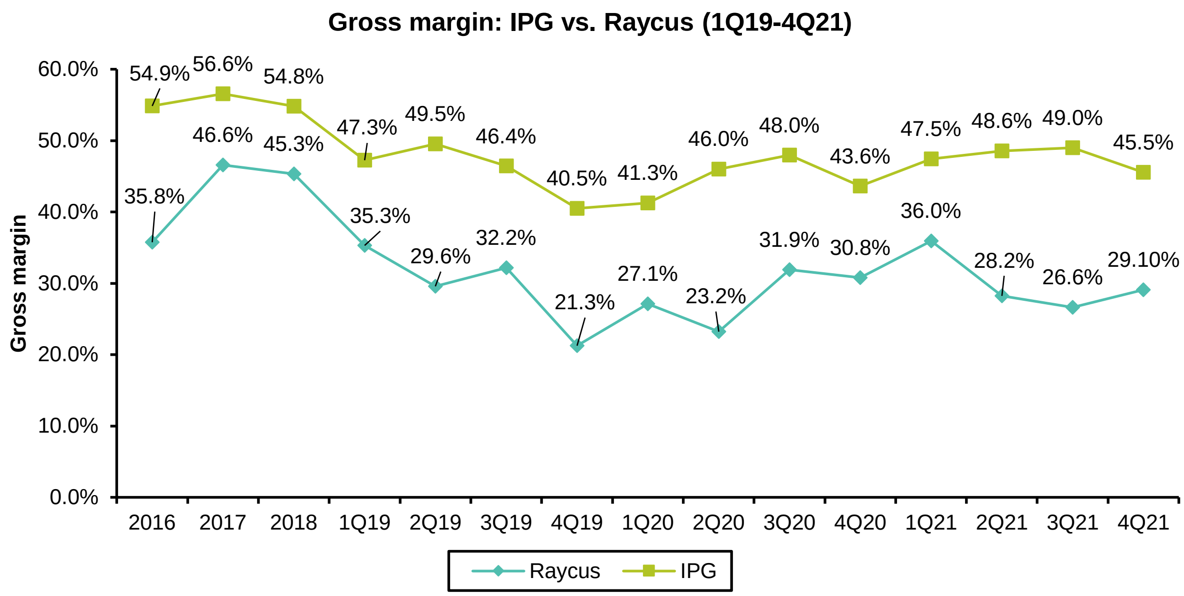
Source: Prospectus and annual/quarterly reports of Raycus, and Bernstein analysis

EXHIBIT 201: **Revenue trends (index): IPG China vs. Raycus**



Source: Bloomberg and Bernstein analysis

EXHIBIT 202: **GP margin trends: IPG vs. Raycus**



Source: Bloomberg and Bernstein analysis

The remaining technology gap

Even though multiple Chinese fiber laser makers have all but "commoditized" 10kW+ fiber lasers, the performance of IPG's "entry level" 1-6kW products is still meaningfully superior in terms of stability, lifetime, consistency, energy efficiency, and form factors (size). As a result, the price discount of Chinese products remains unchanged at 30%+ in that segment over the last three to four years.

Take operational lifetime and form factor as two examples. Chinese 3kW CW fiber lasers typically show 10%+ power degradation after 2,000 hours of operation, while IPG's power degradation is negligible over 3,000 hours. Power degradation becomes a much more serious issue for users at higher power levels of 10-30kW.

In terms of form factor, the size of IPG's kilowatt lasers has reduced by >75% over the years. Its ultra-compact U series lasers introduced in 2020 are 70-80% smaller and 40-60% lighter than Raycus models of the same output (see Exhibit 203). Compact form factors are not only evidence of superior design and engineering, but also save space and cost for machine builders and end-users.

EXHIBIT 203: **IPG's latest U series lasers are 70-80% smaller and 40-60% lighter than Raycus models**

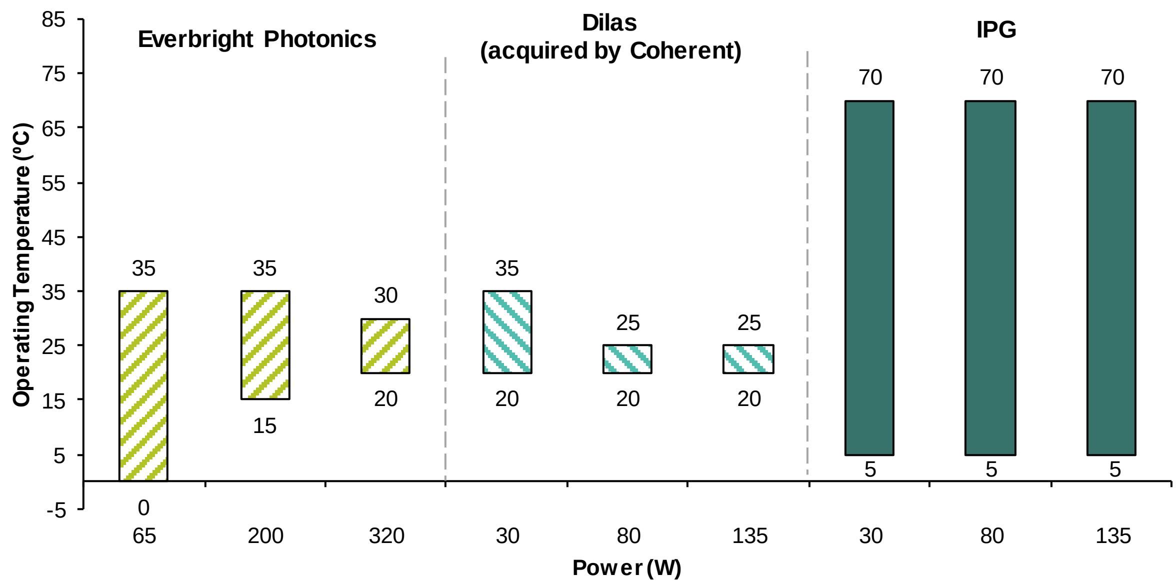
Dimensions (W×D×H, mm)	IPG U series	Raycus	Volume difference
1.0 kW CW fiber laser	448×550×88	485×237×748	-75%
1.5 kW CW fiber laser	448×550×88	900×447×251	-79%
2.0 kW CW fiber laser	448×760×88	900×447×251	-70%
Weight (kg)	**IPG U series**	**Raycus**	**Weight difference**
1.0 kW CW fiber laser	<30	< 50	-40%
1.5 kW CW fiber laser	<30	< 70	-57%
2.0 kW CW fiber laser	<40	< 70	-43%

Source: IPG, Raycus, and Bernstein analysis

IPG's proprietary in-house designs and manufacturing know-how are across most of the components discussed in this chapter, but particularly differentiating in pump diodes and active fibers. We only have a glimpse of IPG's superior technology from open data. For example, IPG's PLDs are spec-ed to work in a much broader temperature range compared with those from Chinese and global open-market suppliers (see Exhibit 204). This is critically important for industrial applications, as environmental temperature is rarely controlled. We have repeatedly heard complaints that domestic laser performance is ok in ideal environments, but stability deteriorates off the ideal range of temperature and humidity. Even when Raycus is getting the best supply from the open market, we believe pump diode quality, including the single-diode chip, the design of the submount with the heat sink, the micro-optics, and the coupling technology within the PLD, contribute the most to this gap vs. IPG. The continued improvement of IPG's diode technology is partly evidenced by its unique products such as high-peak-power lasers, where the diodes are turned on and off thousands of times a second but still maintain stability and long life, and partly by the cost curve independent of the scale factor (see Exhibit 205) — even when production volume decreased in 2019 and 2020, cost reduction continued.[49]

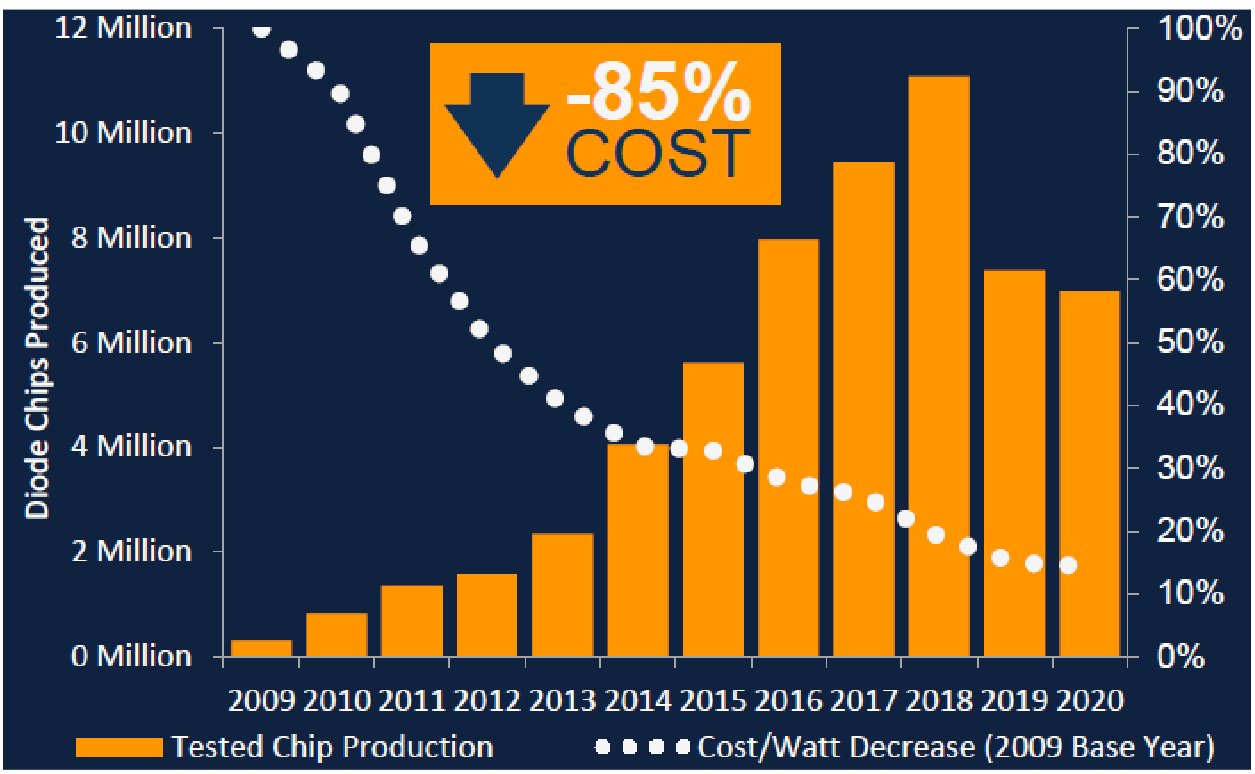
[49] Many people correctly point out that diode is a small fraction of fiber laser cost, but they often miss that diode cost reduction leads to almost proportionate reduction in other parts of COGS, including labor cost for assembly. See IPGP: A glimpse of the company's unique technologies and cost structure.

EXHIBIT 204: **IPG PLDs can work within a much broader temperature range, contributing to the superior stability of its fiber lasers**



Source: IPG, Everbright Photonics, and Bernstein analysis

EXHIBIT 205: **IPG's technology enabled consistent cost reduction, independent of the scale factor**

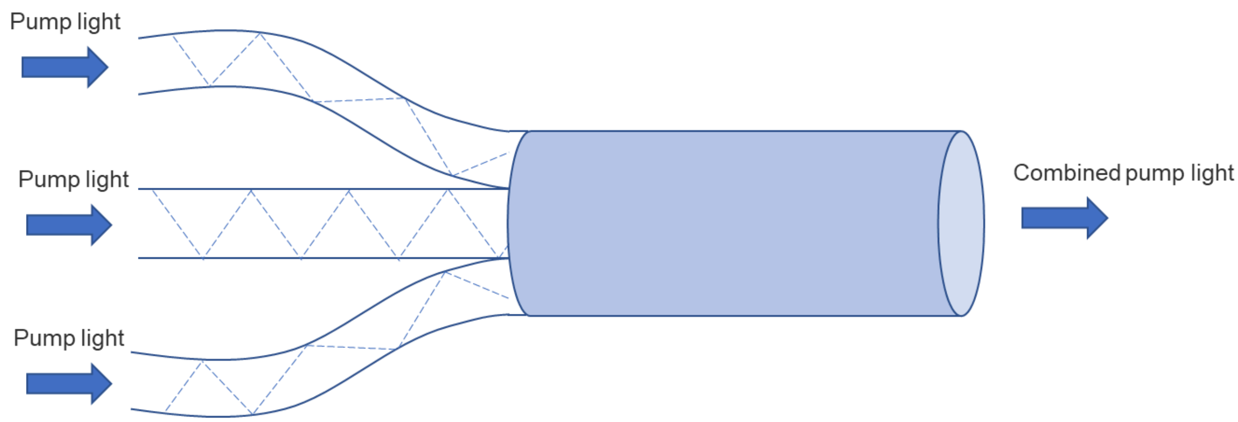


Source: IPG investor presentation

On the fiber side, we have discussed how the inhomogeneity of active fiber doping contributes to "darkening," which is a common reason for power degradation. Compared with most open supply, IPG's active fibers show superior performance at ultra-high powers of 8kW and above, partly due to its proprietary doping recipe and process. Many other parameters of the active fiber greatly impact power and mode stability, although technical details are difficult to obtain.

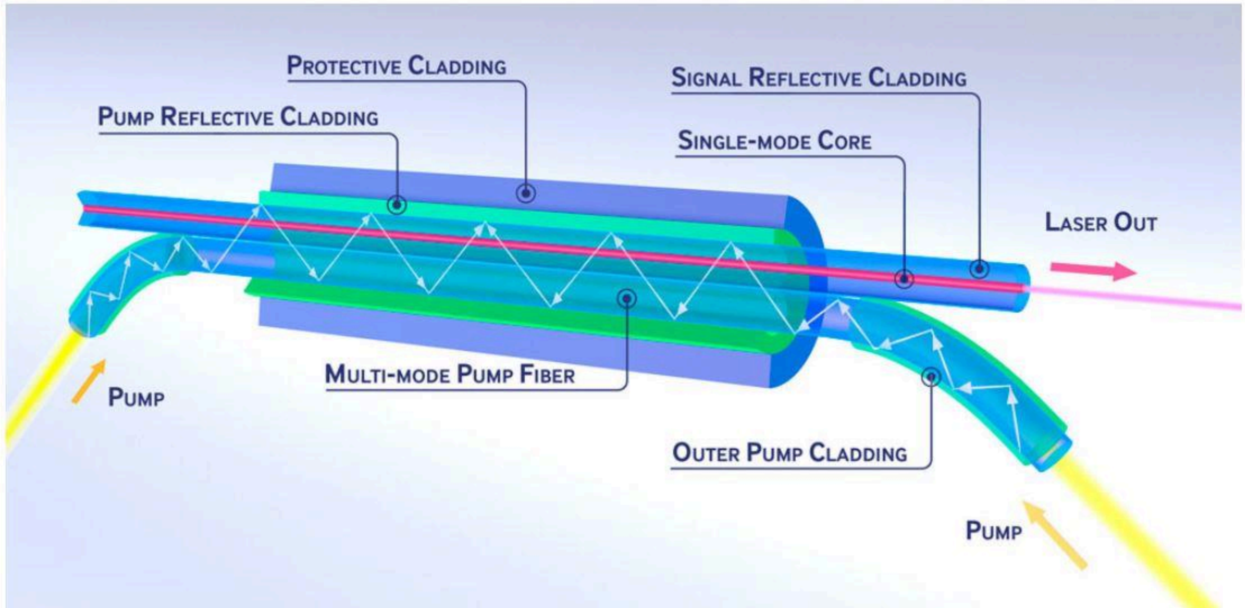
Besides the active fiber, IPG also uses a proprietary side-pumping design to couple the light from the pump to the single-mode active fiber (see Exhibit 207). This is enabled by proprietary designs of the geometry, optical properties of the core, double claddings of the active fiber, and by unique manufacturing processes. Compared with the end-pumping widely used by fiber laser makers around the world (see Exhibit 206), IPG's side pumping demonstrates superior energy conversion efficiency and stability.

EXHIBIT 206: **End-pumping (commonly used by fiber laser makers)**



Source: Bernstein analysis

EXHIBIT 207: **IPG's proprietary side-pumping architecture**



Source: IPG website and Bernstein analysis

Emerging products

Since 2019, IPG has made important breakthroughs after many years of R&D in emerging products,[50] which comprise many types of novel lasers and laser-based systems. These emerging products address multiple secular trends, including the increase in laser welding penetration; EV, battery, and solar investments; microelectronics and medical device production; and non-industrial applications (see Exhibit 208). In these areas, IPG either faces much less Chinese competition (e.g., in welding and battery, solar, and EV), or is itself an attacker taking share from others (e.g., in ultrafast lasers and medical applications). Collectively, the new product expansion more than doubles IPG's TAM (see Exhibit 210).

Emerging products' contribution to IPG has gone up steadily from low teens to ~30% in less than three years (see Exhibit 209). In 2025, we believe the ratio will further increase to 43% (a revenue CAGR of 29% for the relevant products; see Exhibit 194). This becomes the most important driver for IPG to achieve a double-digit five-year CAGR. On average, the growth from emerging products is margin accretive, offsetting the potential negative margin impact from the price competition of mature products in China.

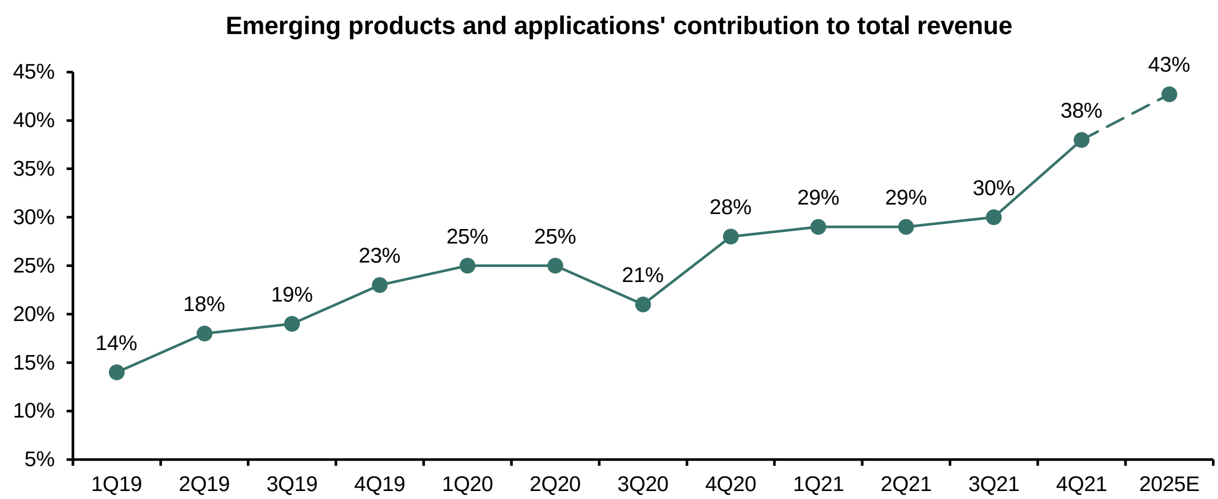
[50] See IPGP: Publish or perish - what papers, patents and Google Scholar tell us about company's future.

EXHIBIT 208: **IPG's emerging products address some of the world's most important secular trends**

Emerging products \ Growth areas	Microelectronics processing	R&D and scientific	Sensors and instruments	Medical / surgery	EV OEM	Battery	Solar	Medical device	General welding
High power pulsed laser	✓		✓			✓	✓	✓	✓
Green pulsed laser	✓		✓			✓	✓		
UV pulsed laser	✓		✓					✓	
Ultrafast pulsed laser	✓	✓	✓	✓				✓	
Adjustable Mode Beam (AMB)					✓	✓			✓
High Peak Power QCW					✓				
Lasers for medical procedures (e.g. mid IR)				✓					
Beam delivery accessories		✓			✓	✓		✓	✓
Products for communication			✓						
Laser-based systems	✓				✓			✓	✓

Source: IPG and Bernstein analysis

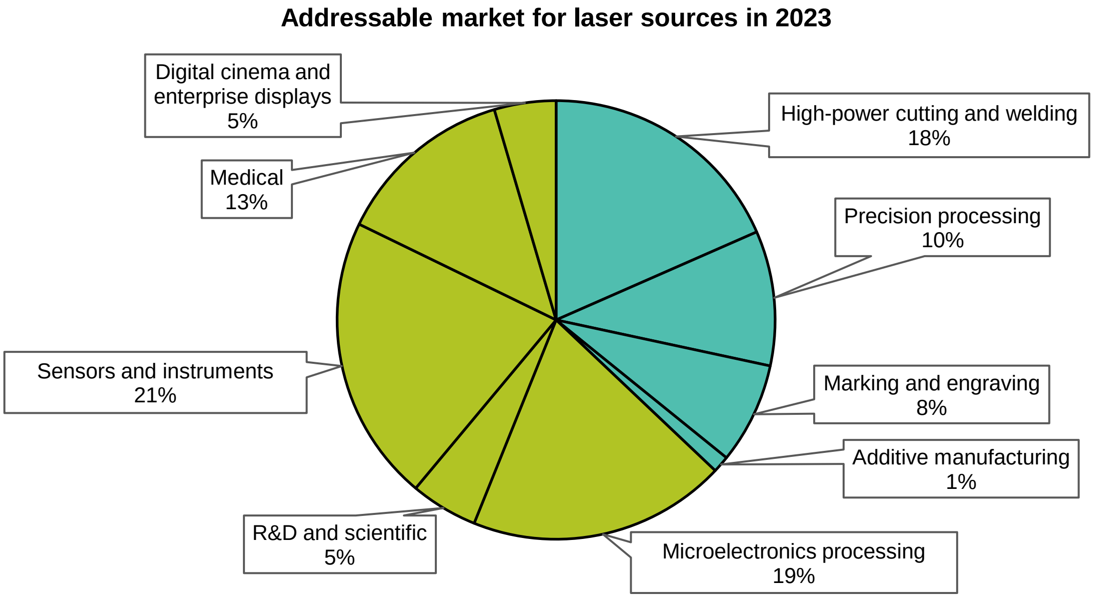
EXHIBIT 209: **IPG's revenue contribution from emerging products more than doubled in less than three years**



Note: "Emerging products and applications" include the following laser products: high power pulsed, green pulsed, UV pulsed, ultrafast pulsed, AMB, HPP, lasers for medical procedures; beam delivery accessories, products for communication and defense, and laser-based systems. Most of Genesis (acquired by IPG) revenue is non-laser systems and is not included here.

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 210: **New applications more than double IPG's TAM**



Source: Optech Consulting, Strategies Unlimited, IPG, and Bernstein analysis

THE DUEL: RAYCUS AND MAXPHOTONICS

For Raycus and Maxphotonics, now that the low-hanging fruits have been picked, the challenges may increase going forward.

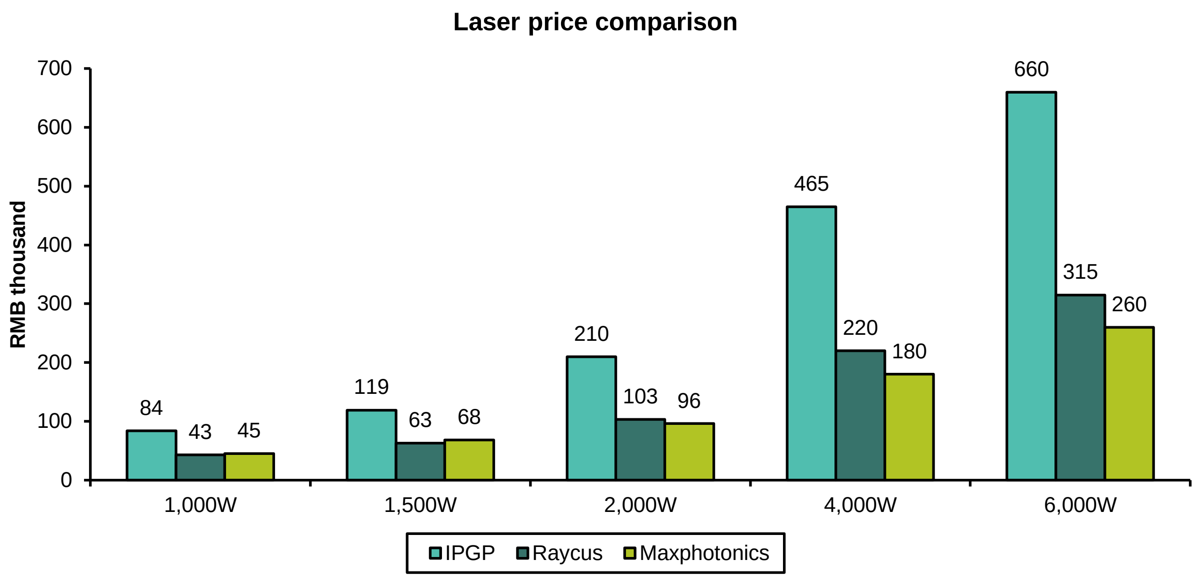
Crowded low end and persistent gap to high end

The path Raycus took in 2017-21 was about riding the improvement of the local component supply chain and designing products around the best open-market component technology. The progress was phenomenal. By 2020, Chinese upstream component players all but closed the gap vs. global open-market suppliers. Yet, even after this first gap was closed, IPG, with its vertical integration, still commands better product designs and component technologies compared with the open market. The remaining gap is much harder to close.

Price gap is the best indicator for tracking Chinese companies' technology levels vs. industry leaders. For fiber laser, the price gap has barely changed since 2018 and is still >30% even for the "entry level" 1-4kW products (see Exhibit 211).

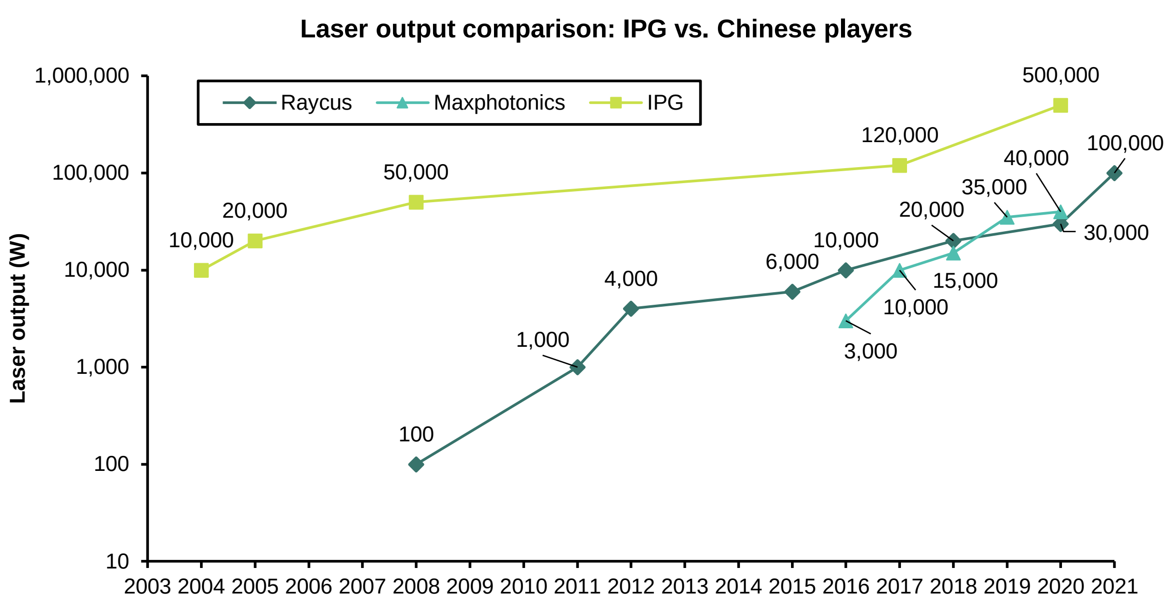
The bigger issue, we think, is that Raycus has not been able to distance itself from local competition. At least five credible Chinese fiber laser makers compete with similar pricing. Raycus products' marginal advantage does not allow it to charge a meaningful premium. Its closest competitor, Maxphotonics, lagged Raycus by one to two years in technology prior to 2017, but the gap had been fully closed by 2020 (see Exhibit 212).

EXHIBIT 211: **Price gaps remain significant between Raycus and IPG, even at the entry level (1-6kW)**



Source: Alibaba Taobao and Bernstein analysis

EXHIBIT 212: **Maxphotonics closed a one- to two-year technology gap vs. Raycus by 2019**

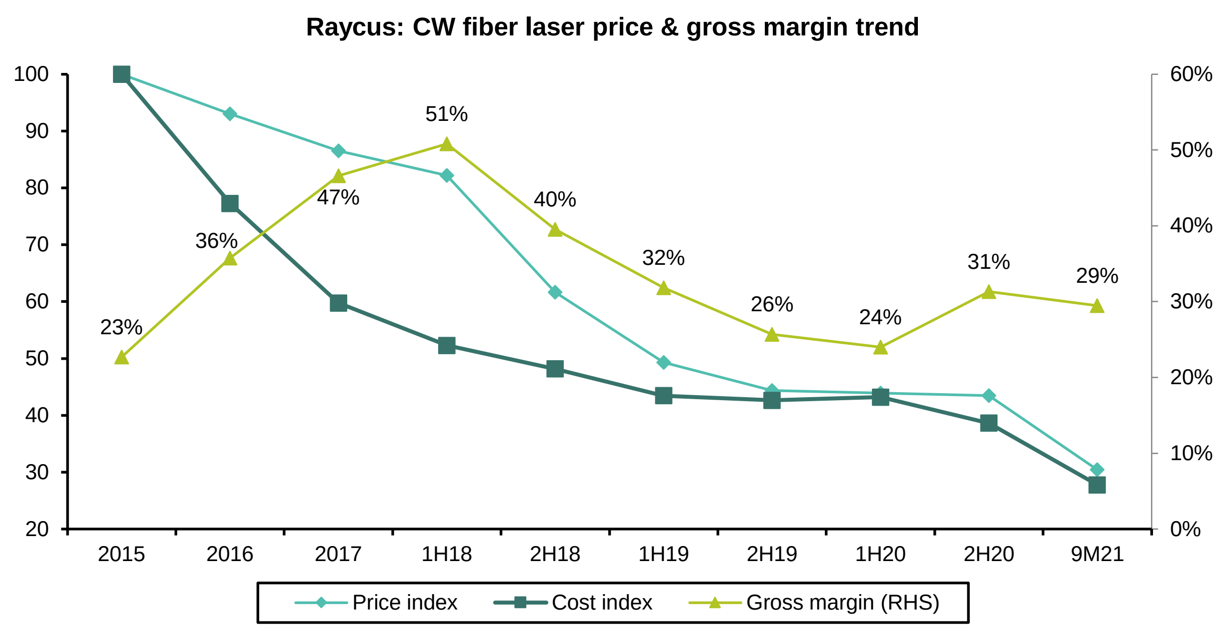


Source: .Prospectus of Raycus, prospectus of Maxphotonics, company websites, and Bernstein analysis

Diminishing cost levers

The factors that slow down Raycus' technology progress are also challenging its cost reduction. Before 2017, cost reduction was mainly driven by economy of scale, as the company grew from a very small base (see Exhibit 214). After the initial phase of steep cost reduction until 2017, Raycus had to continue to cut price to compete, even when the cost curve flattened, resulting in margin contraction in 2018-20 (see Exhibit 213). The latest round of cost reduction in 2021, partly thanks to upstream diode technology improvement, was all but passed on to customers as a further price cut, due to the fierce competition with Maxphotonics. We think this will continue to be the case going forward and, as a result, Raycus' GP margin is unlikely to expand significantly from the current level (see Exhibit 214).

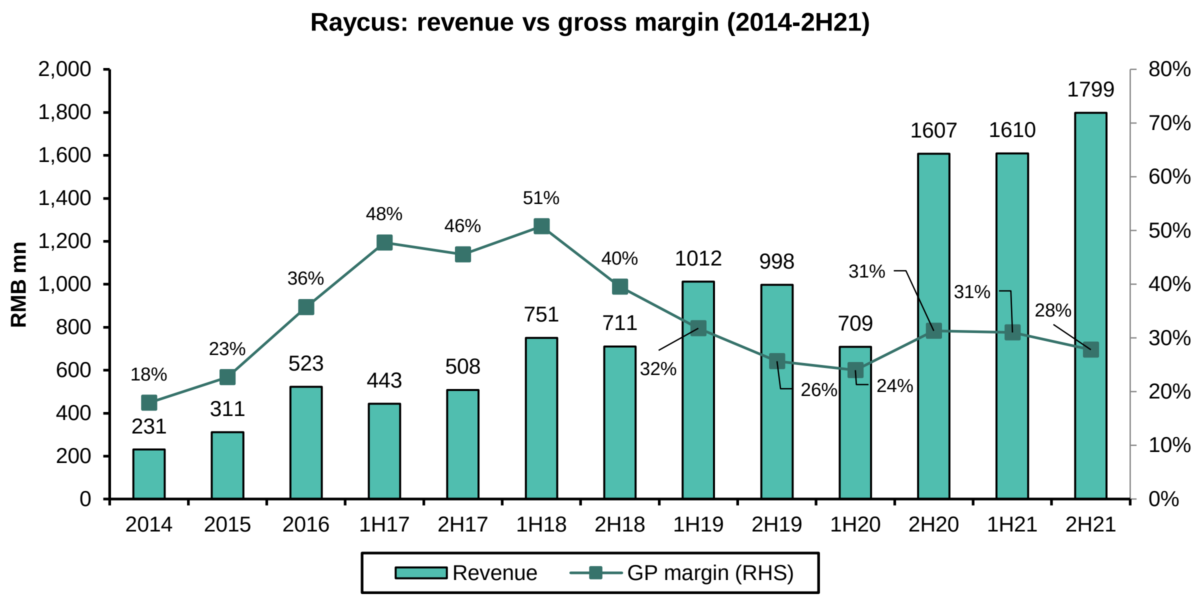
EXHIBIT 213: **Raycus' unit price and cost curves**



Note: Price and cost indexes are based on per unit laser power.

Source: Prospectus and annual/quarterly reports of Raycus and Bernstein analysis

EXHIBIT 214: **Raycus' growing scale did not help it maintain margin after 2018**



Source: Bloomberg, company reports, and Bernstein analysis

Hidden cost

Raycus has executed an aggressive growth strategy since its IPO in 2018. It routinely provided generous customer credit, extended warranty, and free replacement units. As a result, its inventory and receivables increased to dangerously high levels, which paint the picture of a company that was fixated on growing at almost any expense. There may be hidden costs associated with the potential impairment of inventory or receivables. For example, inventory would need to be written off if new units are given to customers for free to replace deteriorating products. To gauge the impact, inventory was about 3x 2020 net profit.

NEW CHAMPION IN THE UPSTREAM: SCARCITY OF LASER CHIPS, URGENCY FOR LOCALIZATION, AND A MARKET TOO BIG TO SERVE

Suzhou Everbright Photonics Co., Ltd. (苏州长光华芯光电技术股份有限公司) is China's leading laser diode chip manufacturer, products of which can be used in industrial laser pumping, laser sensing, high-speed optical communication, etc. In the laser supply chain, Everbright's business is in the upstream (see Exhibit 215). It has four product segments (see Exhibit 216):

- **Single-emitter diode chip series** (88.0% of revenue in 2020 and 75.1% of revenue in 1H21) includes single-emitter diode chip, COS, PLD, and semiconductor lasers. These products form a cascaded structure, with the former being the components of the latter (see Exhibit 180). PLDs typically consist of 10 to 20 single-emitter diode chips and are the energy sources for many types of lasers.

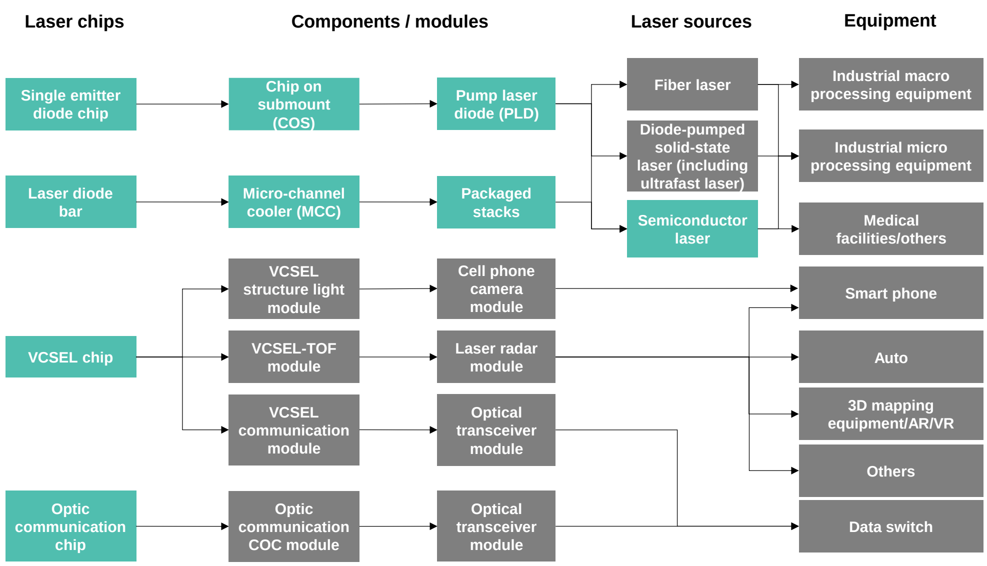
- **Laser diode bar series** (10.4% of revenue in 2020 and 23.4% of revenue in 1H21) includes laser diode bar, micro-channel cooler (MCC), and packaged stacks. Just like single-emitter diode chips in a PLD, laser diode bars are the building blocks in a packaged stake. A laser diode bar is different from a single-emitter diode chip in that the former has multiple laser output points and higher output power. However, with better performance and longer life, more and more laser systems are being built on single emitters.

- **Vertical-cavity surface-emitting laser (VCSEL) series** (1.4% of revenue in 2020 and 1.0% of revenue in 1H21) includes VCSEL chips. While the earlier two segments have edge-emitting laser (EEL) diodes, VCSELs emit laser beams perpendicular to the top surface. VCSEL has seen increasing adoption in 3D sensors of consumer electronics (e.g., facial and object recognition, and AR/VR) and assisted/autonomous driving, as well as in optical communication.

- **Optic communication series** is a product segment under development. While it had no revenue contribution in 2020, Everbright has successfully developed the relevant products.

Across the segments, laser diode chip manufacturing is the foundation. Everbright is an integrated device manufacturer (IDM) with a complete process platform and mass production capability, covering chip design, MOCVD, lithography, cleavage/coating, package testing, fiber coupling, and so on. In the Chinese laser supply chain, there is a scarcity of diode chip manufacturing capability: while China has 30+ fiber and semiconductor laser makers, and about a third of them claim to make pump modules, almost all lack chip capability. As they increasingly look for domestic chip supply, they have few choices (see Exhibit 217).

EXHIBIT 215: **Everbright is a diode chip maker in the upstream of the laser industry**



Note: Everbright's business is in green-colored cells.

Source: Prospectus of Everbright and Bernstein analysis

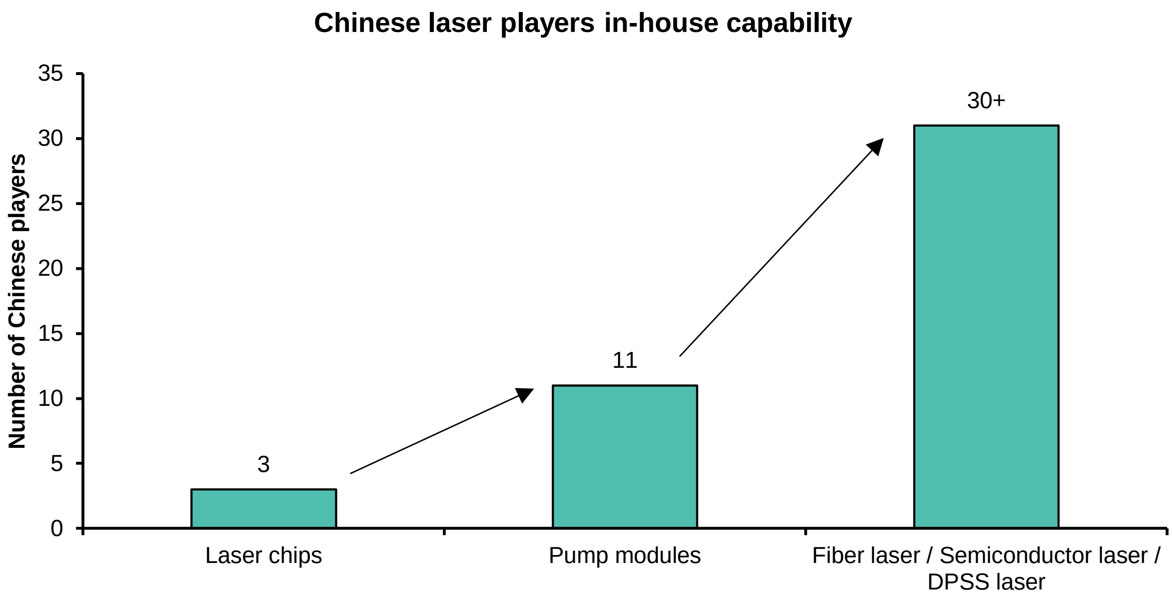
EXHIBIT 216: **Everbright's business segments and competitors**

Everbright products breakdown		% in total 1H21	Downstream applications	Competitors	
				Chinese suppliers	Overseas suppliers
Single emitter diode chip series	Single emitter diode chip	41.2%	Industrial laser pump, scientific research, biomedical science, laser equipment	BDL, Raybow Opto, Huaguang Opto	II-VI, Dilas (acquired by Coherent), OSRAM
	Chip on submount (COS)	1.2%	Industrial laser pump, scientific research, biomedical science, laser equipment	BDL, Raybow Opto, Focuslight	II-VI, Dilas
	Pump laser diode (PLD)	31.5%	Direct-diode laser pump, fiber laser pump, illumination, scientific research, biomedical science, direct material processing	BWT, Focuslight, Huaguang Opto, Xinghan laser	nLight, II-VI, IPG, Lumentum, Dilas
	Semiconductor laser	1.3%	Direct material processing including soldering, welding, cladding, cutting, additive manufacturing	Raycus, Maxphotonics, BWT	Lumentum
Laser diode bar series	Laser diode bar	4.7%	Industrial laser pump, scientific research, biomedical science, laser equipment	Raybow Opto, Huaguang Opto	II-VI, Dilas
	Micro-channel cooler (MCC)	18.2%	Industrial laser pump, scientific research, biomedical science, laser equipment	Focuslight, Huaguang Opto	II-VI, Dilas
	Packaged stacks	0.5%	Direct-diode laser pump, scientific research, biomedical science	Focuslight, Huaguang Opto	II-VI, Dilas
VCSEL series	VCSEL chip	1.0%	Short range sensing, 3D sensing, biomedical science, face recognition, laser radar, AR/VR	Vertilite, BrightPhoton, Qianmu Laser, LEMON Photonics	II-VI, Lumentum, AMS
Optic communication series	Optic communication chip	0.0%	5G, optical access network, metropolitan area network, data center	Vertilite	Lumentum
Others		0.5%			
Total		100.0%			

Note: Of the companies mentioned, Bernstein only covers IPG Photonics.

Source: Prospectus of Everbright, company websites, and Bernstein analysis

EXHIBIT 217: **In the Chinese laser supply chain, upstream is a scarcity; there are just a handful of local suppliers**



Source: Annual Report on Chinese Laser Industry 2021 (published by Wuhan Library, Chinese Academy of Sciences), company websites, and Bernstein analysis

Everbright is a relatively young company. Its operations began in 2012 with the production of PLDs and packaged stacks. It started the development of single-emitter diode chips in 2015 and established two new business units, VCSEL BU for horizontal expansion and Laser Systems BU for vertical expansion, in 2018. Since then, the company's technology and product advancement has greatly accelerated (see Exhibit 218).

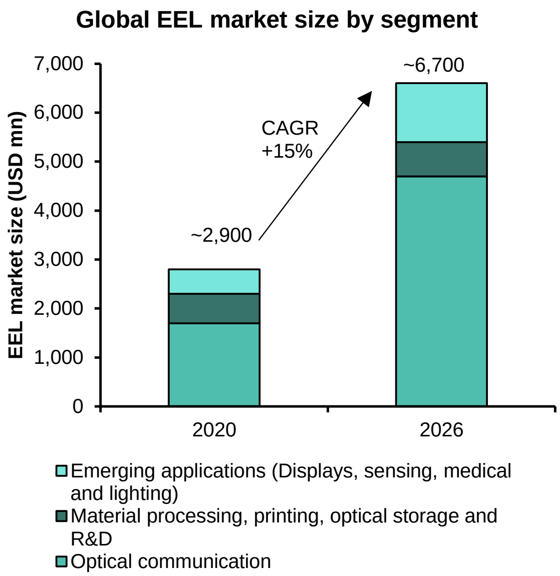
EXHIBIT 218: **Everbright is a relatively young company; its technology and product advancement have accelerated since 2018**

Corporate development		Technology / product development
Dr. Xinsheng LIAO founded Everbright in 2012	**2012**	Started chip design, built lines for packaging, testing, and fiber coupling
Established sales network	**2013**	Mass production of pump laser diodes (PLDs) and packaged stacks
	2014	Started R&D on kW-level semiconductor laser systems
Huadong PAN rejoined in 2015	**2015**	Started R&D on single emitter diodes
	2016	
Dayong MIN and Dr. Jun WANG joined in 2017	**2017**	Launched 360W 200µm 976 nm PLD
Established VCSEL BU (horizontal expansion), and Laser System BU (vertical expansion)	**2018**	Launched various diode bar and PLD products; 6-inch VCSEL line started mass production in 4Q
	2019	Launched 15W single emitter diodes Launched 600w 200µm 976nm PLD and a series of semiconductor laser systems; VCSEL capacity reached 10KK/month
Hubble Investment (a subsidiary of Huawei) acquired 4.98% stake at RMB15/share (12/2020)	**2020**	Launched 18W, 25W single emitter diodes; Commercial launch of VCSEL chips; Initiated InP optical communication chip production process
	2021	Launched 28W, 30W single emitter diodes; launched VCSEL and EEL products for automotive LiDAR
Stock (688048.CH) started trading on STAR board (4/1/2022)	**2022**	To launch 35-40W single emitter diodes

Source: Prospectus of Everbright and Bernstein analysis

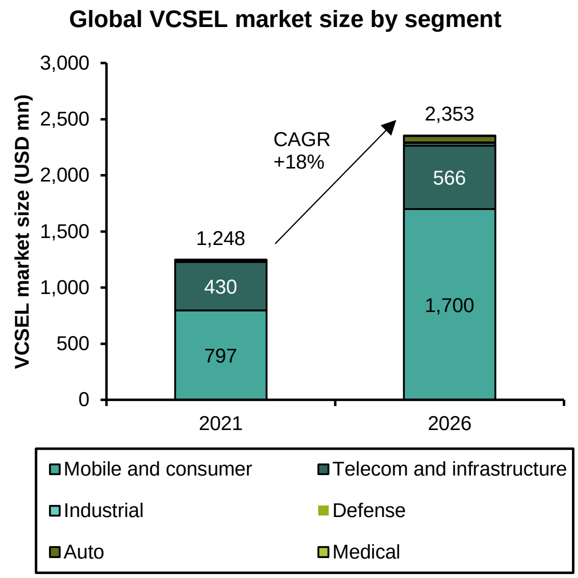
EEL and VCSEL diodes are the two major types of laser chips with different beam orientations. EELs emit light from the side of a chip while VCSELs emit light perpendicular to the top surface of a chip. EEL and VCSEL markets are projected to expand at a double-digit CAGR and reach USD6.7bn (see Exhibit 219) and ~USD2.4bn (see Exhibit 220) by 2026, respectively. Everbright's current revenue is predominantly from EEL and EEL-based modules, but it successfully mass-produced VCSEL chips in 2018 and commercialized the product series in 2020, so we believe both EEL and VCSEL are part of the company's long-term TAM. China is approximately 20% of this global TAM.

EXHIBIT 219: **EEL will likely be a USD6.7bn market by 2026**



Source: Yole Développement SA data and estimates, and Bernstein analysis

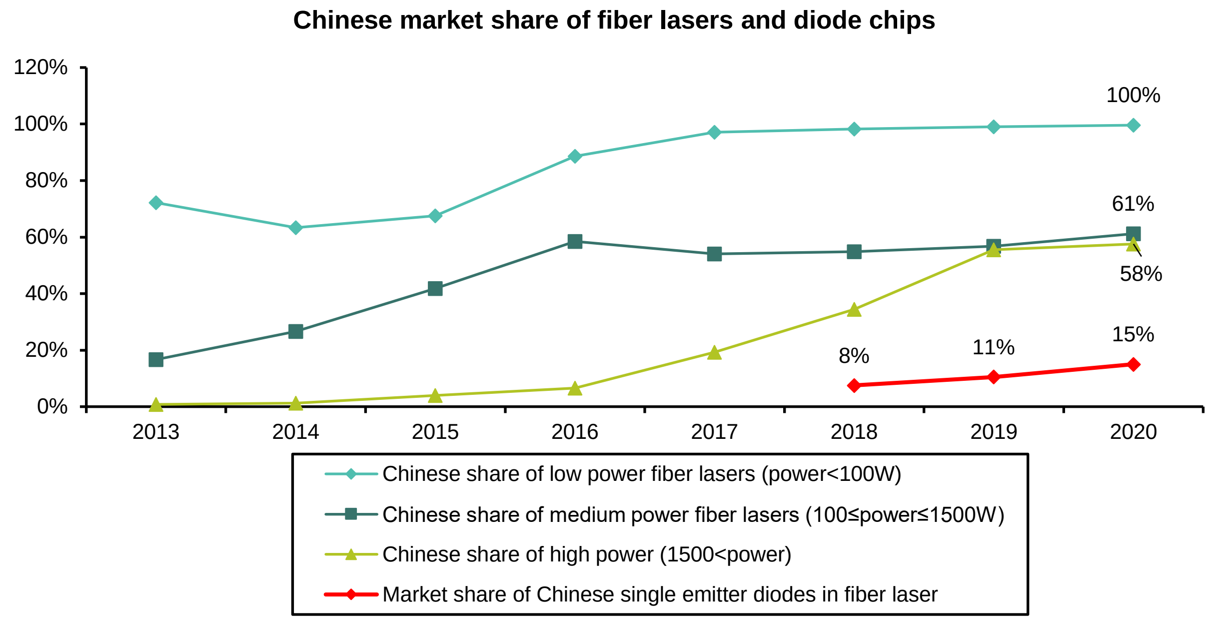
EXHIBIT 220: **VCSEL will likely be a ~USD2.4bn market by 2026**



Source: Yole Développement SA data and estimates, and Bernstein analysis

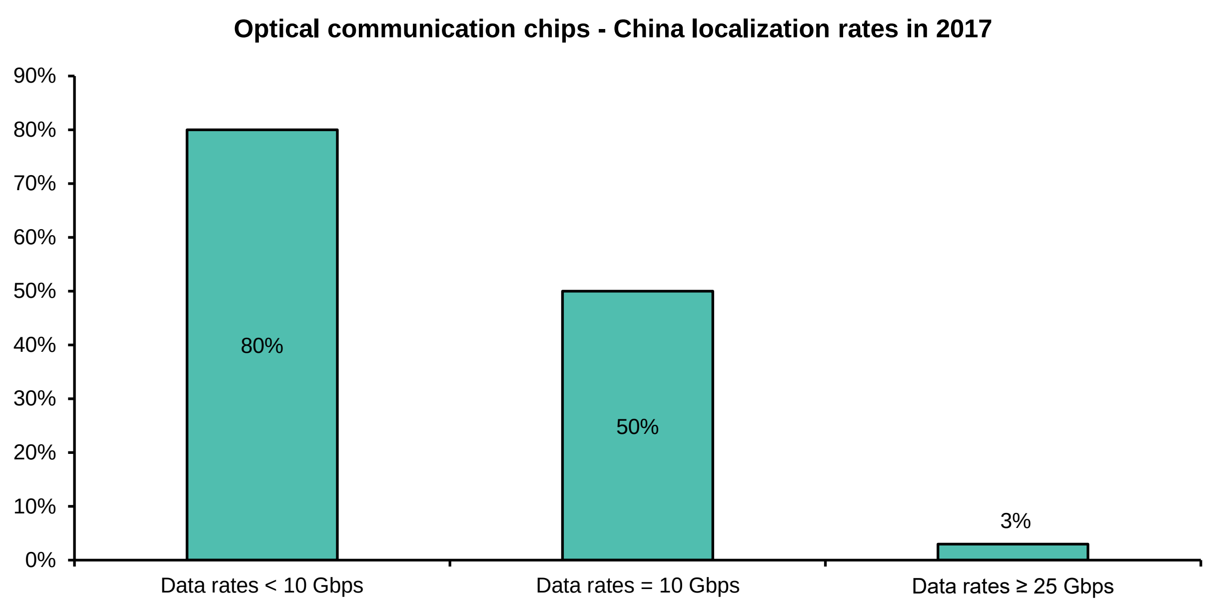
Compared with laser, which is itself an area of import substitution, there is much bigger room for localization in the upstream, especially diode chips. Taking the fiber laser supply chain as an example, the share of domestic brands in China reached 60-100% at various power levels in 2020, and the competitive landscape already started stabilizing. Yet, the domestic share of single-emitter diodes used in fiber lasers was no more than 15% (see Exhibit 221). Similarly, the localization ratio of high-end optical communication chips remains very low in China (see Exhibit 222).

EXHIBIT 221: **In the Chinese fiber laser supply chain, there is much more room for localization in upstream diode chips than in fiber laser**



Source: Prospectus of Everbright, Prospectus of Maxphotonics, Annual Report on Chinese Laser Industry (published by Wuhan Library, Chinese Academy of Sciences), and Bernstein estimates and analysis

EXHIBIT 222: **Localization ratio of high-end optical communication chips remained very low in China**



Source: China Electronic Components Association and Bernstein analysis

Chinese laser makers are feeling the urgency to localize laser diode chips, which are in the US Commerce Control List (CCL). The recent inclusion of China's leading fiber laser maker, Raycus, in the US Entity List will only push the 30+ other Chinese fiber and semiconductor laser makers to move faster toward chip localization, we believe.

In this context, Everbright's growth outlook is one with the highest certainty. Many Chinese laser makers are "waiting in queue" to buy from Everbright, the best among a handful of local diode chip makers. Since 2018, Everbright has operated under tight capacity. Its expansion of diode chip capacity in 2020 from 1.6 million to 4.6 million units/year was immediately utilized (see Exhibit 223) and allowed it to expand its business with major customers (see Exhibit 224). Everbright plans to enlarge its diode chip capacity to 7.3 million units/year in 2022 and extend it to 53.4 million units/year in the long term (see Exhibit 227).

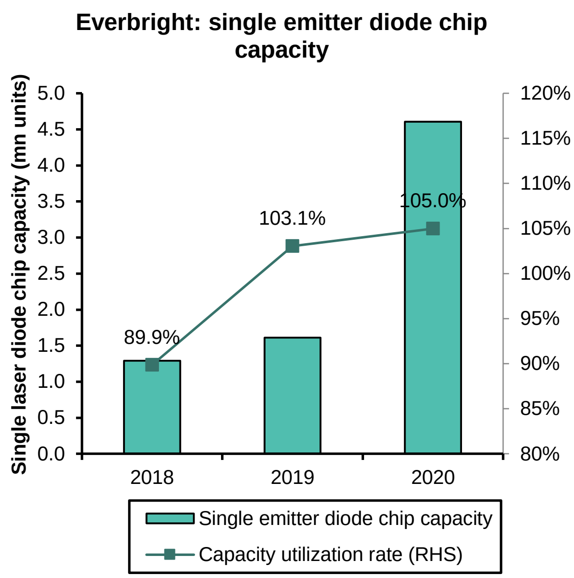
In the fiber laser segment, Everbright's top customers (Raycus, Maxphotonics, FEIBO, GW Laser, and DK Laser) have >80% share among all domestic brands (see Exhibit 226), they all seek higher chip localization ratios, and they routinely upgrade to newer generations of diode chips to improve laser performance and reduce cost. Just by riding the development of these top fiber laser customers, Everbright can expand its EEL business manifold.

In 2021, embracing an accelerating trend of laser chip upgrade, Everbright further established itself as the technology leader and gained share. In less than a year, Chinese fiber laser makers such as Raycus and Maxphotonics migrated from 18-20W single-emitter diode chips to 25-30W chips (see Exhibit 229), a pace that surprised almost everyone. Everbright is ahead of both domestic and global competitors (e.g., II-VI and OSRAM) in introducing these highest power chips and has 35W and 40W+ products in the pipeline already (see Exhibit 234). According to our channel checks, Everbright has ~50% and ~70% share at Raycus and Maxphotonics, respectively, and a key reason for Everbright to gain share against Raycus' brother company BDL (under the same parent company, China Space Sanjiang Group) and OSRAM (the incumbent chip supplier to Raycus) in 2021 was its lead in 30W chips.

Fiber laser accounts for only 28% of lasers using diode chips, so the immediately adjacent opportunity in semiconductor and other lasers is 3-4x as big (see Exhibit 230). This opportunity remains largely untapped by Everbright currently due to capacity constraints. In this segment, many seemingly small laser makers could emerge as a major opportunity for Everbright. Inno Laser, a rising Chinese ultrafast laser company (see Exhibit 231), e.g., has recently started localizing PLDs and named Everbright as a "very good-quality potential supplier in the future." This small company's PLD purchasing scale is similar to Everbright's top customers (see Exhibit 232).

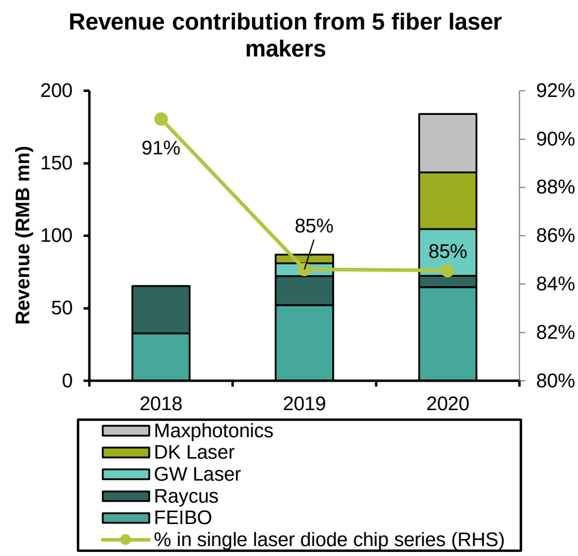
About a third of Chinese fiber and semiconductor laser makers claim to make pump modules (e.g., PLDs) inhouse, and many more purchase PLDs locally. Until recently, they were satisfied with that model, because imported diode chips, although more expensive, are a small part of COGS. The tech war fundamentally changed this, and many laser makers now aim to localize further upstream to diode chips. They have few choices though (see Exhibit 233). Maxphotonics, China's #2 fiber laser maker and a close competitor to Ryacus, made this switch in 2020 to become Everbright's single-emitter diode chip customer. Many more are likely in the queue.

EXHIBIT 223: **Everbright operated at full utilization of diode chip capacity even after expansion in 2020**



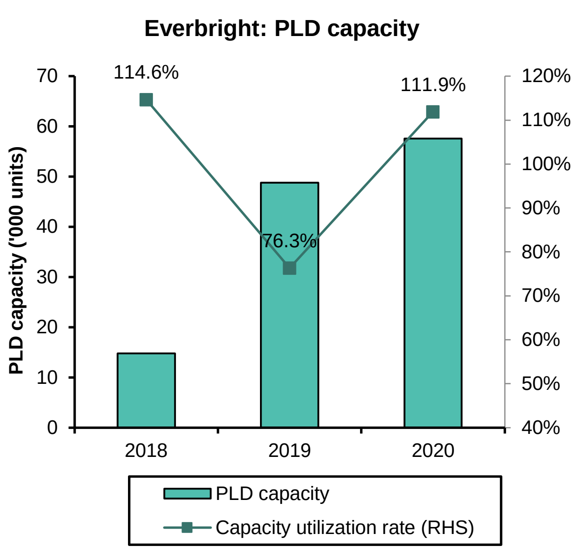
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 224: **New capacity allowed Everbright to expand its business with major customers**



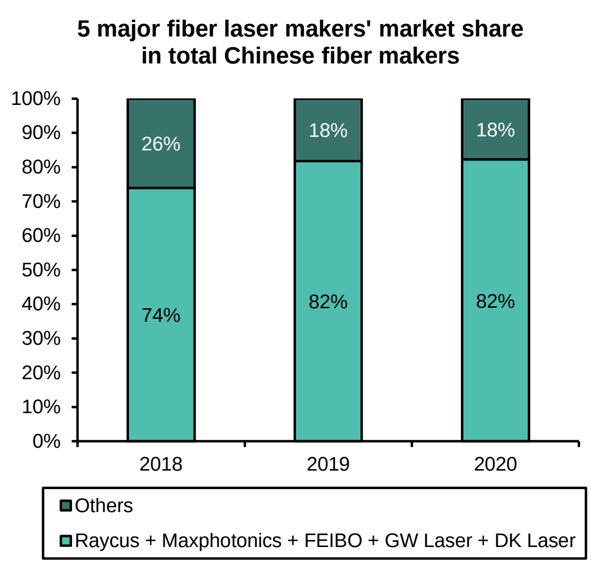
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 225: **Everbright's PLD capacity is also a constraint**



Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 226: **Everbright's top five fiber laser customers have >80% of local market share**



Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 227: **Everbright capacity expansion plan**

Everbright capacity (Unit: volume unit/year)	2018	2019	2020	2022E	Long-term
Single emitter diode chip	1,290,240	1,612,800	4,608,000	7,312,500	53,358,000
PLD/Packaged stacks	14,800	48,800	57,600	NA	382,600
VCSEL chip			NA	3,500,000	70,000,000 + current capacity
Optic communication chip			NA	400	7,000 + current capacity

Source: Prospectus of Everbright and Bernstein analysis

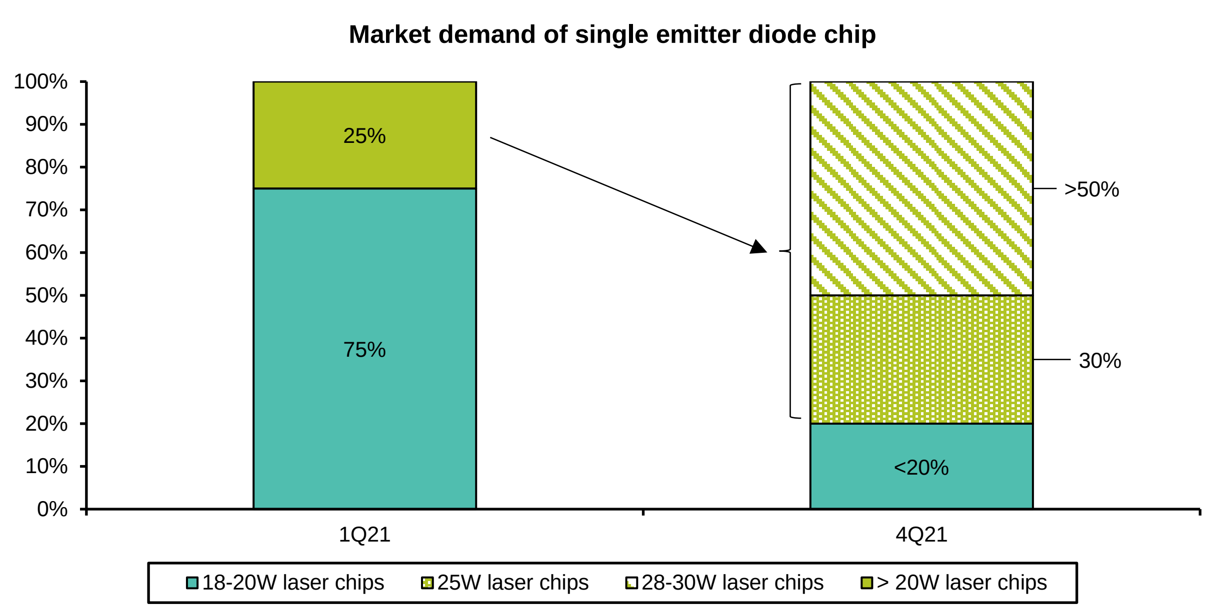
EXHIBIT 228: **Details of Everbright's top five customers (2018-1H21)**

Ranking	2018		2019		2020		1H21	
	Client name	Product sales	Client name	Product sales	Client name	Product sales	Client name	Product sales
Top 1	FEIBO	PLD	FEIBO	PLD	FEIBO	PLD	Maxphotonics	Single emitter diode chip
Top 2	Raycus	Single emitter diode chip, PLD	Client A1	MCC	Maxphotonics	Single emitter diode chip, PLD	Client A2	Micro-channel cooler (MCC)
Top 3	Client B	Single emitter diode chip, laser diode bar, PLD	Raycus	Single emitter diode chip, PLD	DK Laser	PLD	FEIBO	PLD
Top 4	Client A2	Micro-channel cooler (MCC)	GW Laser	PLD	GW Laser	PLD	Raycus	Single emitter diode chip
Top 5	Alma Lasers	Packaged stacks	DK Laser	PLD	Client A2	Micro-channel cooler (MCC)	Huaray Laser	PLD
Contribution in total revenue (%)	86.36%		81.74%		78.90%		82.26%	

Note: Top two Chinese fiber laser makers are highlighted in the table.

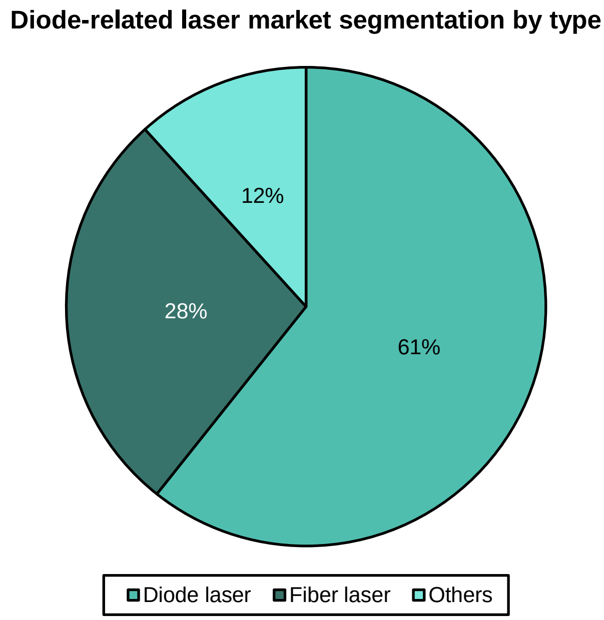
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 229: **Chinese fiber laser makers migrated to 25-30W single-emitter diode chips in less than a year**



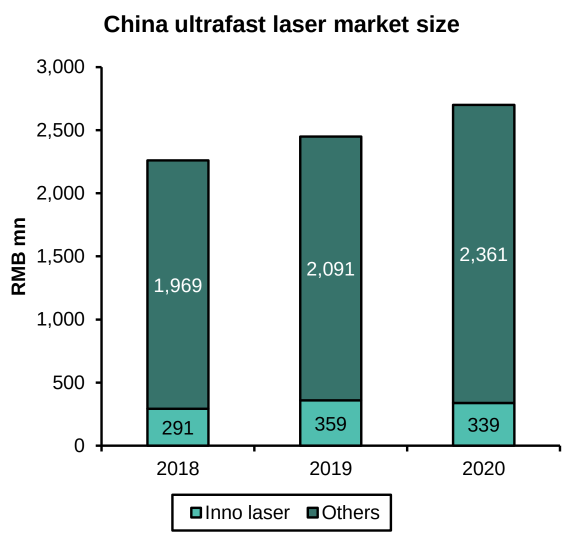
Source: Channel check and Bernstein analysis

EXHIBIT 230: **Besides fiber laser, the opportunity of diode chips in semiconductor and other lasers is 3-4x as big; this opportunity remains largely untapped by Everbright currently due to capacity constraint**



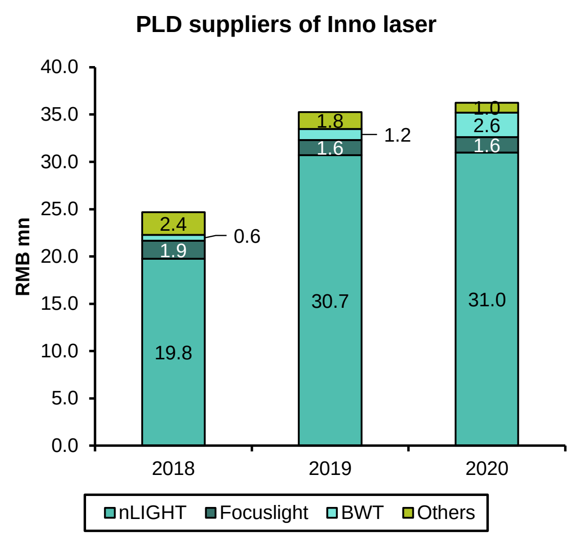
Source: Laser Focus World and Bernstein analysis

EXHIBIT 231: **Inno Laser, a relatively small ultrafast laser maker...**



Source: Prospectus of Inno Laser, Annual Report on Chinese Laser Industry 2021 (published by Wuhan Library, Chinese Academy of Sciences), and Bernstein analysis

EXHIBIT 232: **...embarked on pump module localization; many such companies could potentially become Everbright's major customers**



Source: Prospectus of Inno Laser and Bernstein analysis

EXHIBIT 233: **Diode chip is a scarcity: most Chinese fiber and semiconductor laser makers, even when they make pump modules inhouse, do not have chip capability; they may increasingly purchase from Everbright**

Revenue in 2020	English name	中文名称	Fiber laser	Semiconductor laser/DPSS laser	Pump modules	Chips
RMB1,000+ mn	Raycus	锐科激光	✓	✓	✓	✓ (from BDL)
RMB500~1,000mn	JPT Opto-electronics	杰普特	✓	✓		
	Maxphotonics	创鑫激光	✓	✓	✓	
RMB200~500mn	Focuslight	炬光科技		✓	✓	
	BWT	凯普林	✓	✓	✓	
	Inno Laser	英诺激光		✓		
	Everbright	长光华芯		✓	✓	✓
RMB100~200mn	Huaray Laser	华日激光	✓	✓		
	Feibo	飞博激光	✓	✓		
	RFH Laser	瑞丰恒激光		✓		
	Super Laser	联品激光	✓	✓		
	Inngu Laser	英谷激光		✓		
	CNI Laser	长春新产业	✓	✓	✓	
RMB20~100mn	YSL Photonics	安扬激光	✓			
	CASOE	国科光电	✓	✓	✓	
	RealLight	杏林睿光	✓	✓	✓	
	Desheng	德晟光电		✓		
	Npi Laser	诺派激光	✓			
	ELD Laser	信达雅光电		✓		
	CAS Laser	中科光汇	✓	✓		
	ZKZM Laser	中科中美	✓			
	Grace Laser	卓镭激光		✓		
	Bellin Laser	贝林激光	✓			
	Rays Laser	长光瑞思		✓	✓	✓
	Han's TCS	大族天成	✓	✓	✓	
	GW Laser	光惠激光	✓			
	Logan Laser	罗根激光		✓		
	Reci Laser	热刺激光	✓	✓	✓	
	HK Photonics	华快光子	✓			
	DK Laser	大科激光	✓			
	Gain Laser	格镭激光		✓		

Note: BDL (武汉锐晶) is a brother company of Raycus.

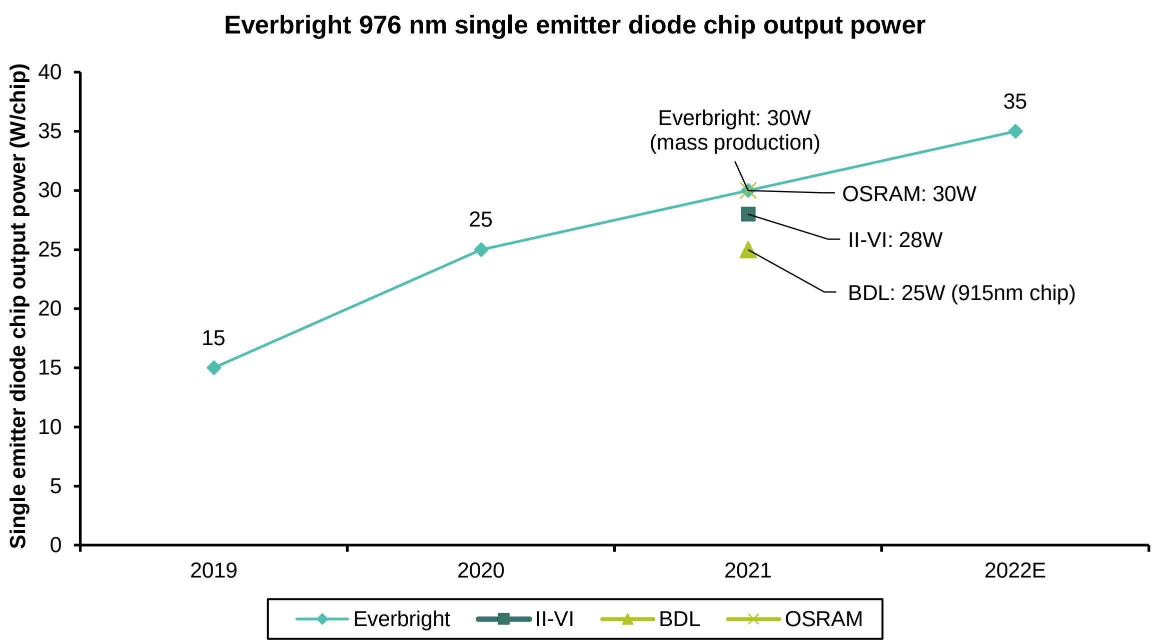
Source: Annual Report on Chinese Laser Industry 2021 (published by Wuhan Library, Chinese Academy of Sciences), company websites, and Bernstein analysis

Championed by Everbright, laser chip is one of the few areas where Chinese technology is approaching the global level. Everbright's technology and product development greatly accelerated around 2018 (see Exhibit 218), and the gap vs. global peers has drastically narrowed in the last three years. In key performance parameters, including single-emitter output power (see Exhibit 234), brightness, and life (>30,000 hours), PLD power and beam quality (see Exhibit 235 and Exhibit 236), and efficiency of VCSELs (see Exhibit 237), Everbright is on par with or very close to global leading levels, and meaningfully ahead of local competition.

The trajectory of single-emitter output power is the most illustrative of Everbright's advancement (see Exhibit 234). The higher this figure is, the lower the cost for laser makers, but the more challenging it is for the diode chip to maintain stability and life. When Everbright introduced 15W single-emitter chips in 2019, we estimated it was three to five years behind global leading technology. Two years later, it introduced 30W chips for commercial use, and came ahead of not only global competitors in the open market, but also its customers — Raycus started adopting 18W chips in 2020.

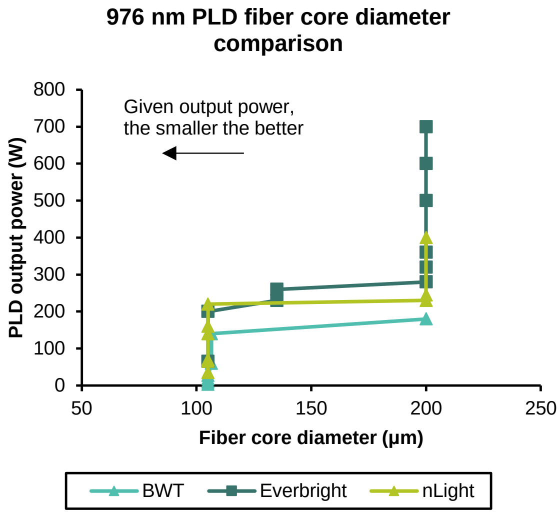
For EEL and VCSEL, Everbright is an IDM, and its end-to-end capabilities in design, epitaxy, tape-out, bonding & packaging, and testing (see Exhibit 238) form a wide moat against local competition. While there are many local design houses, there are few local VCSEL makers with 6-inch MOCVD lines, and even fewer with tape-out capability (see Exhibit 239). Everbright started mass production of VCSEL chips in 4Q2018 and introduced commercial VCSEL chip series in 2020.

EXHIBIT 234: **Everbright is ahead of local and global competitors in introducing highest power chips**



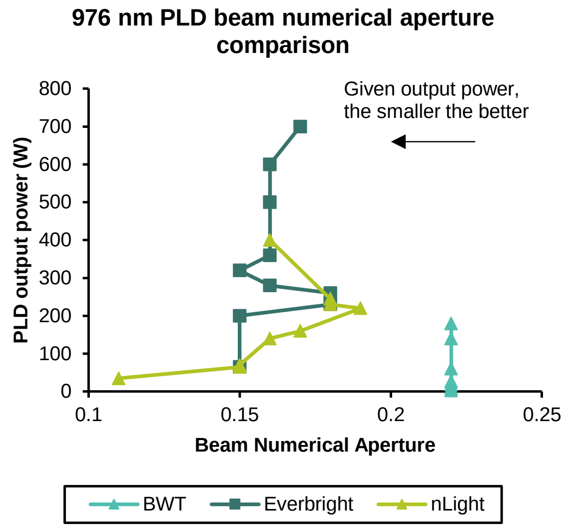
Source: Prospectus of Everbright, II-VI, and Bernstein estimates and analysis

EXHIBIT 235: **Everbright's PLD beam quality is comparable to global peers and much better than local competition (1/2)**



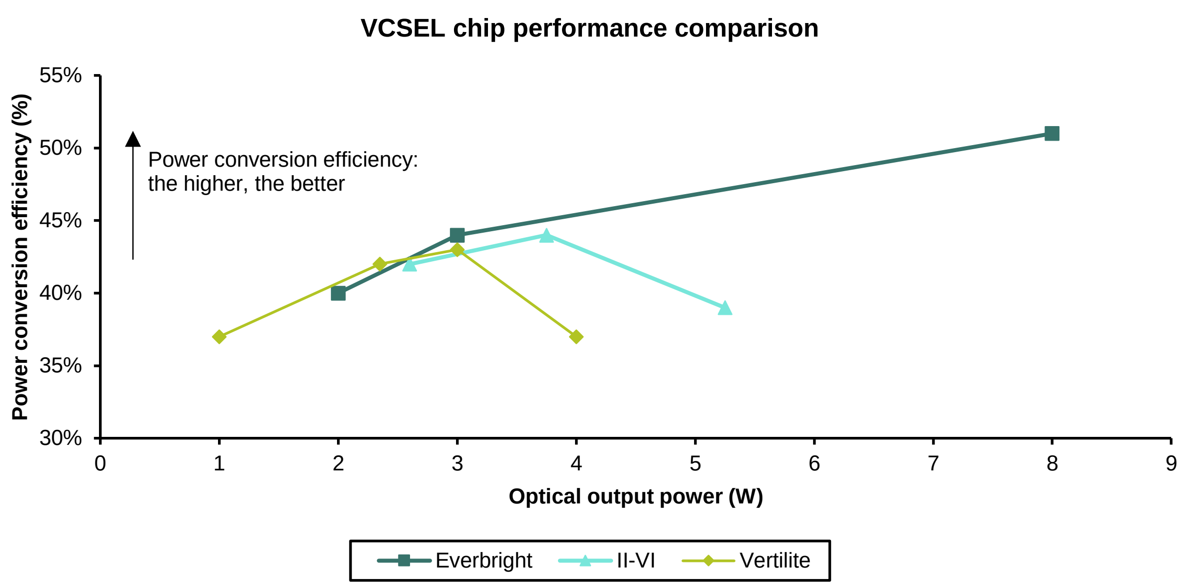
Source: BWT, Everbright, nLight, and Bernstein analysis

EXHIBIT 236: **Everbright's PLD beam quality is comparable to global peers and much better than local competition (2/2)**



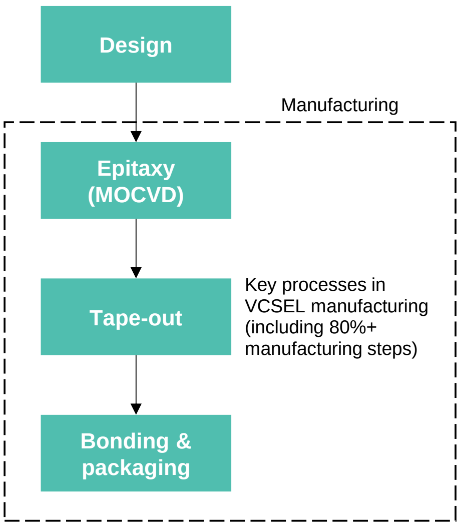
Source: BWT, Everbright, nLight, and Bernstein analysis

EXHIBIT 237: **VCSEL chip performance comparison**



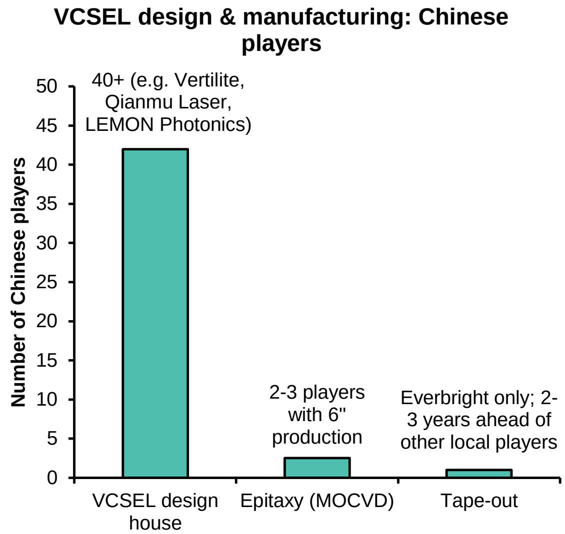
Source: Everbright, II-VI, Vertilite, and Bernstein analysis

EXHIBIT 238: **In EEL and VCSEL, Everbright is an IDM...**



Source: Everbright and Bernstein analysis

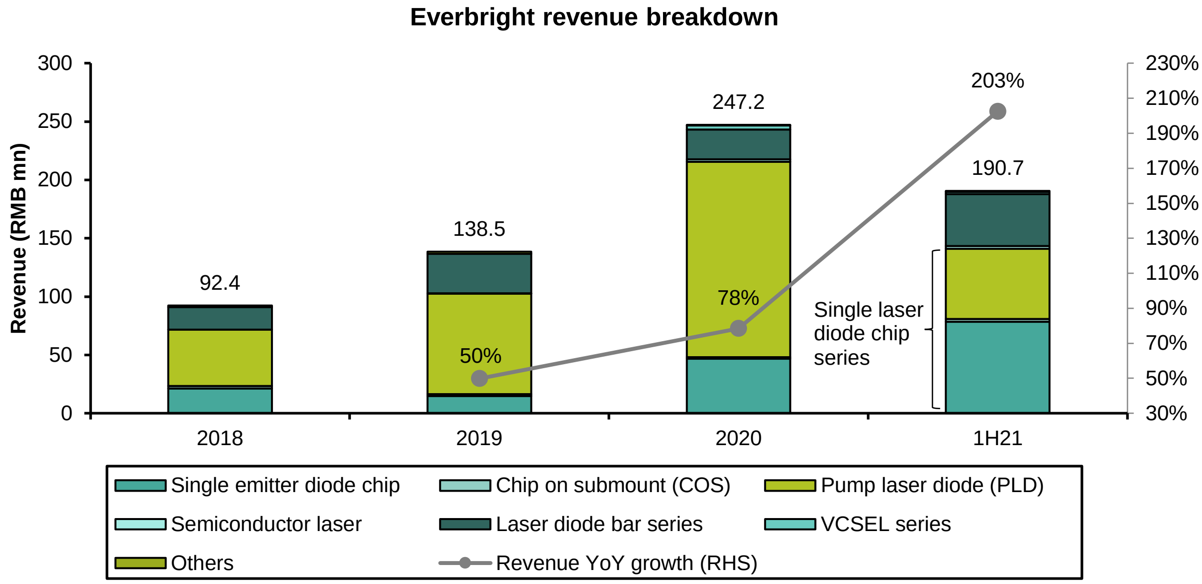
EXHIBIT 239: **...its epitaxy and tape-out capabilities are unique strengths vs. local VCSEL players**



Source: Everbright and Bernstein analysis

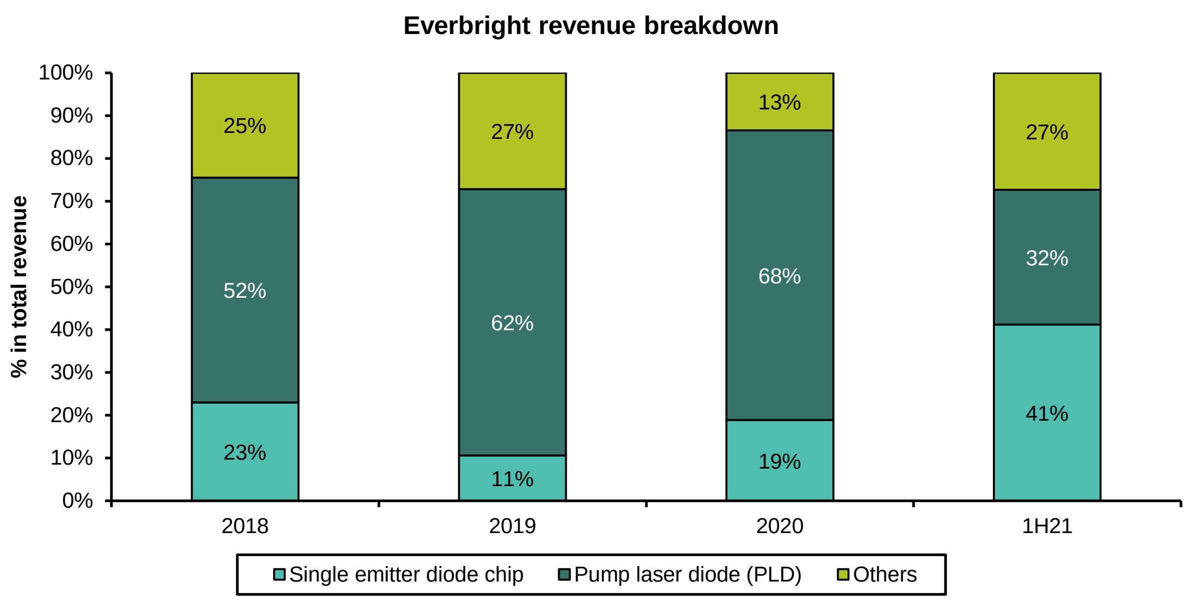
In 1H21, Everbright recorded a revenue growth of 203% yoy (see Exhibit 240). More importantly, we observe a healthy mix shift toward higher contribution from single-emitter diodes (see Exhibit 241), which have much higher GP margin than PLDs (see Exhibit 242). This shift, we believe, is driven by the company's additional capacity, as well as by the fact that more and more Chinese laser makers are not satisfied with localized supply at the PLD level but are increasingly trying to localize further upstream to the diode level. As a result of this mix shift and economy of scale, Everbright's GP margin in 1H21 increased from 31.7% to 53.4% (see Exhibit 242) and adjusted OP margin from 12% to 29% (see Exhibit 243). At much smaller scale, Everbright's opex efficiency already approaches those of its global peers (see Exhibit 244).

EXHIBIT 240: **Everbright's revenue grew 203% yoy in 1H21**



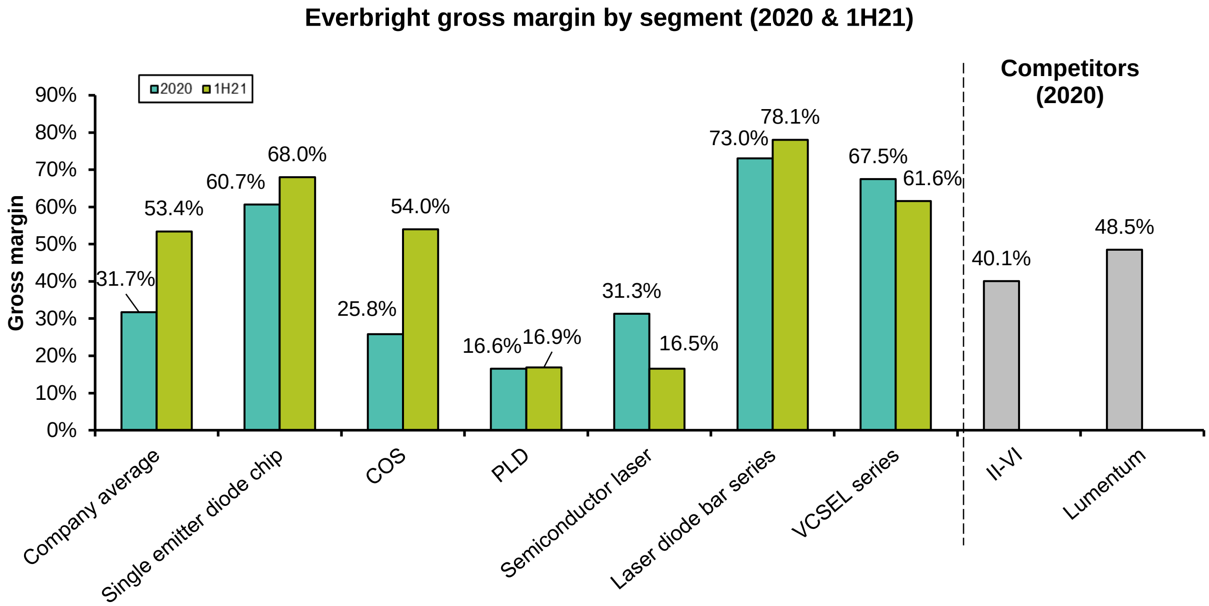
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 241: **Contribution from single-emitter diode chip hiked in 1H21 — a healthy mix shift**



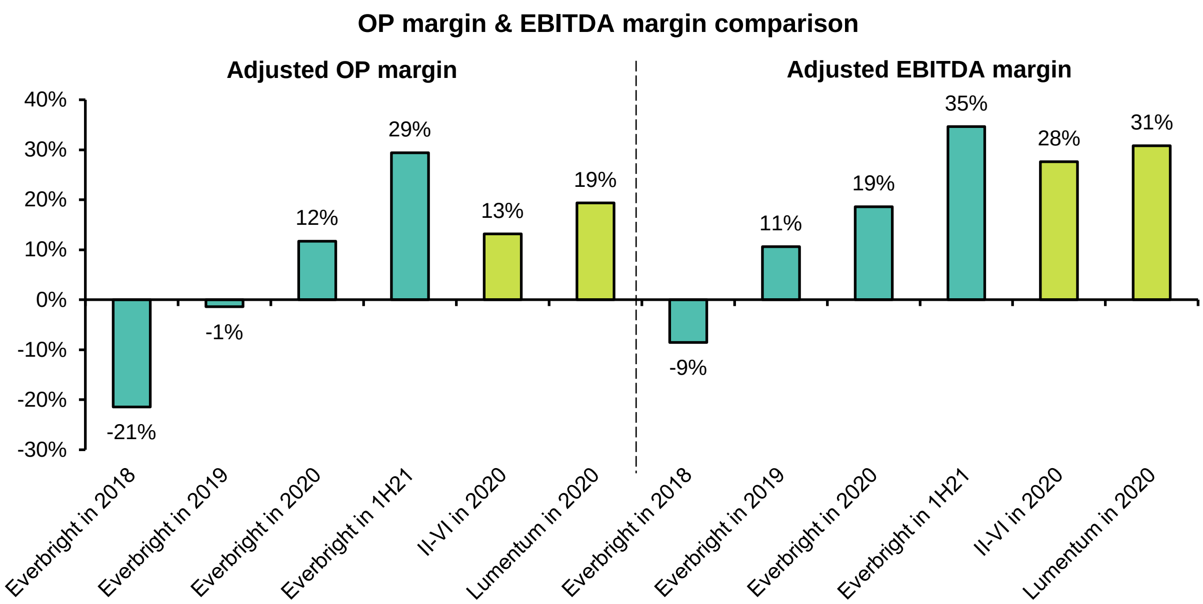
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 242: **Everbright's gross margin significantly expanded in 1H21 due to mix shift and economy of scale**



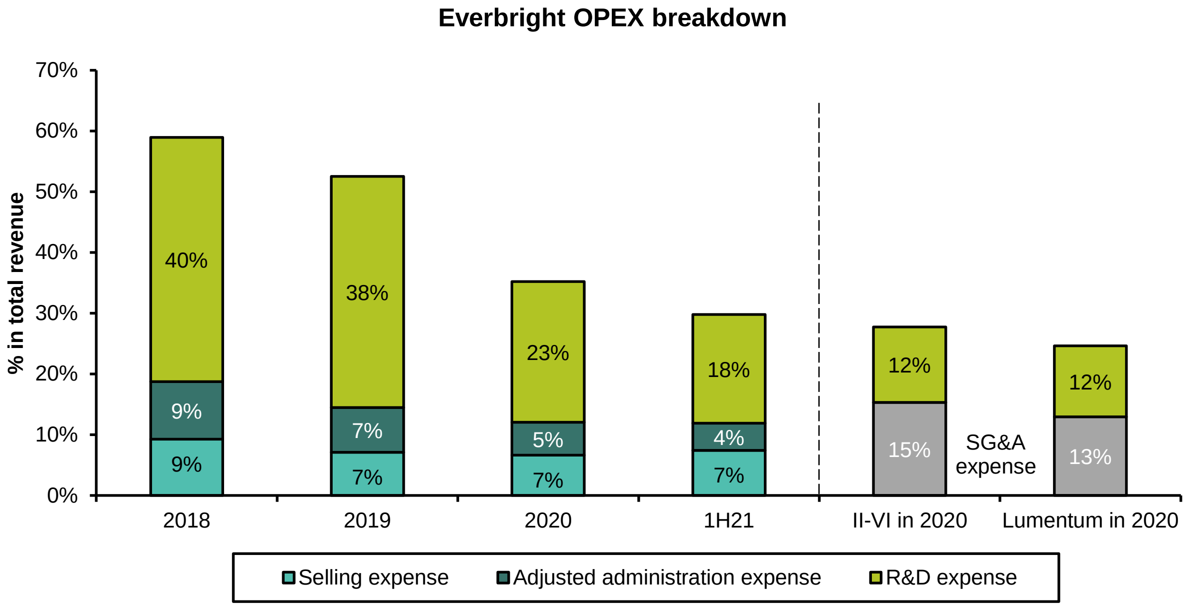
Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 243: **Everbright adjusted OP and EBITDA margins significantly expanded in 1H21**



Source: Prospectus of Everbright and Bernstein analysis

EXHIBIT 244: **An important source of economy of scale is R&D**



Note: Adjusted administration expenses excludes influence from stock-based incentive compensation.

Source: Prospectus of Everbright and Bernstein analysis

INDUSTRIAL VISION

2030 TAM, industry landscape in China, and learning from two global leaders

LONG-TERM OUTLOOK FOR INDUSTRIAL VISION

Vision technologies allow machines to see and respond to the environment, making them more flexible. Together with robotics and laser material processing, vision is one of the secularly growing, technologically advancing automation sweet spots.[51] It is also an enabler for the proliferation of automation in the post-pandemic world, as the flexibility requirement increases with the breadth and depth of automation adoption.[52]

Keyence and Cognex, the two industry leaders, have enjoyed teen-level CAGR for more than two decades, and the vision industry has outgrown not just global capex, but also other automation segments, including industrial robots, in the last decade (see Exhibit 246). Recognizing the attractiveness of vision technology and seeing its historical growth, many investors asked: Can the industry and its leading players continue growing at 10%+ for 10+ years? After all, how many times has one seen an industry expand at double-digit CAGR for more than three decades?

This brings us to the question of industrial vision's TAM. The challenge is that the industry is poorly defined, let alone its TAM quantified. Some investors approach this challenge by trying to come up with an "industrial camera density" metric; others focus on the size of inspection labor by end-verticals. None of these approaches capture most of the vision demand and, therefore, they have not yielded any sensible result.

Our methodology links the key assumptions to the fundamental drivers and trends of the vision industry.

- Vision and automation are mutual enablers. Vision enhances the function and flexibility of automation equipment, and automation is the prerequisite for vision adoption. We, therefore, start from the vision intensity with regard to robots.
    - Two independent factors drive up vision intensity relative to robots. First, more robots will be connected to vision (this is the "penetration" of vision in robotics); second, those vision-equipped robots will use more vision, as robotic vision functions expand from alignment to inspection, guiding, identification, etc. Both factors are considered in our TAM model.

[51] See And There was Light: Vision and Laser at the Frontier of Automation.

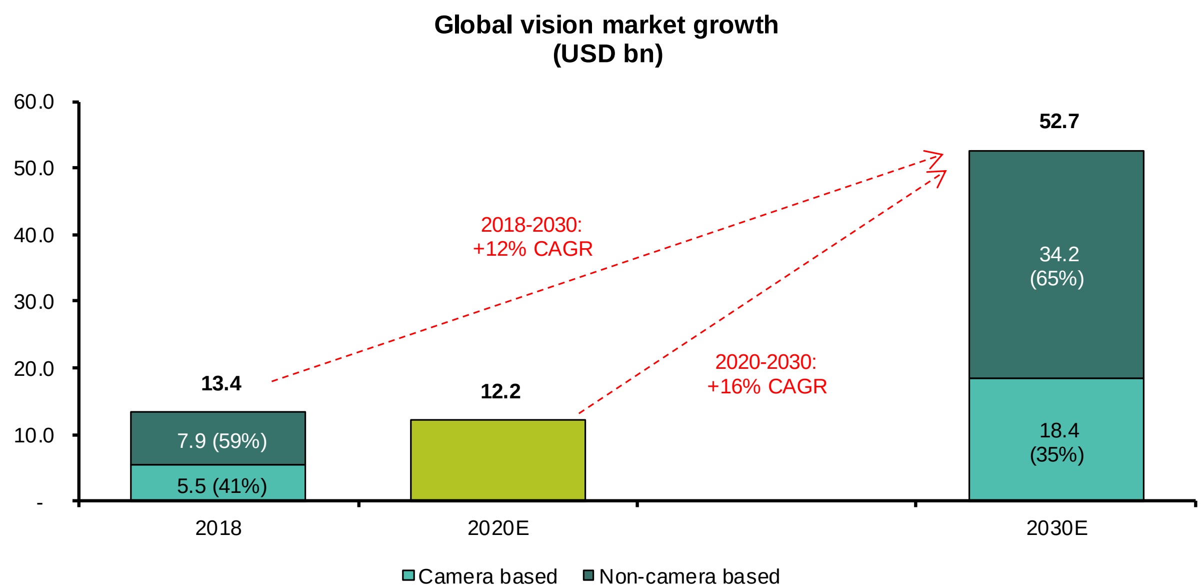
[52] See Automation: The Day After... Structural shifts post-Covid-19 & the case for unmanned factories and human-robot collaboration; Automation in 2021: When is the next peak, what themes are real, and how much is priced in?; The Long View: A moving boundary of automation.

- Vision beyond robotics: With necessary adjustment, we assume a similar trend of vision adoption in other automated but non-robotic processes.

- Further diversification of vision technologies: As 3D vision becomes more important and vision applications proliferate, non-camera technologies (e.g., laser sensing) will steadily outgrow camera-based vision, resulting in the former's contribution modestly rising.

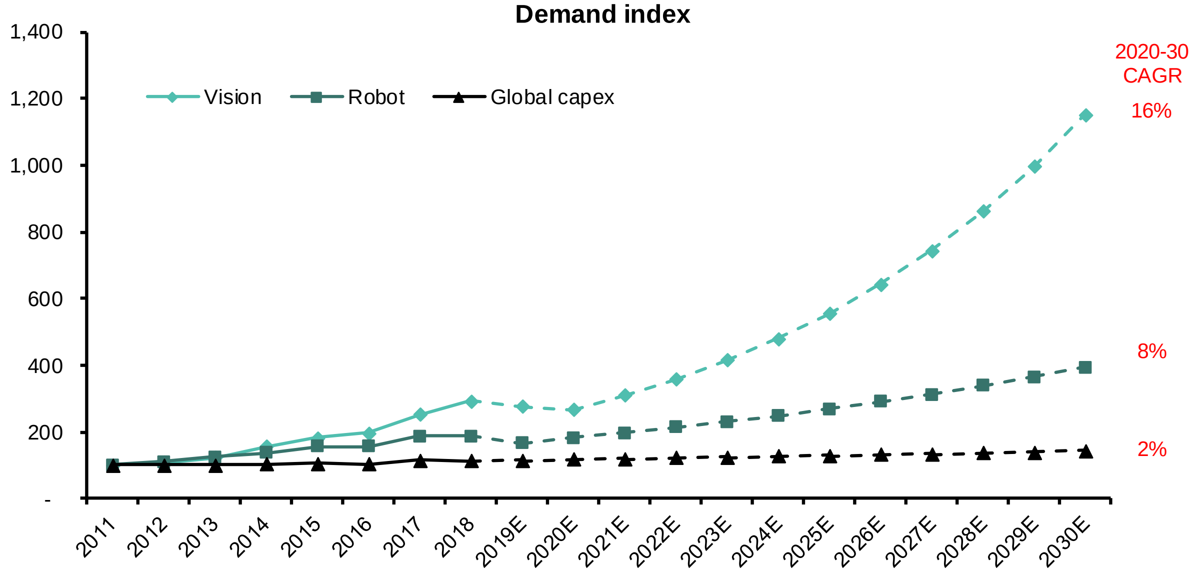
This methodology is illustrated in Exhibit 247, and the analysis flows from the right to the left. The result is an estimated industrial vision market size of ~USD53bn in 2030, implying a CAGR of 16% from 2020, a trough of the recent cycle (see Exhibit 245). Of this, about 35% (USD18.4bn) is projected to be camera-based vision in 2030.

EXHIBIT 245: **We forecast global industrial vision market to grow at 16% CAGR to reach ~USD53bn in 2030**



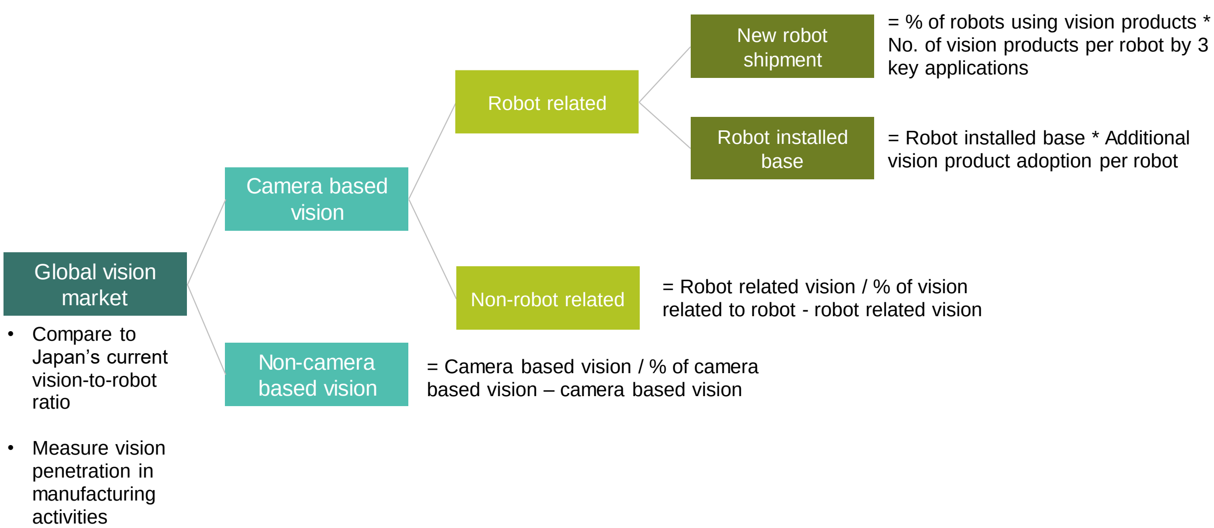
Source: IHS, and Bernstein estimates and analysis

EXHIBIT 246: **Vision will likely continue to outgrow robot in the coming decade**



Source: Company reports, Bernstein Quantitative Team, and Bernstein estimates and analysis

EXHIBIT 247: **Market sizing methodology**



Source: Bernstein analysis

CAMERA-BASED VISION

The global camera-based vision market size was around USD5.5bn in 2018, and we project it to grow at a 11% CAGR to reach USD18.4bn by 2030, driven by increased vision intensity in robotics and general automation (see Exhibit 248).

Vision intensity with regard to robots

We estimate new robot shipments to drive 24% of camera-based vision growth between 2018 and 2030, and account for 21% of the market in 2030 (see Exhibit 248). This strong growth is anticipated to be driven by robot shipment growth, vision penetration in robots (i.e., percentage of robots using at least one vision function), and possession rate (number of vision products per robot) (see Exhibit 249).

- Robot shipment will continue to grow, driven by continued progression of automation. We forecast global robot shipments to grow at a 10% CAGR from 2019's low base to 2030, implying ~1 million robot shipments globally in 2030. Considering a 2% annual price deflation, the robot market size in value will expand at 8% p.a.

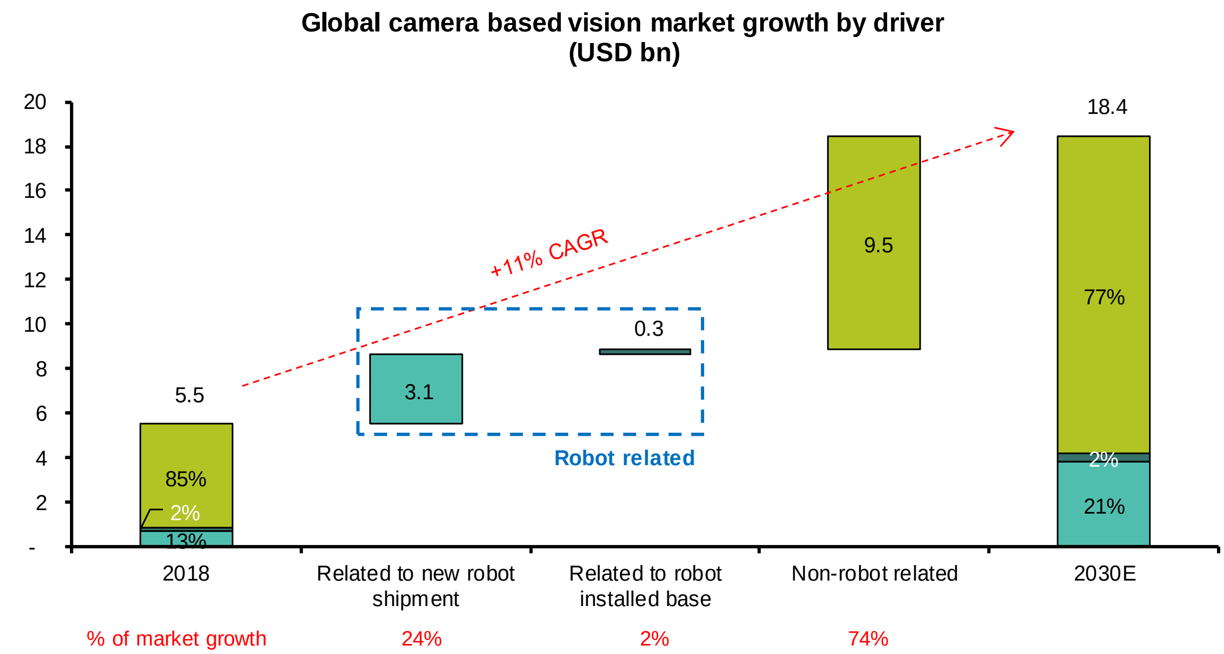
- We assume different vision penetration rates for different robot applications (see Exhibit 249). The average penetration rate is anticipated to increase from 20% in 2018-19 to 35% in 2030.

- For robots using vision, each can be equipped with multiple vision products for different functions. These functions fall into four key categories: inline inspection, offline inspection, alignment and guiding, and identification (see Exhibit 250). For example, per our estimate, a vision-guided handling/machine tending robot on average uses 0.5 camera to locate the workpiece for picking and placing (alignment/guiding purpose), 1 camera for inspection after processing, and 0.2 camera for code reading (identification). Therefore, such a robot would, on average, use 1.7 vision cameras. We made similar assumptions for each robot application, detailed in Exhibit 249.

- Because of the last two factors, the shipment of camera-based vision products as a ratio of robot shipment is likely to increase from 0.30 in 2018 to 0.65 in 2030. Historically, there has been a growth premium of vision vs. robots, and we believe the trend will continue (see Exhibit 246).

- As a result of all three factors — robot shipment growth, more robots to use vision, and each robot to use more vision — the 1 million robots shipped in 2030 would result in camera-based vision shipment of 688k units. We further assume camera-based vision ASP to stay at today's average of USD5.6kand that new robot shipment would drive the camera-based vision demand of USD3.8bn in 2030 (see Exhibit 248).

EXHIBIT 248: **We estimate camera-based vision market to reach USD 18.4bn in 2030, driven by the increasing level of automation**



Source: IHS, IFR, and Bernstein estimates and analysis

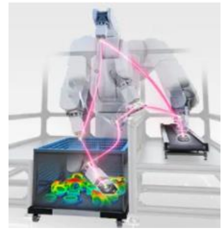
EXHIBIT 249: **Key assumptions for vision intensity with regard to robots**

Unit: K	Robot shipment			Penetration (% of robots with vision)	No. of camera based vision products per robot (Unit)				Avg. # of camera based vision per robot (Unit)	Total # of camera based vision products
Robot by application	**2019**	**2030**	**19-30 CAGR**	**2030**	**Inspection**	**Alignment / Guiding**	**Identification**	**Total**	**2030**	**2030**
Handling/ Machine tending	156	445	10%	30%	1	0.5	0.2	**1.7**	**0.5**	227
Welding and soldering	75	214	10%	40%	1	0.5	0.2	**1.7**	**0.7**	146
Assembling	36	103	10%	50%	1	1.5	0.5	**3.0**	**1.5**	154
Dispensing	12	34	10%	40%	1	0.5	0	**1.5**	**0.6**	21
Palletizing	10	29	10%	30%	0	0.5	1	**1.5**	**0.5**	13
Processing	6	17	10%	20%	1	0.5	0	**1.5**	**0.3**	5
Stamping	3	10	10%	30%	1	1	0	**2.0**	**0.6**	6
Inspection	3	9	10%	100%	1	0.1	0	**1.1**	**1.1**	10
Others	71	203	10%	30%	0.5	0.75	0.5	**1.8**	**0.5**	106
Total	**373**	**1,064**	**10%**	**35%**	**330**	**193**	**109**		**0.65**	**688**

Note: Data in blue/light gray are actual figures, red/dark gray are Bernstein estimates, and black are recalculated results.

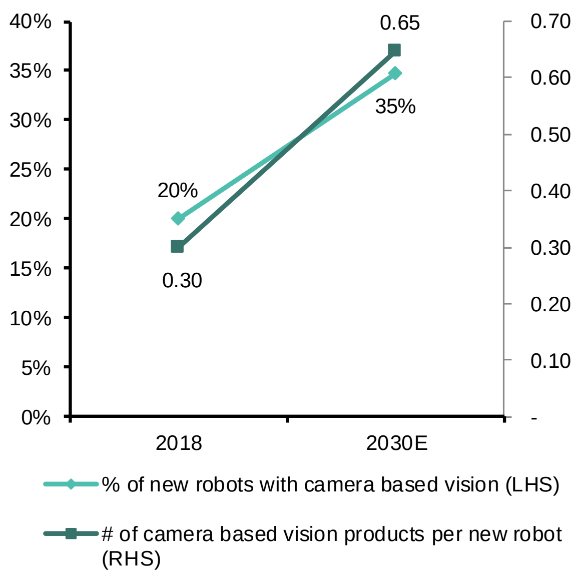
Source: IFR, and Bernstein estimates and analysis

EXHIBIT 250: **Keyence product examples for major categories of vision applications**

	Inline inspection	Offline inspection	Alignment / Guiding	Identification / Code reading
Application				

Source: Keyence websites and Bernstein analysis

EXHIBIT 251: **Vision penetration in robot and adoption per robot both increase over time**



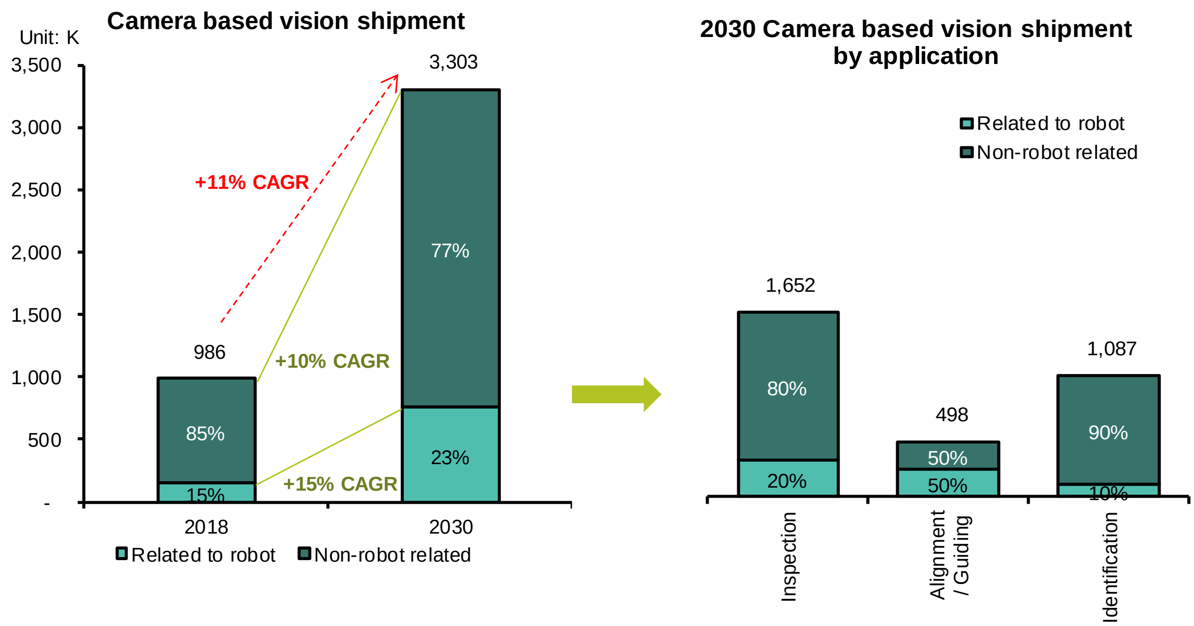
Source: Bernstein estimates and analysis

Vision beyond robotics

Beyond robotics, in the field of general automation, the same secular trend takes place and drives increasing vision adoption. In fact, only about 15% of today's vision demand is related to robots. Going forward, we believe robot-related vision applications will grow at a faster pace, increasing their contribution to 23% in 2030 (see Exhibit 252). This means the total shipment of camera-based vision products will grow to ~3.3 million units in 2030. Should the ratio stay at 15%, it would imply an even bigger TAM.

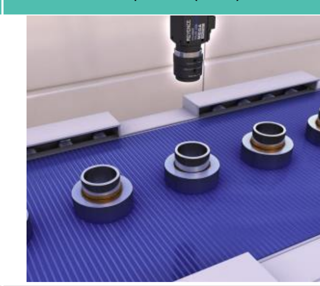
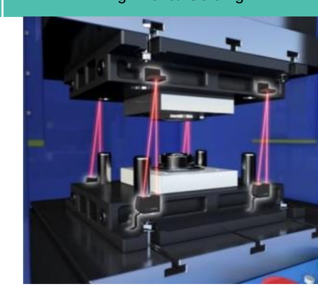
Exhibit 253 shows some examples of vision applications not related to robots from Keyence's portfolio. They include all major application categories, i.e., inline and offline inspection, alignment/guiding, and identification.

EXHIBIT 252: **The majority of vision demand will likely continue to come from non-robot related applications**



Source: IHS, and Bernstein estimates and analysis

EXHIBIT 253: **Keyence product examples of non-robot-related vision applications**

	Inspection (inline)	Inspection (inline)	Inspection (inline)
Application			
Example	Thickness measurement of thin film	Expiry date detection	Grease detection
Technology	Laser sensors	Camera based	Camera based
	Inspection (offline)	Alignment / Guiding	Identification / Code reading
Application			
Example	Coordinate measuring (handheld)	Stamping alignment	DataMatrix code reading
Technology	Laser sensors	Laser sensors	Camera based

Source: Keyence websites and Bernstein analysis

DIVERSIFICATION OF VISION TECHNOLOGY BEYOND CAMERAS

Industrial vision is much more than camera-based products (see Exhibit 254). Laser sensing and other non-camera products make up 55-60% of the vision market today (see Exhibit 245). These technologies span the full range from one-dimensional (1D) to two- and three-dimensional (2D and 3D), and are more important than cameras at the two ends (1D and 3D). As 3D vision[53] becomes a key driver for the expanding scope of vision inspection for advanced robot guiding,[54] we believe non-camera technologies will steadily outgrow camera-based vision, resulting in the former's contribution to modestly rise to 65% in 2030 (see Exhibit 245).

Keyence has by far the broadest vision product portfolio with >2,500 SKUs and is a leading player with ~50% global market share in 3D vision.[55] Of the Keyence portfolio (see Exhibit 256), we categorize 60-65% of revenue, including all machine vision systems and code readers (these are mostly camera-based vision), the majority of sensors and measuring systems, and a small part of safety products, within the estimated vision TAM; another ~20% (microscopes) using vision technology but not part of the estimated TAM; and the rest being non-vision automation components (other industrial sensors, CMM, safety products, laser markers, etc.). By comparison, 100% of Cognex is within the camera-based vision TAM (USD18.4bn in 2030) shown in Exhibit 245.

To help readers understand what non-camera-based vision is, we have chosen some Keyence product examples, focusing on new products introduced in the last two years (see Exhibit 255). This is not an exhaustive list.

- Laser triangulation: The light source projects a laser spot onto an object, and the reflected light falls onto a receiving sensor at a certain angle (thus the name "triangulation"). This transforms the depth of the object surface into displacement on the receiving sensor. Laser triangulation accurately measures the depth data of each point of the object's surface, but has limited scanning speed and working range. It is often used in inline inspection and alignment/guiding applications.

- 3D measurement system (offline): It uses two optical transmitter lenses to scan 3D objects in 360 degrees, and a large, high-resolution CMOS sensor to collect detailed surface data and information, including height, shape, angle, and color (up to 16 million data points per scan). This technology is suitable for high-precision offline inspection. The latest models allow comparison of measurement with the original CAD design of the workpiece.

- Laser interference: Being a coherent light source, laser can generate interference patterns that are sensitive to miniature changes in light paths. This technology is most suitable for high-speed inline inspection that requires high precision in 3D (submicron level).

- Laser confocal: This 3D technology uses the focal point as a "probe" for depth. Through the lens system, the reflected light is refocused to another detection focal plane, where a small aperture close to the detector blocks any light that is out of focus,

[53] See the "And There Was Light" chapter in our previous *BlackBook*: The Tech Side of Automation.
[54] See Collaborative Robot: Bin picking - latest progress and enabling technologies for a multi-billion-dollar opportunity.
[55] See Keyence: The (true and false) secret sauce.

so the sensor only sees one depth layer at a time. Laser confocal has the highest accuracy among major vision technologies, but relatively low speed and the smallest field of view.

- Image-based laser sensor: This solution combines camera and laser technologies. It first uses a camera to rapidly confirm the target position, orientation, and placement. A laser then irradiates the specified location to calculate the distance with the CMOS sensor for height inspection. It is useful in inline inspection of parts that do not have a fixed location or orientation.

- Projection image (silhouette measurement): In this, high-intensity LED illumination is emitted from the transmitter and captured by a high-sensitivity CMOS sensor in the receiver. When objects pass by in between, their silhouettes will be captured and measured. It is useful in high-accuracy inline inspections, such as dimensional and size measurement, especially when objects are hard to picture due to the challenges associated with focus or surface contrast.

- Laser micrometer: In this system, the transmitter emits a multi-wavelength laser, and the receiver monitors the amount of light received. The blocked part implies the length, width, or height of the object measured. This solution can also be used to monitor and control object position.

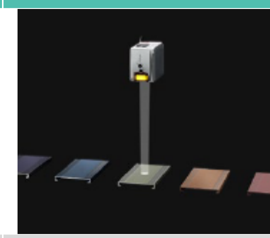
- Full spectrum photelectric sensor: It utilizes a white LED light and full color spectrum to detect any change of a target surface, including the presence/absence, shape, material, and color of the targeted object.

EXHIBIT 254: **Major types of vision products using camera and non-camera technologies**

Vision products	1D	2D	3D	
Camera	Line scan camera	Image-based code reader	Stereoscopic ("double eye") camera	ToF camera and sensor; Structured light camera (laser and non-laser)
		Area camera		
Non-camera	Laser and optical presence, positioning, distance sensor; laser micrometer	2D laser displacement sensor; image-based laser sensor	3D laser displacement scanner	
			Laser confocal sensor	
	Laser code reader		Laser interference sensor	
		Offline measurement system; image based laser sensor		

Source: Company websites and Bernstein analysis

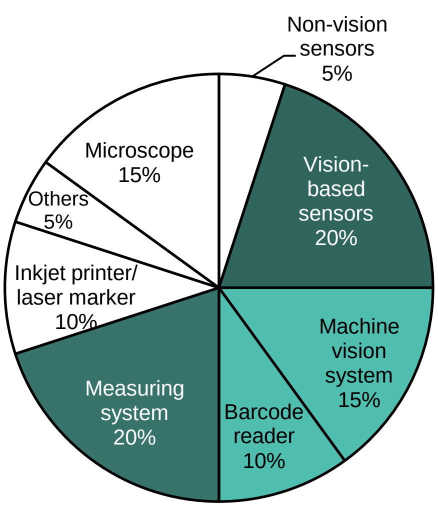
EXHIBIT 255: **Examples of Keyence's non-camera-based vision products**

	LJ-X8000 series	VL Series	WI-5000 series	CL-3000 series
Model				
Technology	Laser triangulation	3D measurement system (offline)	Laser interference	Laser confocal
	IX Series	TM-X5000 series	IG series	LR-W series
Model				
Technology	Image-based laser sonsor (Camera + Laser)	Projection image	Laser micrometer	Full spectrum photoelectric sensor

Source: Keyence websites and Bernstein analysis

EXHIBIT 256: **Keyence revenue, by product segment**

Keyence Revenue Breakdown by Product



Source: Company reports and Bernstein analysis

SANITY CHECK THE TAM

When the vision industry reaches USD53bn in 2030, how penetrated would the technology be? Our estimate is made on several premises:

- Automation adoption will continue to progress, and the robot industry will grow at a 10% volume CAGR (or an 8% value CAGR) through to 2030.
- Vision intensity will continue to increase against the robot baseline, resulting in a 600-800bps growth premium of the former (see Exhibit 246).

To sanity check the first point, we calculated that the projected robot growth CAGR implies a global robot density in 2030 similar to that in Japan and Germany in 2019 (see Exhibit 257). Considering that the density in Japan and Germany has continued increasing in recent years, this does not seem a stretched estimate.

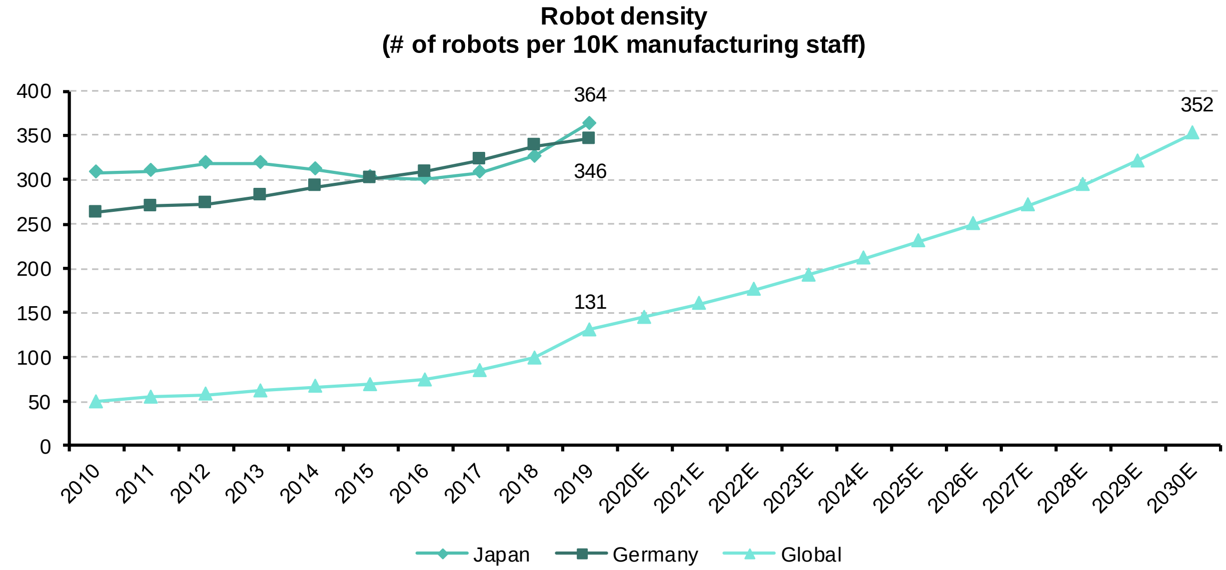
We estimate current vision penetration to be around 15%. This is an average figure coming from expert interviews, and depending on who you talk to, the definition of "penetration" may differ (see Exhibit 259):

- The percent of robots guided by vision is <10%.
- 20-30% of components in the automotive industry, but ~10% in others, are inspected inline.
- Direct parts marking (i.e., parts marked with matrix codes to be tracked by code readers) covers 50-90% of components in cars, EV batteries, and iPhones, but is practically nonexistent in most other industries or non-Apple smartphone makers.
- 5% of automotive final assembly and 10-20% of electronics assembly are automated, and that is the upper limit for the estimate of vision guided assembly today.

Given our forecast of the vision industry growth rate, the "vision installed base" will become ~5x as big in 2030 as it is now. Assuming a 3% CAGR of manufacturing activities, this expanded installed base implies an overall penetration of around 55% in 2030 — the vision industry will be much more mature than today, but not quite saturated.

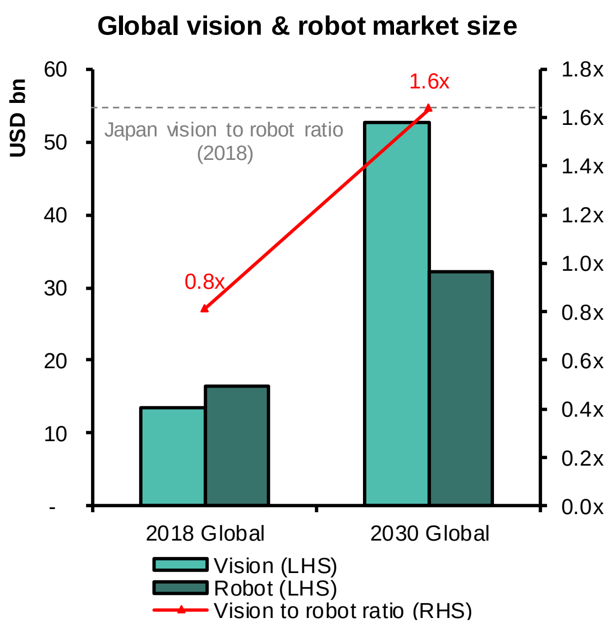
A final, less subjective check is to benchmark the vision market size to robot market size. The vision-to-robot market size ratio stood at about 0.8x globally in 2018. Our TAM estimate implies that it will ramp up to 1.6x in 2030, a ratio comparable to that in Japan in 2018 (see Exhibit 257).

EXHIBIT 257: **Our forecast implies that global robot density in 2030 will reach Japan's and Germany's level in 2019**



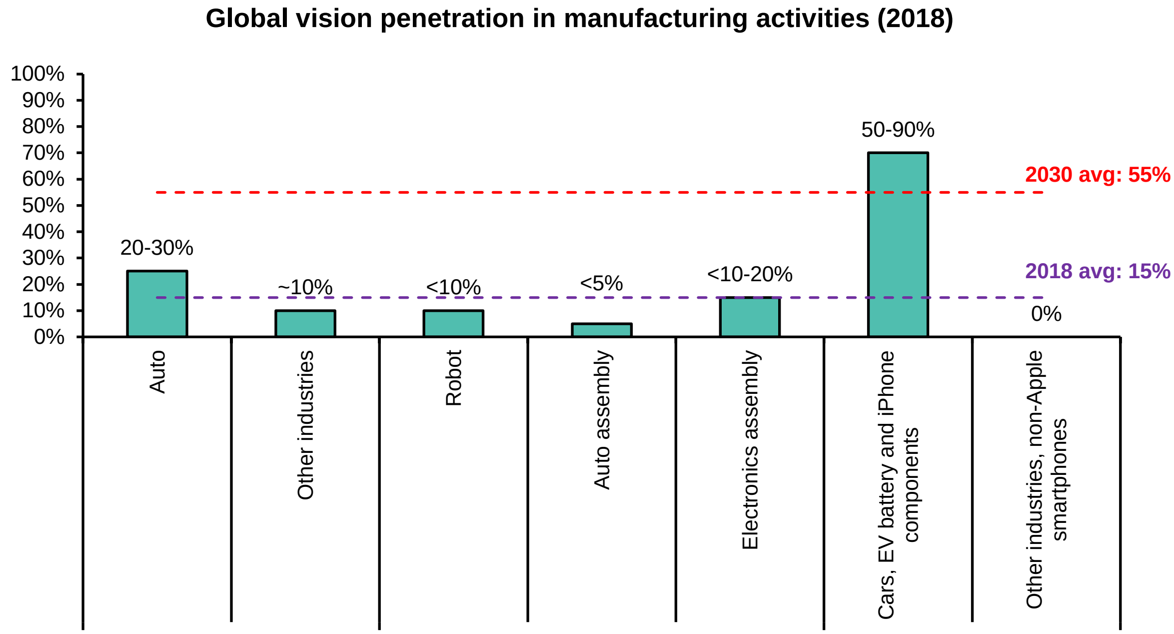
Source: IFR, and Bernstein estimates and analysis

EXHIBIT 258: **Our vision market estimate implies global vision-to-robot ratio in 2030 to reach Japan's 2018 level**



Source: IFR, Keyence, and Bernstein estimates and analysis

EXHIBIT 259: **Our vision market size forecast implies that overall vision penetration will reach 55% in 2030**



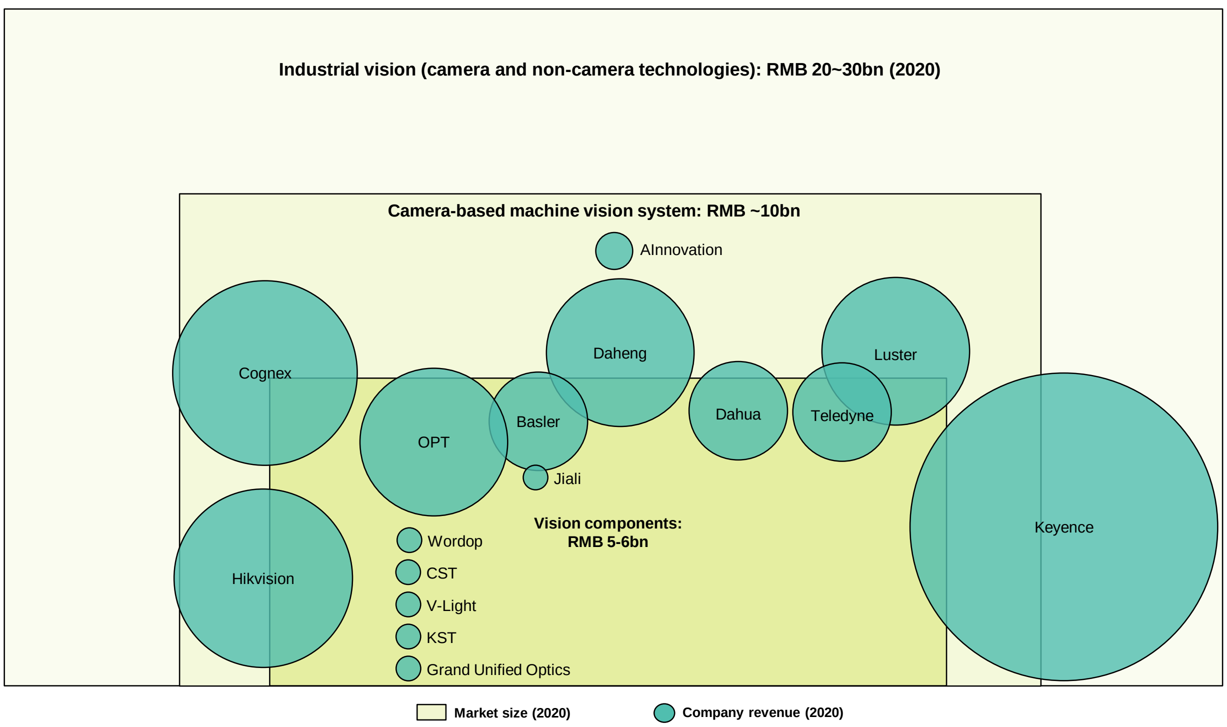
Source: Industry interviews, and Bernstein estimates and analysis

MACHINE VISION IN CHINA: AN INDUSTRY MAP

China's camera-based machine vision system market, the focus of this section, is an RMB10bn market (see Exhibit 260). Within that, upstream components (industrial camera, lens, light source, software, etc.) account for about half of industry value (RMB5-RMB6bn); beyond that, we estimate the broader industrial vision market (including non-camera technologies) to be 2-3x as big (RMB20-RMB30bn).

Along the vision value chain, Chinese capability is the most developed in upstream light sources and lenses and downstream vision-based equipment (e.g., for inspection and processing), followed by industrial cameras, and the least developed in vision software and the midstream embedded vision system (see Exhibit 261).

EXHIBIT 260: **The variously defined "machine vision" market — this chapter focuses on the ~RMB10bn camera-based vision opportunity in China**



Note: For overseas companies, only China's revenue is considered. For all companies, only vision-related revenue is considered.

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 261: **Machine vision in China — a map of key players' business scope and upstream capability**

Company	Ticker	Upstream Machine Vision Components				Midstream	Downstream Vision Equipment				Machine Vision Revenue (2020, USD mn)	
		Light source	Lens	Camera	Software	Embedded machine vision system	Inspection equipment	Measuring system	Processing /assembly equipment	Sorting equipment	Mainland China	Global
Cognex	CGNX US		+	+	S +	S					~150	811
Keyence	6861 JP	+	+	+	+	S		S			~140	~1,000
Basler	BSL GY	S +	S +	S +	S +	S					60~90	195
ISRA vision	IRAVF US	+		+	+	S	S				~50	145
Baumer	Private	S +	S +	S +	S +	S						
Teledyne	TDY US	+	+	S +	S +	S					~60	986
SICK	3397Z GR	S +	S +	S +	S +	S						
Omron	6645 JP	S +	S +	S +	S +	S	S					
ifm	Private	S +	+	S +	S +	S						
CCS	6669 JP	S										80
MORITEX	7714 JP	S	S									
MVTec	Private				S							
Ai	Private	S										
Hikvision	002415 CH	+	+	S +	S +	S					~140	
Daheng	600288 CH	(Philips)	(RIOCH)	S +	(MVTec)	S	S				~130	
Luster	Pending IPO	+	(Moritex)	(Teledyne)	+	S	S				166	
Dahua	002236 CH	S +	S +	S +	S +	S					~60	
OPT	688686 CH	S +	S +	(Basler)	S +	S					93	
Jiali	Private	S	S	(Basler)								
Wordop	Private	S										
CST	Private	S	S	S								
V-Light	Private	S										
Grand Unified Optics	Private	S	S	S								
KST	Private	S						S				
AInnovation	Pending IPO				+	S	S					
Koh Young	098460 KS						S					152
KLA	KLAC US						S	S				~750
ASM Pacific	522 HK						S		S			
TZTEK	688003 CH						S	S	S		140	
Jingce	300567 CH						S				301	
HYC	688001 CH						S				243	
Keda	688328 CH						S		S		94	
Meiya	002690 CH									S	217	
Jutze	300802 CH						S				70	
BOZHON	688097 CH						S		S		306	

S	Where sales are generated with own technology
+	Where inhouse technical capability is sufficient
( )	Where sales / integration are done with third party products

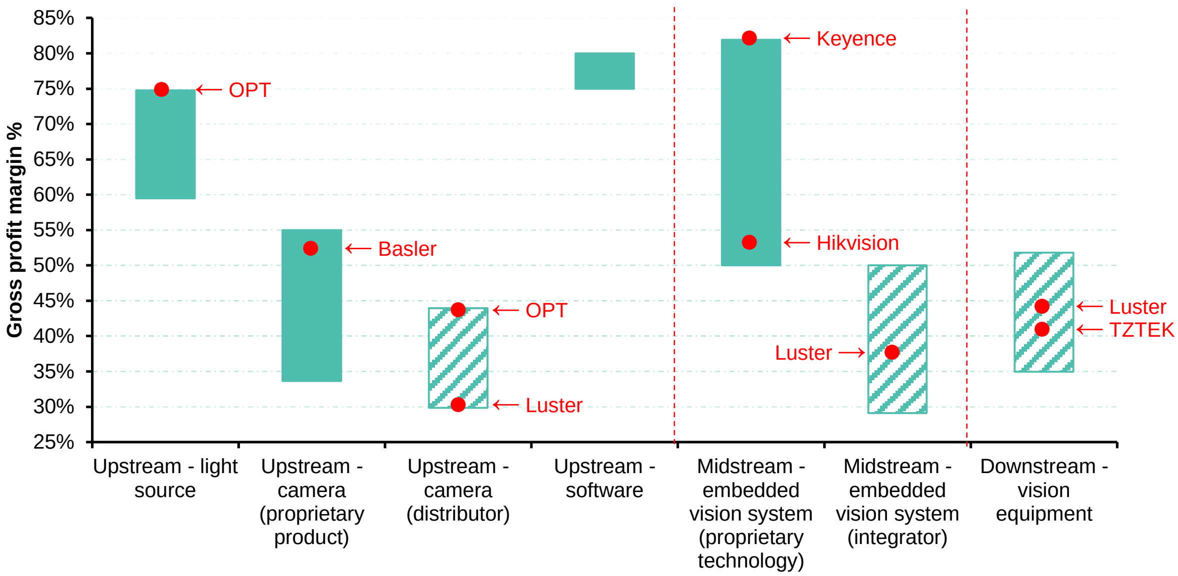
Note: Revenue figures only include camera-based machine vision business. Among these names, only Keyence, Cognex, and Hikvision are covered by Bernstein.

Source: Bloomberg, MIR Databank, company reports and websites, and Bernstein estimates and analysis

Margins vary in a wide range and are a function of one's technical capability and where it plays (see Exhibit 262 and Exhibit 263). The most profitable are midstream vision system providers with proprietary upstream technology, represented by Keyence and Cognex (GPM 75%+). Integrator and distributor margins are much lower (30-50%).

The margin of light source is, in our view, abnormally high. Its barrier is by no means higher than other hardware vision components. With increasing competition, light source GP margin is unlikely sustainable at 70%+. Moreover, the expansion from light source to other vision segments is almost certainly margin dilutive.

EXHIBIT 262: **Margins vary in a wide range and are a function of one's technical capability and where it plays**



Note: Margin numbers are as of 2020; we used 1H20 disclosed segmental breakdown for OPT.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

EXHIBIT 263: **Vision companies' margins by category**

Segment	Company	Proprietary technology or not	Gross profit margin
Upstream components			
Light source			
	CCS	Proprietary	59%
	OPT	Proprietary	75%
Camera			
	Basler	Proprietary	52%
	OPT	Distributor	44%
	Hikvision	Proprietary	50~55%
	Daheng	Proprietary	34%
	Luster	Distributor	30%
Software			
	OPT	Proprietary	~80%
Midstream embedded vision system			
	Keyence	Proprietary technology	82%
	Cognex	Proprietary technology	75%
	SICK	Proprietary technology	~70%
	ISRA Vision	Proprietary technology	56%
	Hikvision	Proprietary technology	50~55%
	OPT	Partial proprietary	50~55%
	Luster	Integrator	38%
Downstream vision equipment			
	Meiya	Machine builder	52%
	HYC	Machine builder	48%
	Jingce	Machine builder	47%
	BOZHON	Machine builder	46%
	Luster	Machine builder	44%
	KLA	Machine builder	43%
	TZTEK	Machine builder	42%
	Keda	Machine builder	39%
	Jutze	Machine builder	36%
	ASM Pacific	Machine builder	35%

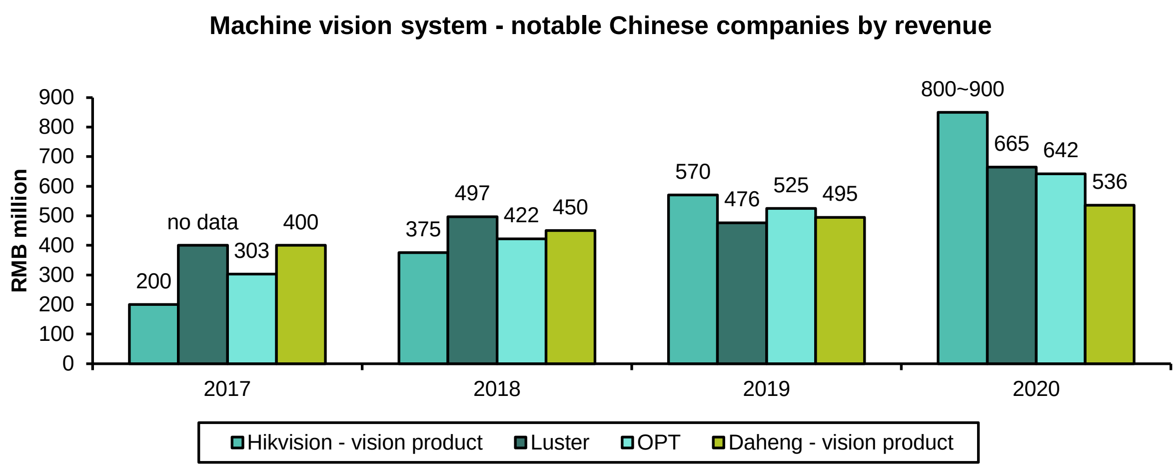
Note: Margin numbers are as of 2020; we used 1H20 disclosed breakdowns for OPT; PCB, Display and Component Inspection segment margin for KLA.

Source: Bloomberg, company reports, and Bernstein estimates and analysis

Among the Chinese "vision big four," while OPT is the only listed vision pureplay and Luster is applying for listing, Hikvision is clearly the emerging local champion. Not only has Hikvision's machine vision business (under the subsidiary Hikrobot) outgrown the other three (see Exhibit 264), its upstream technology is also complete (see Exhibit 261). With that, Hikvision's vision business is pivoting from industrial cameras, which are comparable to the global leader, Basler (see Exhibit 266), to embedded vision systems (see Exhibit 265). As this evolution continues, we believe its GP margin will further expand to the 60%+ level.

A key differentiator vs. local competition is Hikvision's proprietary vision software (VM). Since its first launch in 2017, VM has evolved from free and basic to highly valuable and sophisticated (see Exhibit 267), and competes with MVTec's Halcon, OpenCV, and Cognex's VisionPro as the leading industrial vision software platforms used by Chinese integrators and end-users. Recently, one of the authors completed the training to become a machine vision engineer. Our first-hand experience testifies to the substantial software capability gap between Hikvision and OPT (see Exhibit 268 to Exhibit 270).

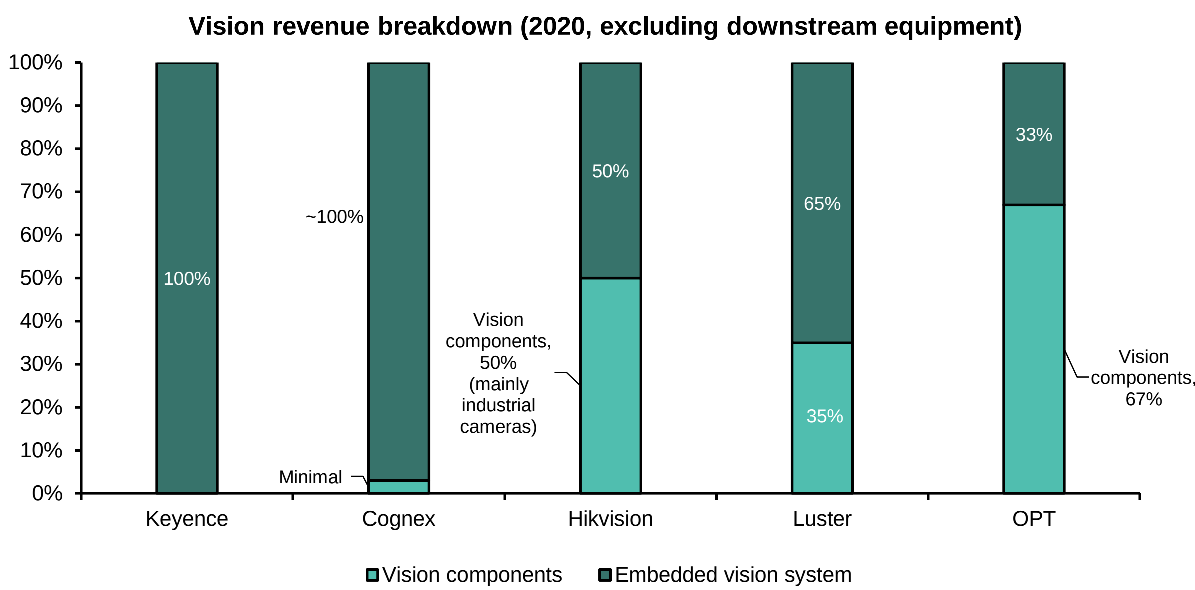
EXHIBIT 264: **Chinese "vision big four" — Hikvision was a late entrant, but has outgrown the other three**



Note: For Luster and Daheng, we included only their machine vision system and upstream components revenue, and excluded the downstream equipment revenue.

Source: MIR Databank, company reports, and Bernstein estimates and analysis

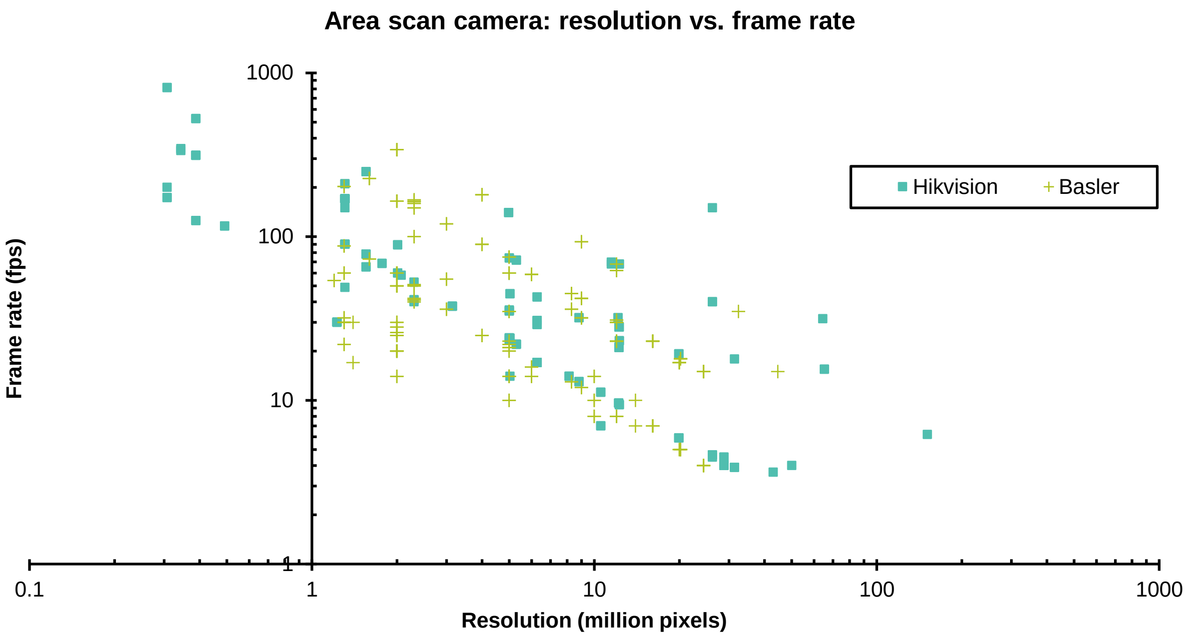
EXHIBIT 265: **Top international players are integrated vision system providers; Chinese companies typically start in upstream**



Note: For Luster, we only included upstream components and midstream vision system, and excluded downstream equipment revenues.

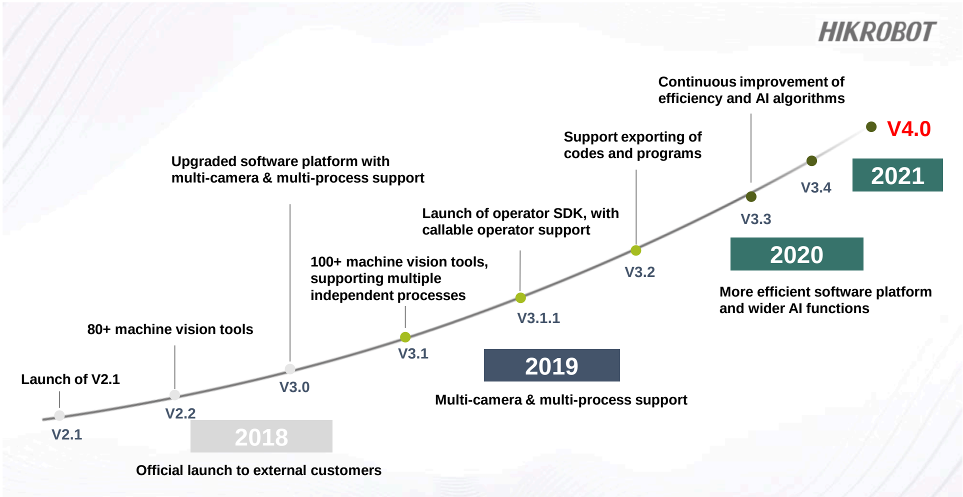
Source: Company reports and Bernstein analysis

EXHIBIT 266: **Industrial cameras need to cover a broad range of specs to meet the needs of diversified applications**



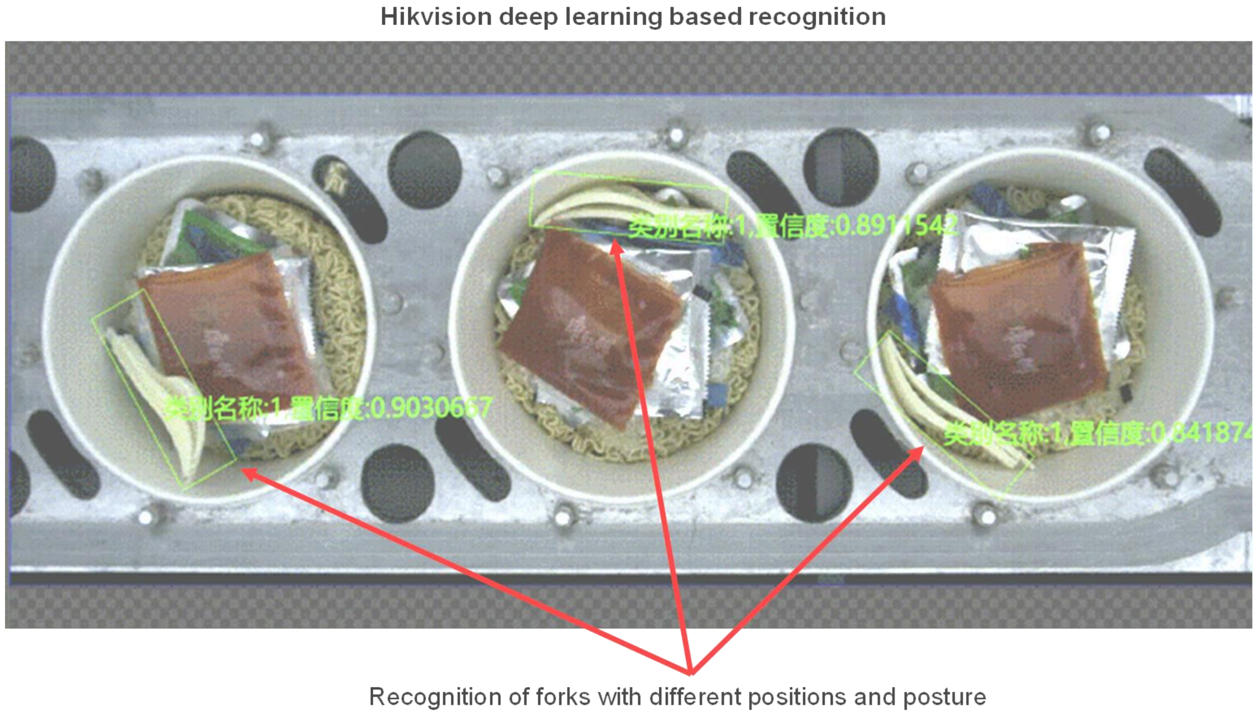
Source: Company websites and Bernstein analysis

EXHIBIT 267: **Since 2017, Hikvision's VisionMaster has evolved from a free element to one of the leading vision software platforms used in China**



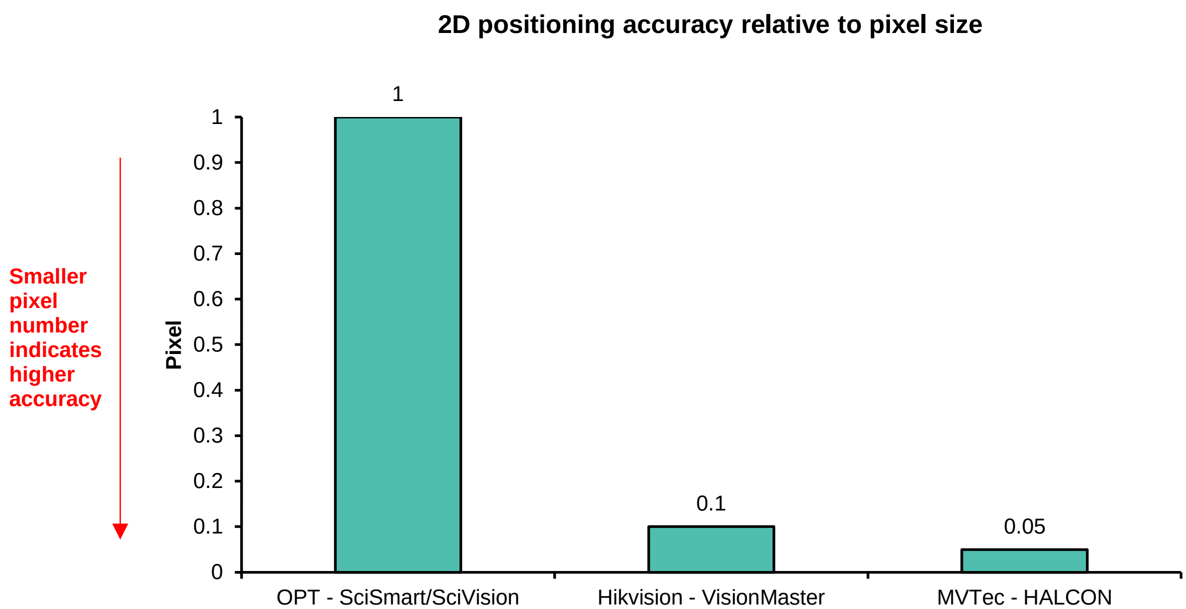
Source: Hikvision and Bernstein analysis

EXHIBIT 268: **Hikvision's deep learning software recognizes objects in different positions and postures**



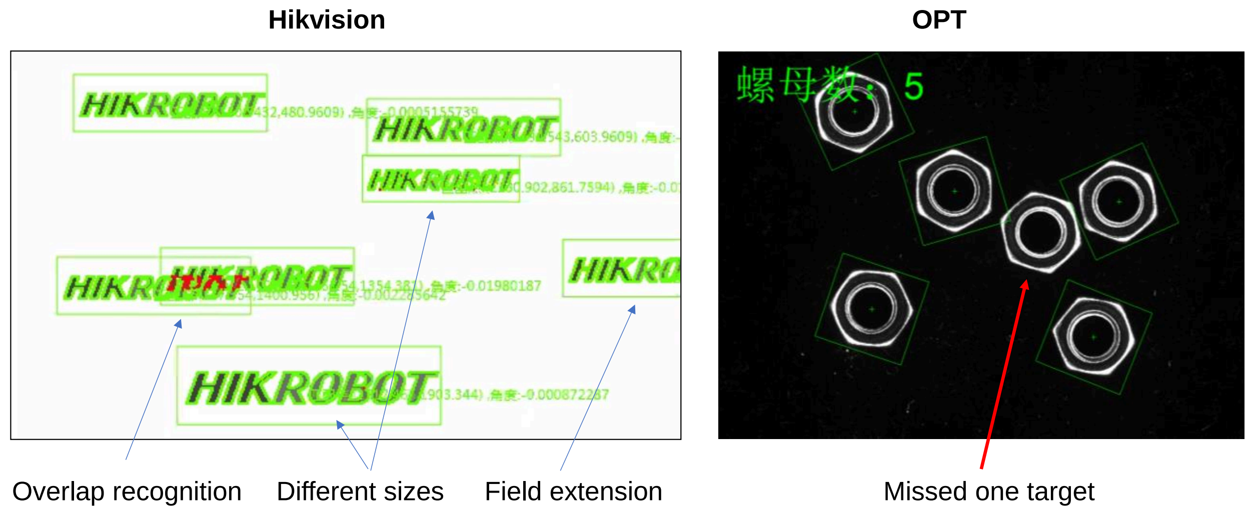
Source: Hikvision and Bernstein analysis

EXHIBIT 269: **Hikvision's VM software is 10x more accurate than OPT's and is approaching world-leading level**



Source: Company materials and website, and Bernstein analysis

EXHIBIT 270: **Vision software comparison: Hikvision (correctly recognizing overlapped or partial objects) vs. OPT (missing an easy target)**



Source: Hikvision, OPT, and Bernstein analysis

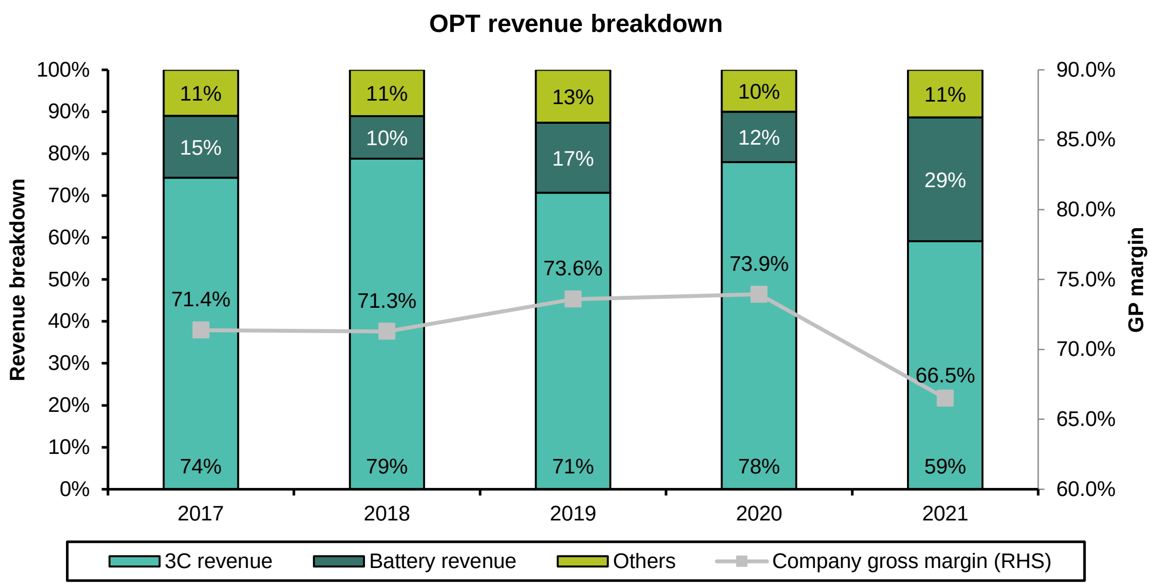
OPT Machine Vision is the only listed vision pureplay in China. The capital market holds high hopes of it riding the local substitution trend and becoming "the next Keyence from China" — growing out of lighting to become a core vision player and significantly outgrowing the underlying market through product expansion and share gains in the long term. In our study of technologies and industry dynamics, however, we see industry leaders' competitive moat underestimated. The potential hurdles on the paths ahead of the Chinese rising star include:

- Underestimated challenges in the expansion from lighting to industrial camera and vision systems: The additional challenges include camera hardware, vision software, and diversified application and vertical know-hows. In all these, OPT is unlikely to catch up with Hikvision, let alone Cognex. The analogy to Keyence is even more misleading, because only 20-25% of Keyence's business is camera-based machine vision, and the rest is other vision technologies (e.g., laser sensing) not even talked about by OPT.

- Limited market share upside in lighting: If the expansion beyond lighting is less than successful, OPT's CAGR may not be much higher than 20% in the coming years. Although its share in the Chinese vision industry is just ~5% and there seems to be much room from share gains, its real share in lighting (light source and controller) is already 30% and, given how fragmented the industry is, the market share upside is very limited in our view.

- Margin and competitive pressure: Light source, being a relatively low barrier part of vision systems, turns out to be the most profitable for OPT. This abnormal margin profile is partly due to the highly customized lighting for its big customer, Apple. As the company expands to serve other verticals such as lithium battery, growth becomes margin dilutive (see Exhibit 271). The increase of "system revenue" (from 25% in 2019 to 41% in 2021) also proved margin dilutive. Moreover, vision system and industrial camera suppliers such as Hikvision are offering integrated lighting solutions, making the competition more intense for OPT and likely further pressing its margin.

EXHIBIT 271: **Increasing revenue contribution from battery industry leads to dilutive GP margin**

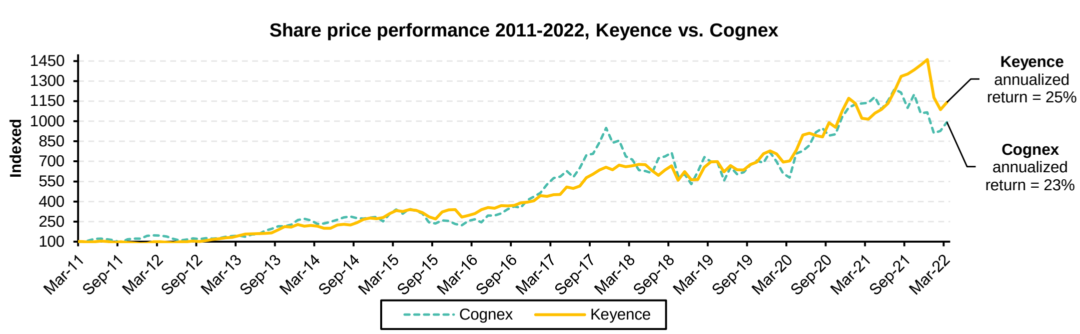


Source: OPT Prospectus, OPT annual reports, and Bernstein analysis

KEYENCE VS. COGNEX: SAME SPECIES, DIFFERENT BREEDS

Keyence and Cognex are two unequivocal leaders in industrial vision. Investors often ask about their differences, which in a sense hardly matter — anyone who stayed invested in these two since 2011 would have achieved similar annualized returns of 23-25% (see Exhibit 272). Yet, comparing the two helps us gain deeper understanding of each.

EXHIBIT 272: **Keyence and Cognex stocks had a stellar run since 2011**



Note: Share prices are indexed, with 1Q11 monthly average price = 100.

Source: Bloomberg and Bernstein analysis

PRODUCTS AND TECHNOLOGY

The most fundamental difference between Keyence and Cognex is, we believe, product and technology scope.[56] All else follow.

We have consistently used a broad definition of industrial vision to include camera and non-camera photonic technologies (e.g., laser sensing) both, as long as these technologies allow machines to "see" by enabling functions such as locating, measuring, guiding, and inspecting. Under this definition, as discussed earlier in this chapter, the USD13-USD15bn global vision market today is about 40% camera-based, 60% non-camera-based, with the latter's portion expanding slowly (see Exhibit 245).

While both companies have the majority of business in vision, Cognex is 100% in camera-based vision segment and, by our estimate, Keyence is 20-25% in camera-based vision,[57] 40-45% in non-camera-based vision, and the rest is non-vision[58] (see Exhibit 273 and Exhibit 274). Exhibit 255 shows some examples of Keyence's various non-camera vision products. Compared with Cognex's product examples in Exhibit 275, one can see they are very different products aiming at broadly overlapping applications.

When Keyence started in 1974, the industrial vision industry didn't exist. Its birth as "a sensor company solving manufacturing problems" allowed the company to embrace vision solutions across a range of photonics technologies when cameras and lasers became increasingly important in production lines, and it pivoted to a vision company. Cognex was started by a computer vision scientist in the 1980s and has built the business around "image acquisition and analysis" ever since. They started as very different companies, and the overlap only increased later.

Keyence is by far the largest industrial vision player with ~26% overall market share, followed by SICK and Cognex (see Exhibit 277). In the camera-based vision segment, Keyence and Cognex are leaders with a combined ~40% share (see Exhibit 278). Keyence is bigger because it has about 45% revenue and a much more dominant position in Japan. Outside Japan, we estimate that Cognex's camera-based vision business is slightly bigger than Keyence's.

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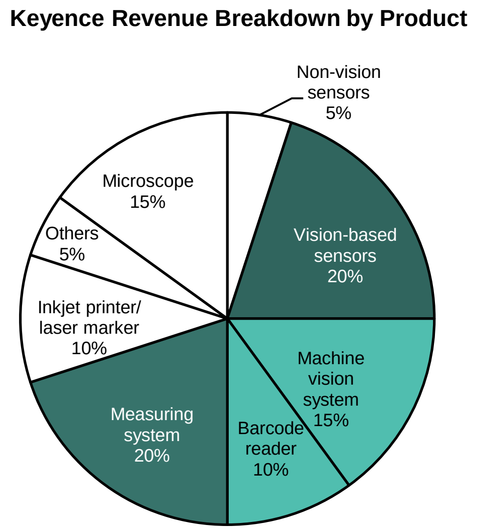
[56] To read just one report to understand Keyence, we suggest Keyence: The (true and false) secret sauce.
[57] Quite often, people in the automation/tech industry and in finance use the term "machine vision" to refer only to camera-based vision. It follows that "only a small part of Keyence is in machine vision." This does not contradict our view that Keyence is close to a "vision pureplay"; it is a matter of lacking standard definitions.
[58] We classify microscope in the non-vision segment of Keyence. Although microscope is also a photonic technology that sees objects, its use is different from other vision technologies in industrial settings. If one wishes to include microscope also in vision, then Keyence would be even closer to a vision pureplay (80%+ revenue exposure).

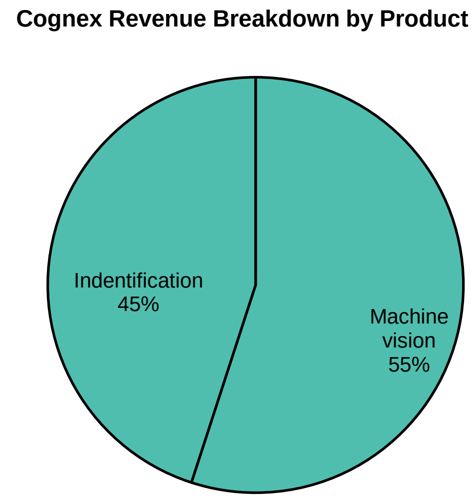
EXHIBIT 273: **Around 65% of Keyence's business is in vision, of which a little over one-third is camera-based**



Note: Non-vision sensors include, e.g., flow sensors.

Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 274: **Cognex's machine vision and identification products are almost entirely camera-based**

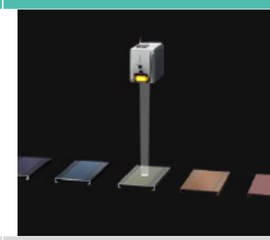


Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 275: **Applications of Cognex products**

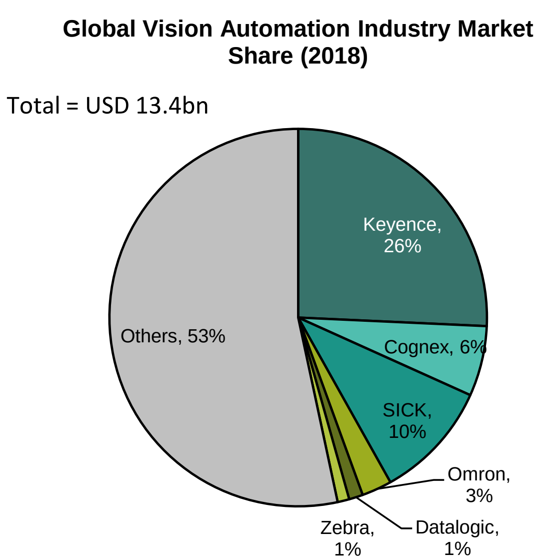
Source: Cognex website and Bernstein analysis

EXHIBIT 276: **Examples of Keyence non-camera-based vision products, for many of which hardware design is an important differentiator**

	LJ-X8000 series	VL Series	WI-5000 series	CL-3000 series
Model				
Technology	Laser triangulation	3D measurement system (offline)	Laser interference	Laser confocal
	IX Series	TM-X5000 series	IG series	LR-W series
Model				
Technology	Image-based laser sonsor (Camera + Laser)	Projection image	Laser micrometer	Full spectrum photoelectric sensor

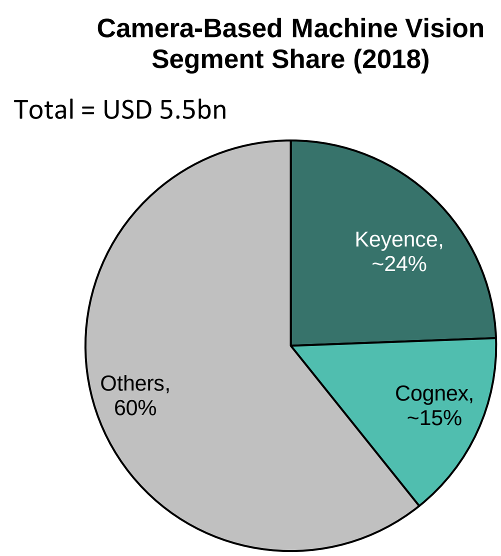
Source: Keyence websites and Bernstein analysis

EXHIBIT 277: **Keyence is by far the global leader in industrial vision, followed by SICK and Cognex**



Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 278: **Keyence and Cognex are the top two in the camera-based vision segment**



Source: Company reports, and Bernstein estimates and analysis

The distinct product focuses at Keyence and Cognex give rise to several other important differences in their product portfolio:

- **SKU scope and new products:** We estimate that Keyence's ~3,000 SKUs are ~10x that of Cognex (see Exhibit 279).[59] Keyence also leads the industry's advancement, with 70% of its products being the world's first and 20-30% of total sales from new products annually. These figures emphasize Keyence's innovative nature and reflect the many technology branches its portfolio covers. Camera-based technology alone simply does not have nearly as many variations or "new stuff" to be invented.

- **Hardware vs. software:** Cognex has made it clear that it is a software company. While hardware (industrial cameras) quality matters, a similarly high-quality hardware portfolio is available from several other suppliers. Most of Cognex's value-add and differentiation is in the embedded vision software, while Keyence is much more hardware-centric. If we artificially assign 90% of Cognex's value-add to software, the figure for Keyence would likely be 50%. However, we argue that the difference is not due to the companies' business model choice, but due to where they play — we suspect that for the 20-25% camera-based business at Keyence, the ratio of software value-add is very similar to that of Cognex, but the other 2,500+ SKUs of Keyence (like those in Exhibit 255 and many more) simply require much deeper and broader hardware design know-how, changing the relative value split between hardware and software.

- **3D vision:** The broader photonic technology scope gives Keyence an important edge in 3D vision, in which we estimate that Keyence has ~50% global market share. In 1D and 2D vision, camera-based technology can cover most applications, and the functions of camera and non-camera products overlap. In 3D vision, however, non-camera (especially laser-based) technologies (see Exhibit 280) are required in half or more of all applications, i.e., camera and non-camera technologies are more complementary than competing.[60] This is especially true for precision measurement or dealing with hard-to-image (e.g., transparent, highly reflective, low contrast, and hard-to-focus) surfaces. Cognex has made dedicated efforts and clear progress in recent years to strengthen its 3D vision portfolio through organic R&D and acquisitions both. However, being limited in a single (camera-based) technology path may continue to handicap its competition vs. Keyence in this segment.

Both companies have successfully developed AI technology for industrial vision.[61] Keyence has done it organically and Cognex through the acquisition of two AI start-ups: ViDi Systems (2017) and SUALAB (2019). Here, the technology difference is less fundamental than their respective business models, which we discuss later in this chapter.

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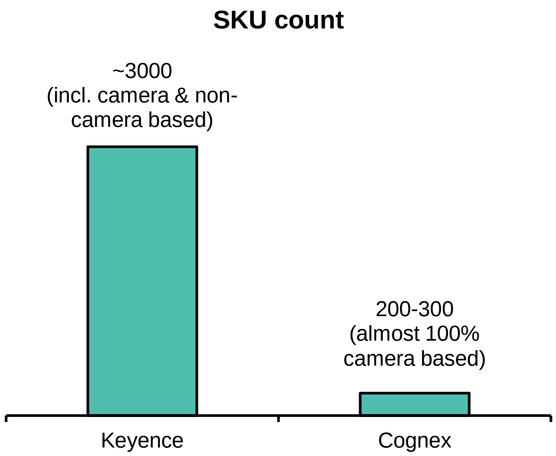
[59] We do not know with certainty how many SKUs Cognex has, but our experience is that 200-300 industrial camera models cover the application space.

[60] Note that within non-camera technologies, there are several distinct technology branches for 3D vision. See "And there was light (the rise of 3D vision)" section in our The Tech Side of Automation *Blackbook*.

[61] See AI in Manufacturing: A primer on the next leg of industrial revolution - where is adoption, why now, who is winning.

EXHIBIT 279: **Keyence has ~3,000 SKUs, about 10x that of an industrial camera company's portfolio**



Note: Cognex's exact number of SKUs is unknown. We use typical industrial camera SKU numbers as a proxy for estimation.

Source: Company websites and Bernstein analysis

EXHIBIT 280: **Non-camera-based photonic technologies are more important in 3D vision and give Keyence an advantage over other vision players**

Vision products	1D	2D	3D	
Camera	Line scan camera	Image-based code reader	Stereoscopic ("double eye") camera	ToF camera and sensor; Structured light camera (laser and non-laser)
		Area camera		
Non-camera	Laser and optical presence, positioning, distance sensor; laser micrometer	2D laser displacement sensor; image-based laser sensor	3D laser displacement scanner	
			Laser confocal sensor	
	Laser code reader		Laser interference sensor	
		Offline measurement system; image based laser sensor		

Source: Keyence websites and Bernstein analysis

CUSTOMER STRATEGY

Keyence is famous for its 100% direct sales model, whereas Cognex is 40-50% indirect. It is worth noting that for both companies, the direct channel serves not only end-user factories, but also machine builders and automation system integrators that procure products from Keyence and Cognex directly (see Exhibit 281).

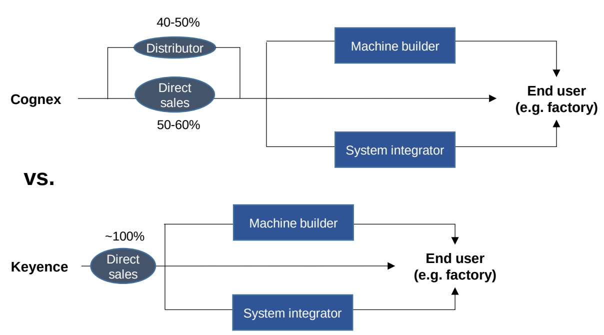
We think the apparent difference in direct sales ratios is rather superficial. The more profound difference is in their strategy toward customization and key accounts. Keyence repels customization for individual accounts and serves over 300,000 customers worldwide; Cognex proactively targets key accounts, heavily customizes for them, and the largest two customers, Amazon and Apple, accounted for ~27% of company sales in 2020 (see Exhibit 282). The end-customer vertical exposure is similar in the two companies' TAM; however, their respective key customer approaches have resulted in a different revenue mix (see Exhibit 283 and Exhibit 284), with consumer electronics and logistics being much larger segments for Cognex.

Keyence innovates but does not customize.[62] When Keyence introduces a new product, it is meant to be used by as many of its 300,000 customers as possible, and it refuses to tailor-make solutions for large customers. This "mass customization" approach is key to scalability and in a way more difficult than tailor-making, because it requires all products to be highly versatile with robust performance in very different setups. The direct sales model then ensures that Keyence creates a feedback loop to stay updated with new trends and identify latent needs earlier than the competition and even the customers themselves. The idea is widely misunderstood, leading many to believe that Keyence's products are "generic," and the secret sauce is only in the sales model.

Cognex, being a smaller company, takes the more conventional approach. It correctly concludes that the most advanced manufacturers are often the first adopters of new technologies, and grabbing these flagship opportunities is important for TAM expansion and staying ahead of the competition. It, therefore, is willing to work closely with those large customers to make the adoption happen by customizing heavily at product and solution levels both. In the best case, some of these tailored solutions become more standard as adoption broadens to the long tail of customers in the same industry, although it does not always happen.

For Keyence's model to work without the risk of commoditizing its entire portfolio, it needs to be in a sufficiently complex field with confusingly abundant products and plenty of chances to innovate. The broad vision industry is such a field, though the narrower camera-based machine vision segment is likely not. Here again, we see that the product scope difference precedes the commercial difference. However, the commercial choices do leave their marks on products. Comparing Keyence's and Cognex's AI products for instance, Keyence's use cases cover lots of common objects, each with a limited number of defect types but used by hundreds of thousands of customers, while Cognex's focus more on complex objects and defects (see Exhibit 285). To serve the broader customer base, Keyence is also famous for its intuitive, easy-to-use product user interface (see Exhibit 286). Even highly sophisticated applications such as vision-guided robot bin picking are packaged into intuitive menu options. By contrast, Cognex allows its expert customers to use an Excel-style interface to do much more serious programming (see Exhibit 287).

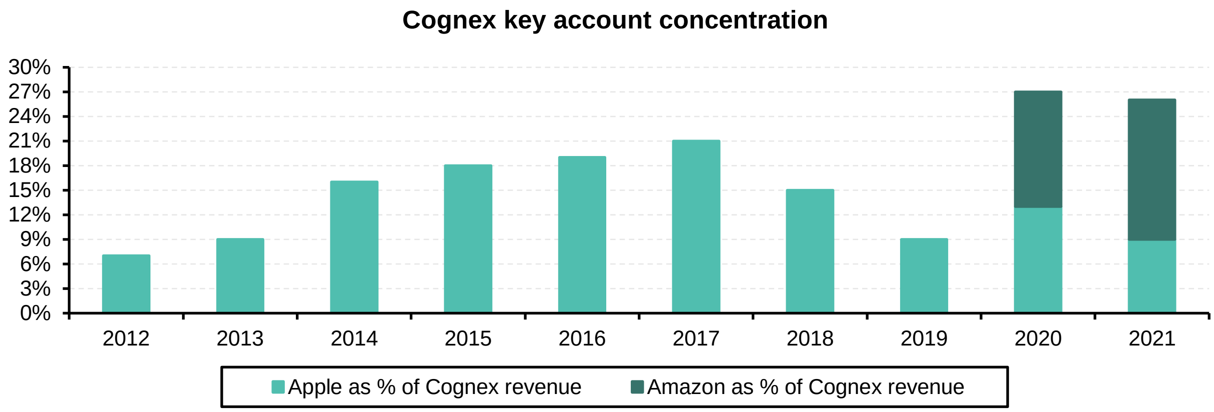
EXHIBIT 281: **Keyence has a higher direct sales ratio than Cognex, but this is a superficial difference**



Source: Company reports and Bernstein analysis

[62] See Keyence: The (true and false) secret sauce.

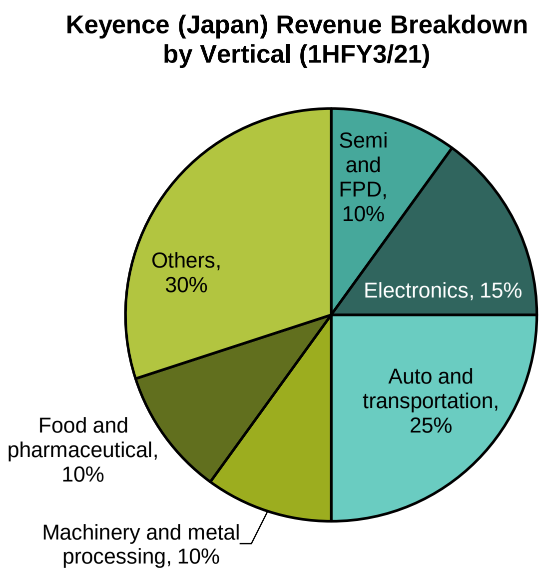
EXHIBIT 282: **Cognex's two largest customers, Amazon and Apple, accounted for >25% of company sales in recent years**



Note: Cognex disclosed that no single customer accounted for over 10% of revenue in 2012, 2013, and 2019; we don't know the exact contribution from Apple in those years but estimate it to be in the 7-9% range. In 2021, Apple contributed to less than 10% of total revenue; we estimate it to be 9%.

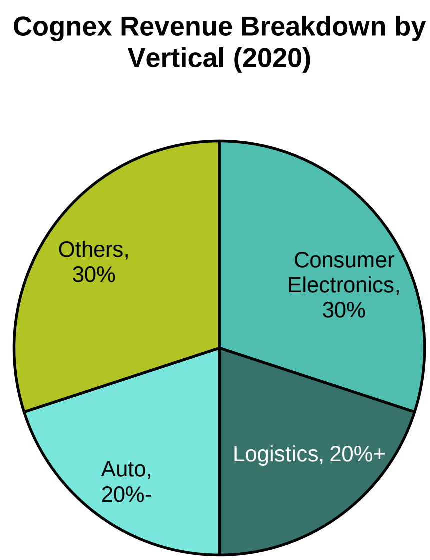
Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 283: **Keyence's end-market exposure is more diversified...**



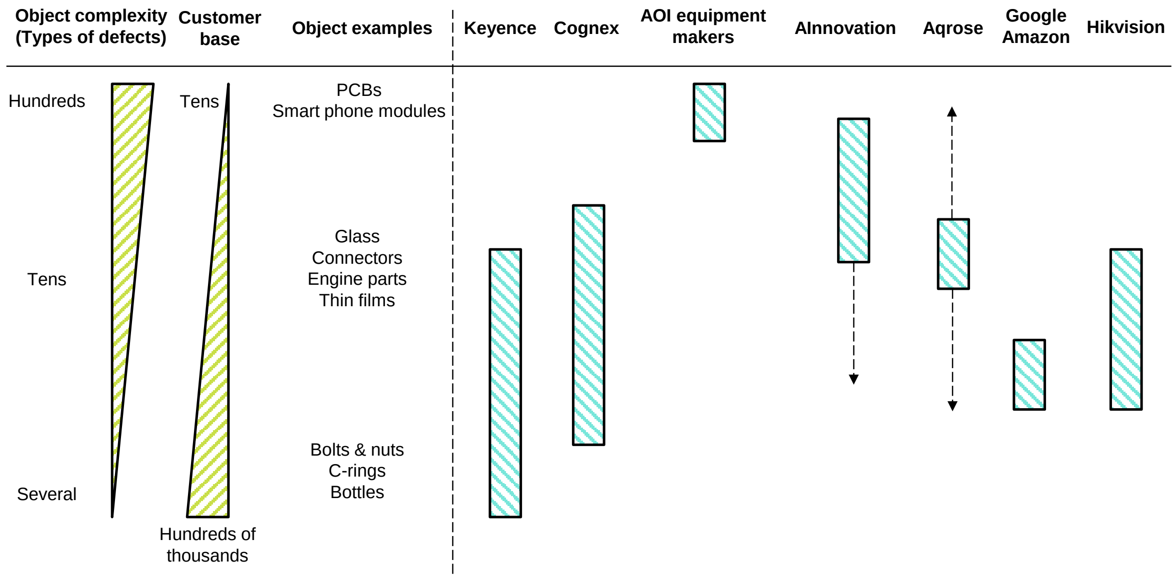
Source: Company reports and Bernstein analysis

EXHIBIT 284: **...while Cognex is more concentrated in logistics and electronics due to two key accounts**



Source: Company reports, and Bernstein estimates and analysis

EXHIBIT 285: **Machine vision players' strategies: universal or specialized?**

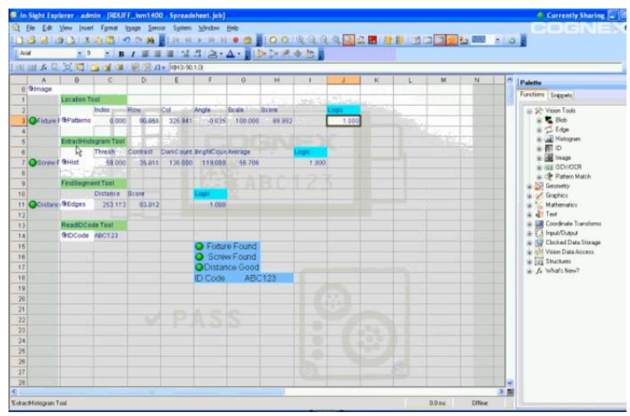


Source: Bernstein analysis

EXHIBIT 286: **Keyence's intuitive interface pre-packages many user functions; it suits general users**

Source: Keyence website

EXHIBIT 287: **Cognex allows expert users to do coding on its products using an Excel-style interface**



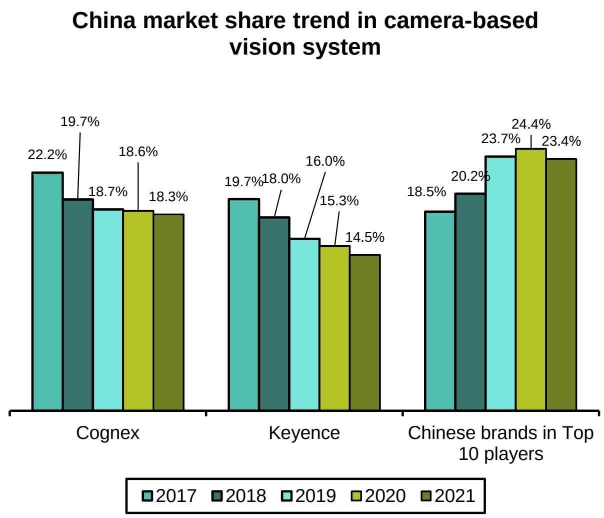
Source: Cognex website

In the past, except for some additional volatility, the different customer strategies have not yielded much difference in the two companies' growth profiles (see Exhibit 291). We think it may remain so in the medium term, but believe there is more uncertainty associated with the key account-oriented strategy. Apple remained Cognex's oversized customer for many years, and other smartphone makers' production lines have not caught up in vision intensity. After the vision demand at Apple started saturating, it was a short gap before Amazon rose to become Cognex's most important growth engine, but we doubt there will be another

Amazon to Cognex's logistics segment. If its growth continues to rely on the emergence of new oversized customers, how sustainable is it in the long run? We don't know.[63]

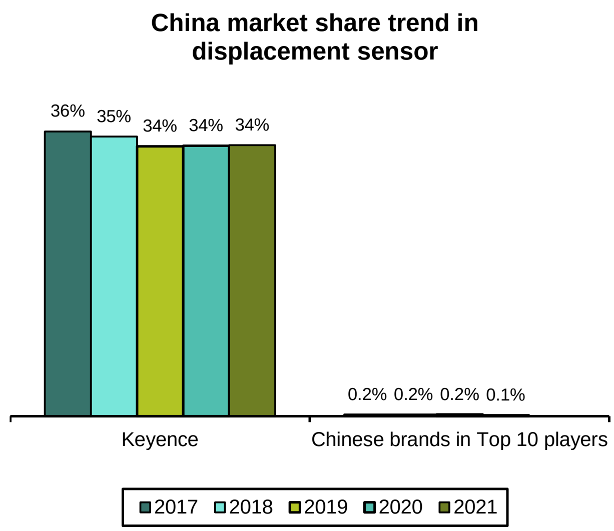
Given the nature of its product portfolio and customer strategy, Cognex is facing more competition from China than Keyence. The likes of Hikvision, OPT, and AI start-ups such as Smartmore, AInnovation, and Aqrose are taking market share in the camera-based vision segment (see Exhibit 288). It is a relatively contained issue in China currently, but as this market grows, Chinese players increasingly eye the global market, and large individual customers in new industries emerge from China (e.g., CATL in EV battery), the pressure on Cognex will only gradually increase. Keyence is facing the same headwinds in this segment, but the company-level impact is much smaller. In Keyence's other product categories, e.g., non-camera sensors, Keyence is holding its share firmly (see Exhibit 289). Simple calculation based on product and geographical exposure shows that as much as ~19% of Cognex's revenues are under threat from Chinese competition, vs. ~3% for Keyence (see Exhibit 290).

EXHIBIT 288: **Cognex and Keyence have been losing share in China's camera-based vision market...**



Source: MIR Databank and Bernstein analysis

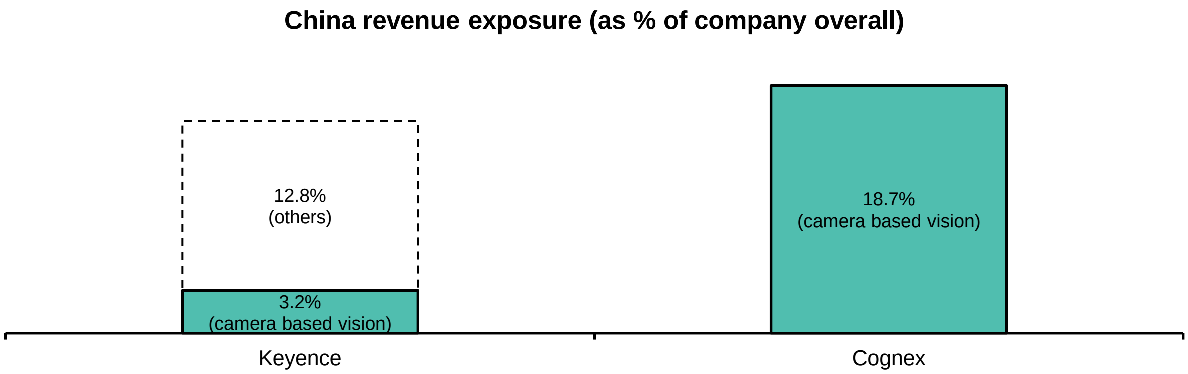
EXHIBIT 289: **...while Keyence is holding up well in vision sensors, where Chinese players remain marginal**



Source: MIR Databank and Bernstein analysis

[63] See Cognex: The burden of customer concentration weighs on.

EXHIBIT 290: **About 19% of Cognex's business is under threat of Chinese competition vs. ~3% of Keyence's**



Note: Cognex 2020/Keyence FY3/21 numbers are used in this calculation. We assume 90% of Cognex's greater China sales are in mainland China; 20% of Keyence's China sales are camera-based machine vision.

Source: Company reports, and Bernstein estimates and analysis

Financials and valuation

Keyence and Cognex had similar CAGRs between 2005 and 2021, with additional volatility in both top (see Exhibit 291) and bottom lines (see Exhibit 292) for the latter due to key account concentration.

Both companies are highly profitable. Yet, the OP margin gap (1,500-2,000bps) is much bigger than the GP margin gap (500-800bps) (see Exhibit 293). We believe this is the direct consequence of their respective customer strategies. Keyence, avoiding customization, has an R&D intensity of 3%. Cognex, on the other hand, spends over 15% of its revenue on RD&E, and we estimate that two-thirds of this expense is in E (engineering expenses) associated with solutions customization and deployment for key accounts.

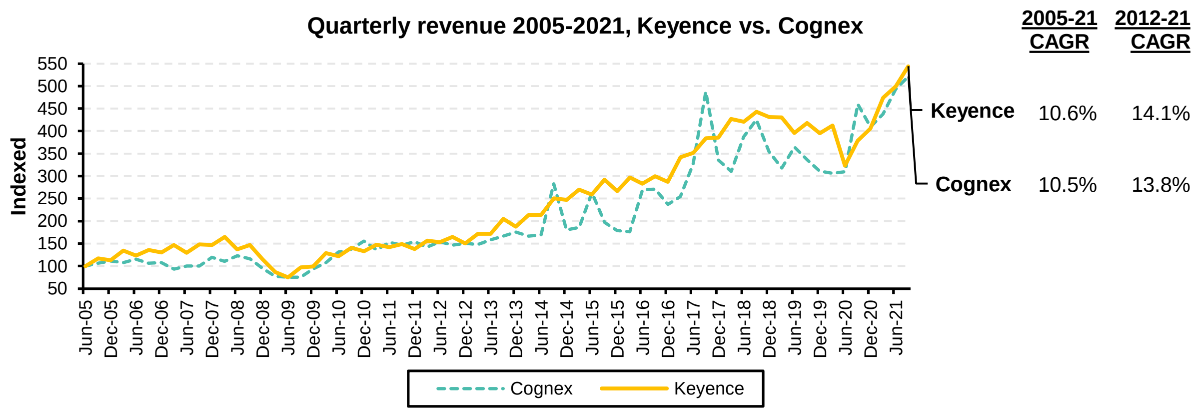
If Keyence is so innovative, how come it spends only 3% of revenue in R&D? Many investors have found this concerning. One reason we have explained is Keyence's mass customization approach, which greatly helps scalability and R&D efficiency. But another straightforward explanation might be even more powerful — the company is just too profitable. People customarily use R&D-to-revenue ratio to measure R&D intensity, but the comparison is only valid for businesses with similar GP margins. For tangible products, the real R&D intensity is, we argue, better measured by R&D-to-COGS ratio. After all, if the same product is marked up 10x in price, the R&D content in that product does not change, but the R&D-to-revenue ratio becomes much lower. Following this line of thought, we compare Keyence's R&D-to-COGS ratio with other industrial tech companies and find Keyence's true R&D intensity to be higher than most (see Exhibit 294).

Both companies have seen multiple expansion in the last decade as vision technology became more important in the automation field and more visible to investors. Keyence's multiple is further helped by its successful global expansion since 2012, its steadier results delivery through cycles, and its slow yet noticeable improvement in ESG.[64] Cognex usually

[64] See Keyence: ESG in Action... Improvers and Enablers - Small yet steady steps toward disclosure and access.

trades at a premium to Keyence, due partly to the notion popular among investors that the former is the only vision pureplay while the latter is an automation generalist. Our analysis in this chapter shows this is not true. The relative valuation between the two is largely explained by the growth differential (see Exhibit 295), which was a function of the business cycle at Cognex's two large customers.

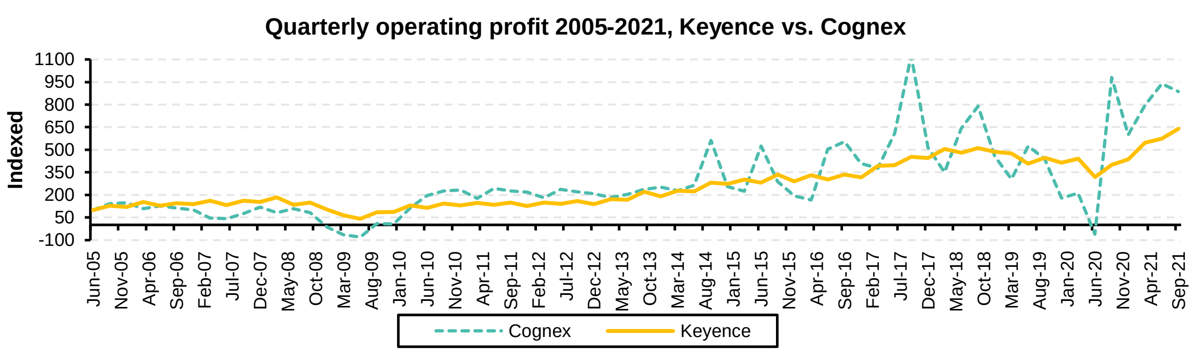
EXHIBIT 291: **Keyence and Cognex have similar long-term growth profiles, with the latter being more volatile...**



Note: Quarterly revenues are indexed, with June 2005 quarter = 100.

Source: Bloomberg, company reports, and Bernstein analysis

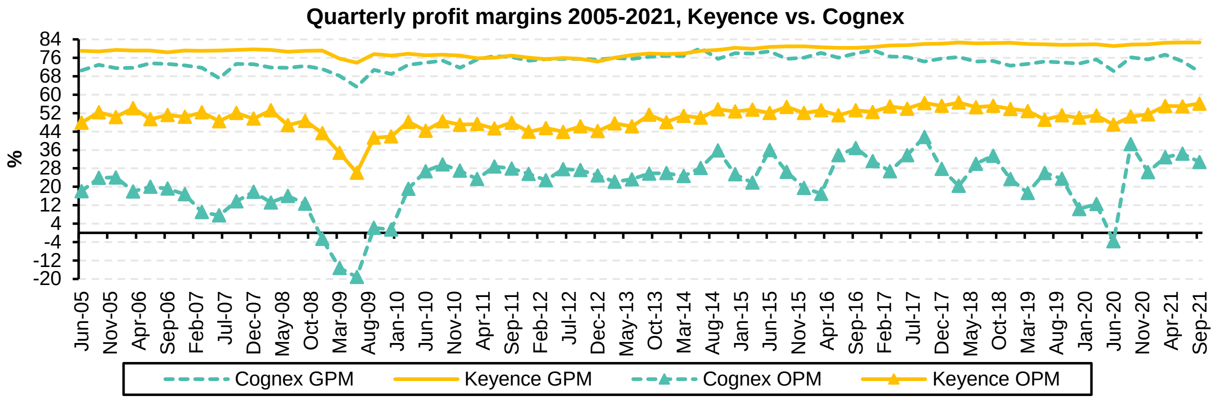
EXHIBIT 292: **...as it is in profit growth**



Note: Quarterly revenues are indexed, with June 2005 quarter = 100.

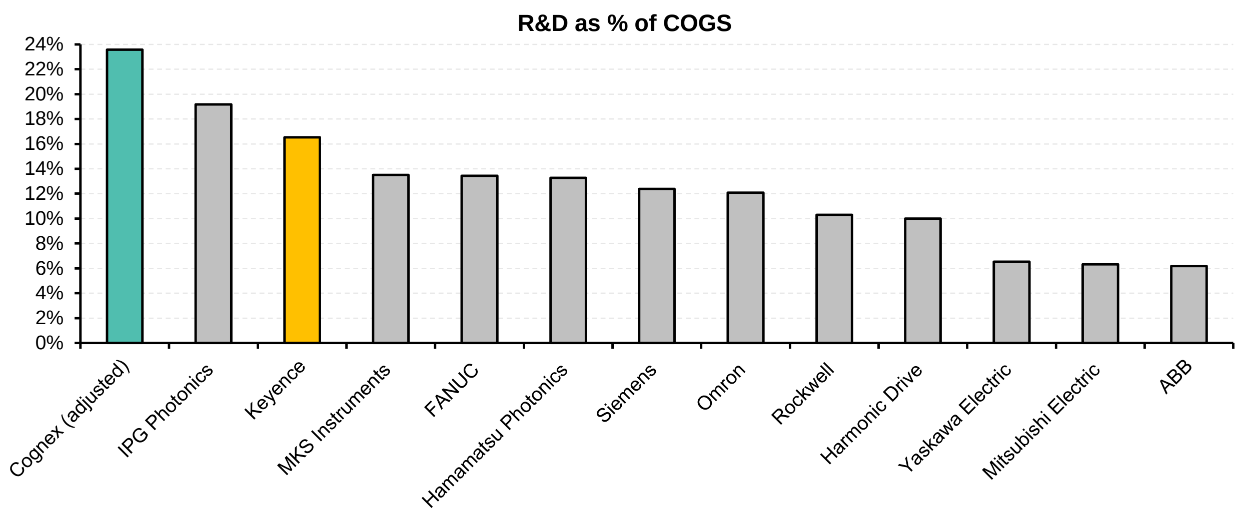
Source: Bloomberg, company reports, and Bernstein analysis

EXHIBIT 293: **Both companies are highly profitable, but the OPM gap is substantially bigger than the GPM gap due to their different customer strategies**



Source: Bloomberg, company reports, and Bernstein analysis

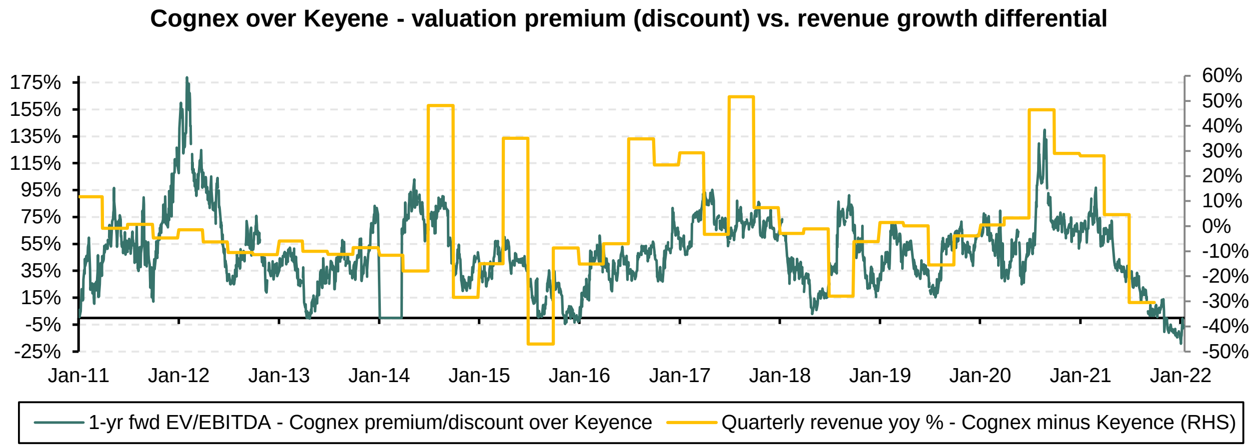
EXHIBIT 294: **Across companies with very different GPM profiles, we propose R&D-to-COGS ratio as a better measure of R&D intensity; Keyence and Cognex are among the most R&D-intensive industrial tech names**



Note: We estimate two-thirds of Cognex's reported RD&E expenses are engineering costs related to key account customization and have excluded it from the analysis.

Source: Bloomberg, and Bernstein estimates and analysis

EXHIBIT 295: **Cognex usually trades at a premium to Keyence; the gap correlates with the growth rate differential between the two names**



Note: EV for both companies has been adjusted for the excess cash positions held in long-term investments.

Source: Bloomberg and Bernstein analysis

ARTIFICIAL INTELLIGENCE

The next leg of industrial revolution

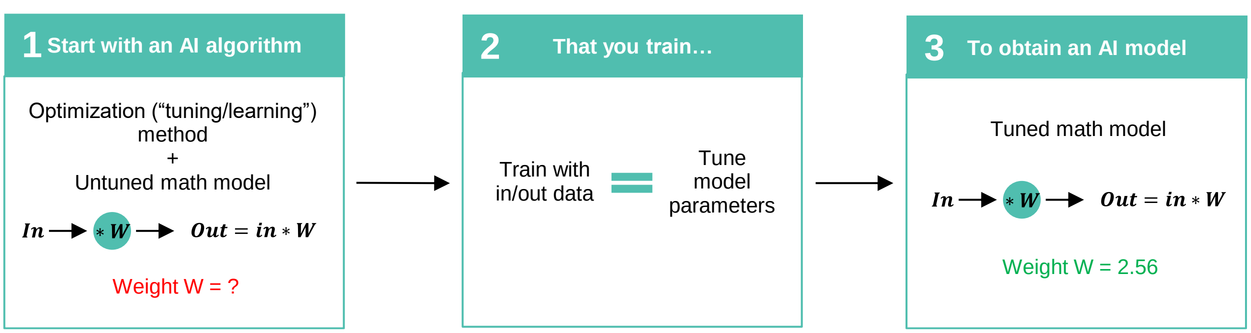
AI IN MANUFACTURING: A PRIMER

We are witnessing an inflection in industrial tech. Since our first note on the topic in 2017,[65] AI has seen great progress in manufacturing, moving in just three years from proof of concept to viable commercial solutions that quickly multiply.

Now as then, we start by defining the term AI for our discussion. We are not referring to any form of general intelligence, super intelligence, or sentient beings. An AI algorithm as we know it today is simply an untuned mathematical model and the method used for optimizing it (see Exhibit 296). Training an algorithm is shorthand for tuning the model parameters with data for desired output. The "intelligence" of an AI algorithm is nothing but its ability to "learn" optimized parameters automatically.

For the practical purposes of this chapter, we take an even narrower view of AI, focusing solely on deep learning algorithms. Deep learning differs from conventional machine learning in that it does not need to be told what features (e.g., colors, shapes, and sizes of an image) to learn beforehand and will extract the interesting features automatically (see Exhibit 297). This is often made possible with multi-layer neural networks and large datasets, the latter of which is deep learning's Achilles heel, especially for fields where data is scarce, such as manufacturing.[66]

EXHIBIT 296: **The "intelligence" of AI is but its ability to automatically "learn" optimized parameters in a mathematical model**

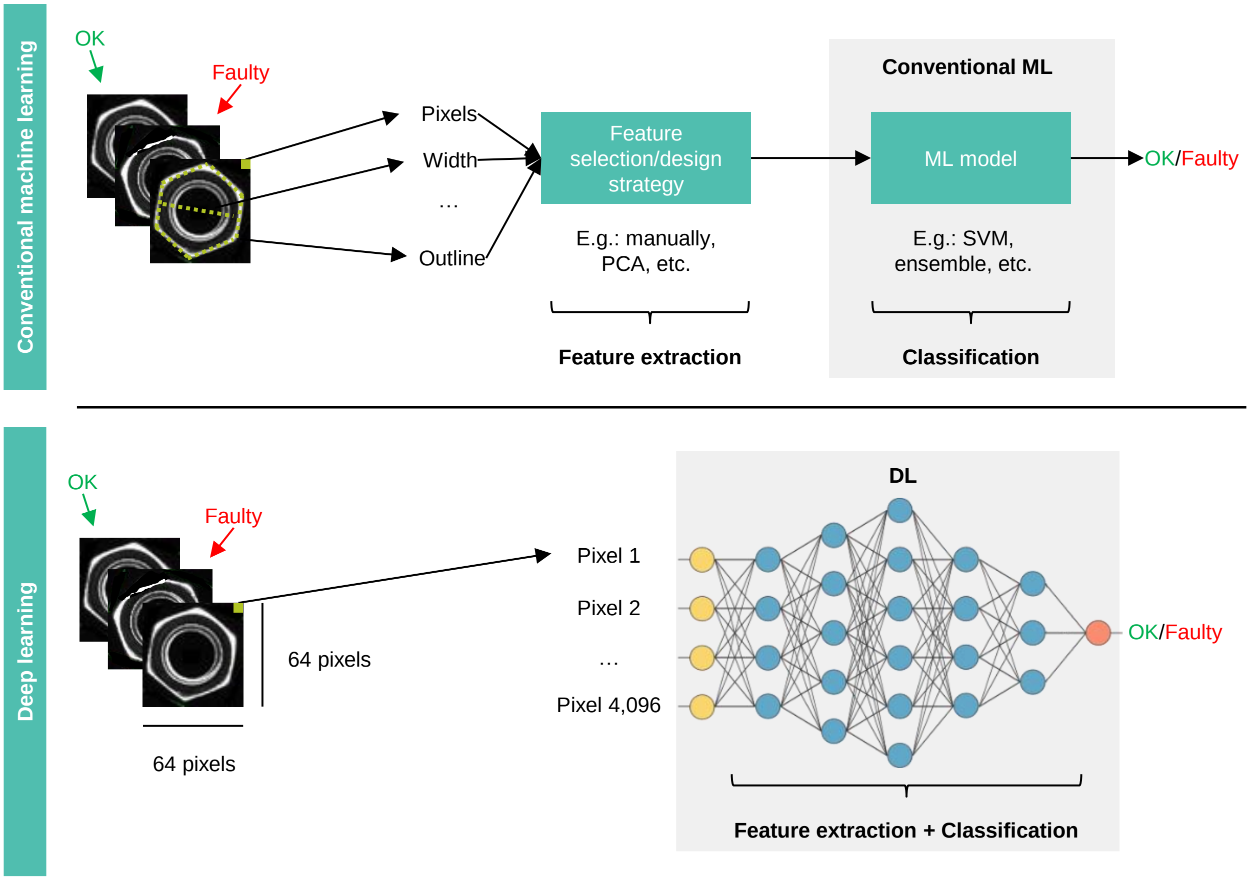


Source: Bernstein analysis

[65] See Artificial Intelligence in Automation: You say disruptor, I say multiplier.

[66] But there are ways to get around this, otherwise you wouldn't be reading this chapter.

EXHIBIT 297: **Deep learning vs. conventional machine learning: the former extracts relevant features without being told what to look for**



Note: Principal component analysis (PCA) is a variance-based dimensionality reduction technique used for designing a smaller set of new higher variance features. Support vector machines (SVM) and ensemble models are commonly used ML models.

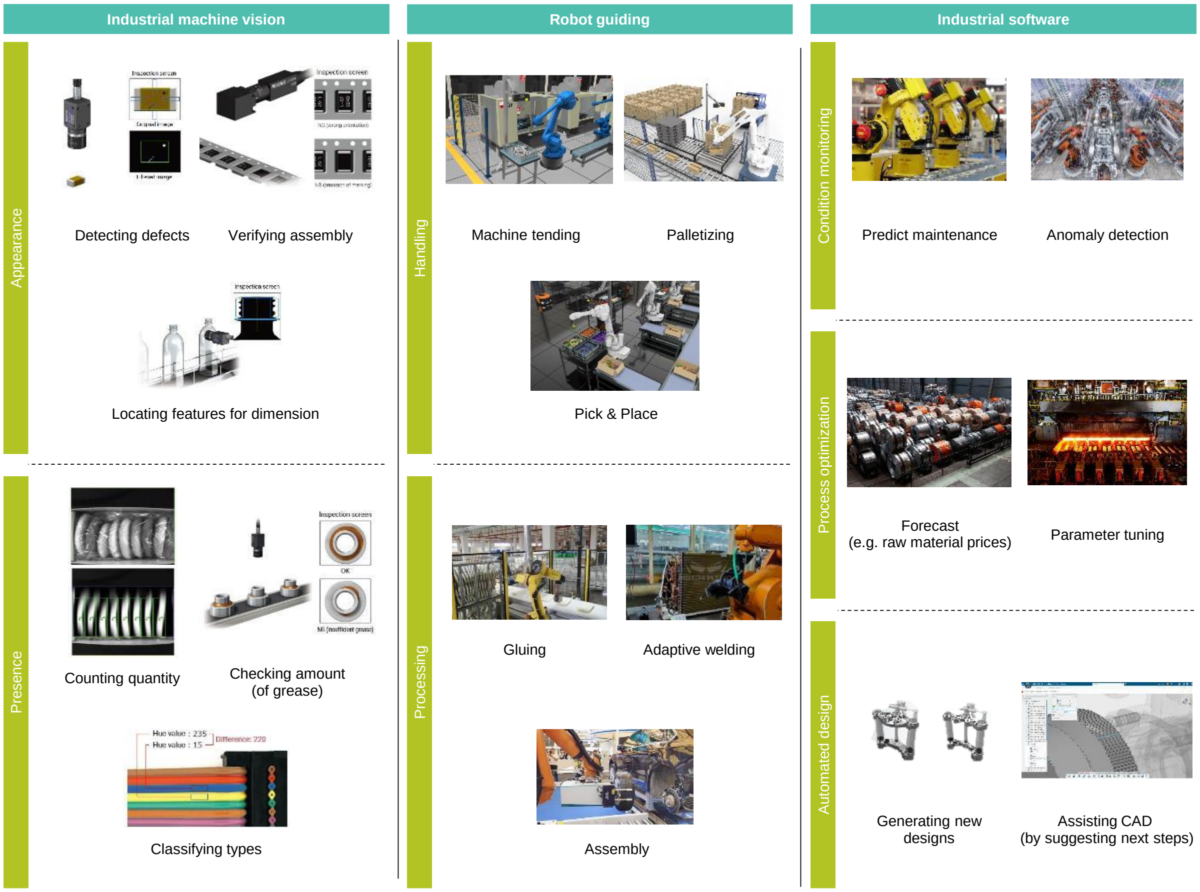
Source: Bernstein analysis

WHAT CAN AI DO IN MANUFACTURING?

In manufacturing, AI is used in three application areas: industrial machine vision,[67] robot guiding, and industrial software (see Exhibit 298). Tasks in these areas are often hard to predefine a rule set for,[68] and a potential solution can be found in an infinite number of ways[69] — a perfect challenge for deep learning to tackle.

[67] Although not discussed in detail in this chapter, video technology, an adjacency of industrial machine vision, is also seeing increasing adoption in the digitalization of manufacturing enterprises.
[68] For example, it is hard to define a set of deterministic rules for a robot to grab metal slugs from a bin and place them in a CNC machine with all the random influencing factors, such as slug orientation, lighting, obstacles, etc.
[69] For example, the number of paths the robot could take and execute a pick is infinite.

EXHIBIT 298: **Key application areas of AI in manufacturing**



Note: Cost reduction compares the cost of implementing an AI solution over manual labor; hence, it is not applicable to industrial software.

Source: BMW, Mech Mind, Autodesk, Keyence, Getty Images, and Bernstein analysis

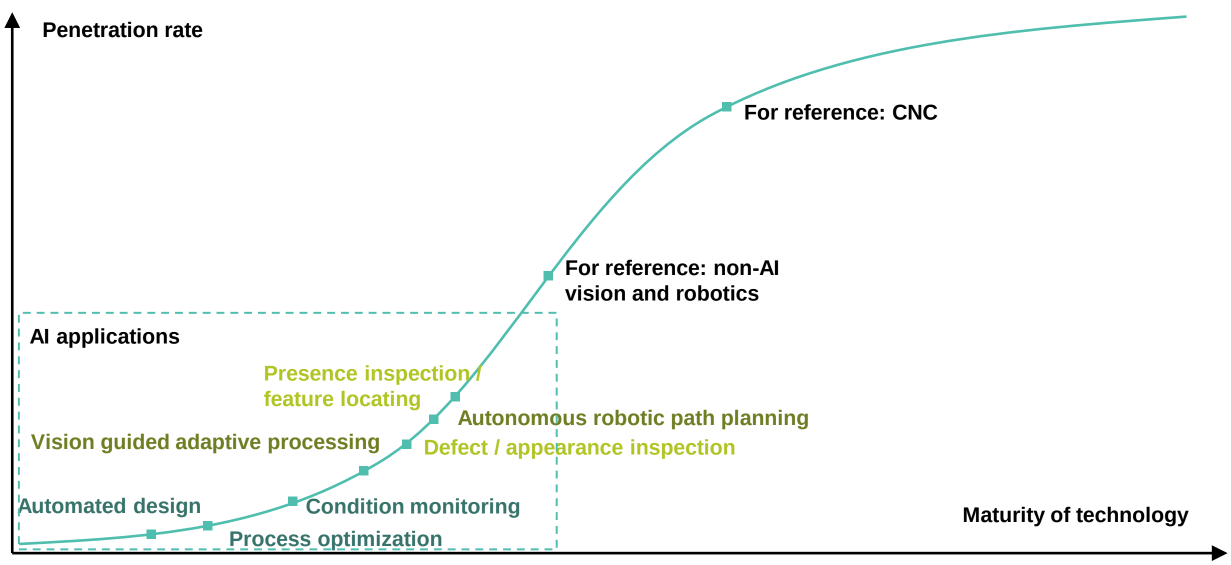
Use of AI in manufacturing is still new, and its applications show different levels of maturity and adoption (see Exhibit 299).

- AI-powered industrial machine vision significantly expands the scope of automated inspection by augmenting rule-based vision functions. AI is used for detecting appearance or presence, such as defects or quantity of objects. While rule-based vision has long been used for straightforward inspection tasks, AI's strength is in complex cosmetic defects, texture and material classifications, complex assembly verification, deformed features, and variable feature location. When inspecting machined parts for defects, AI-based machine vision can reduce costs and inspection times by >90% over manual inspection and has a typical payback of less than a year. AI also helps in other vision functions such as measurement, recognition (code reading and OCR), and guiding, and is often integrated with rule-based vision functions.

- In robot-guiding applications such as tending CNC machines, welding, and assembly, AI helps robots "understand" the surroundings and plan optimal paths. It expands the scope of robot applications to those that require precise hand-vision coordination in unstructured environments. One such example is the joining of wheels to vehicles moving on automotive production lines. Due to the large variety of vehicle models and high precision requirements, this task has remained largely manual — even in modern car factories. AI robot guiding systems enable industrial robots to know precisely where everything is located and rapidly plan a feasible path to join wheels to moving vehicles, with 60-70% cost reduction.

- In industrial software, AI is used for condition monitoring of production lines, manufacturing process optimization, and automated design. In condition monitoring, AI models use machine sensor outputs to predict machine maintenance needs, detect manufacturing anomalies, etc. For process optimization, AI uses process inputs and outputs to forecast outcomes and optimize production processes. In automated design, AI assists with the design process by generating new designs or streamlining the 3D modeling procedure. Unlike in the previous applications, AI does not play a direct labor-substituting role in industrial software, but strengthens the functions.

EXHIBIT 299: **We are at an inflection point: AI in manufacturing has just entered the steep part of adoption S-curve**



Source: Bernstein analysis

To better understand the role of AI in manufacturing, we take a closer look at two applications.

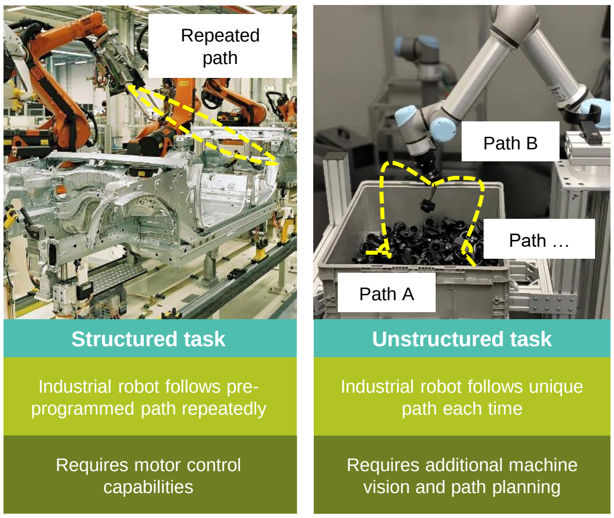
- Barcode reading is a straightforward machine vision application. In most cases, it does not involve AI. However, AI greatly enhances the recognition rate while reading partially blocked or damaged codes.

- In robotics, most applications are for "structured" tasks where a robot follows a preprogrammed path repeatedly. Recently, however, robotic applications have started expanding to "unstructured" tasks, such as bin picking,[70] where a unique path

[70] See Collaborative Robot: Bin picking - latest progress and enabling technologies for a multi-billion-dollar opportunity.

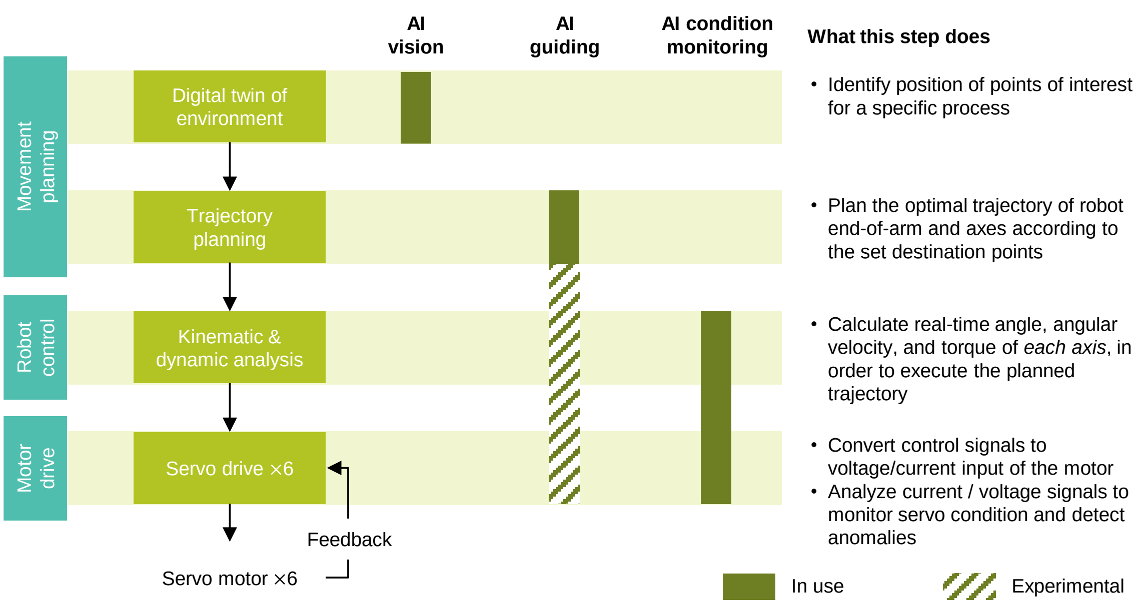
needs to be calculated for each cycle (see Exhibit 300). In the latter case, AI is an important tool for object recognition and locating (using 3D vision), and for autonomous path planning. AI has started finding its place in every layer of the robotic software architecture,[71] including building the virtual copy of environment, trajectory planning, core control optimization, and condition monitoring/predictive maintenance (see Exhibit 301).

EXHIBIT 300: **AI helps autonomous path planning and allows robots to take on "unstructured" tasks**



Source: Bernstein analysis

EXHIBIT 301: **Uses of AI around a robot**



Source: "Design of industrial robot control system" and Bernstein analysis

[71] See: Robotics: a Technology Deep Dive.

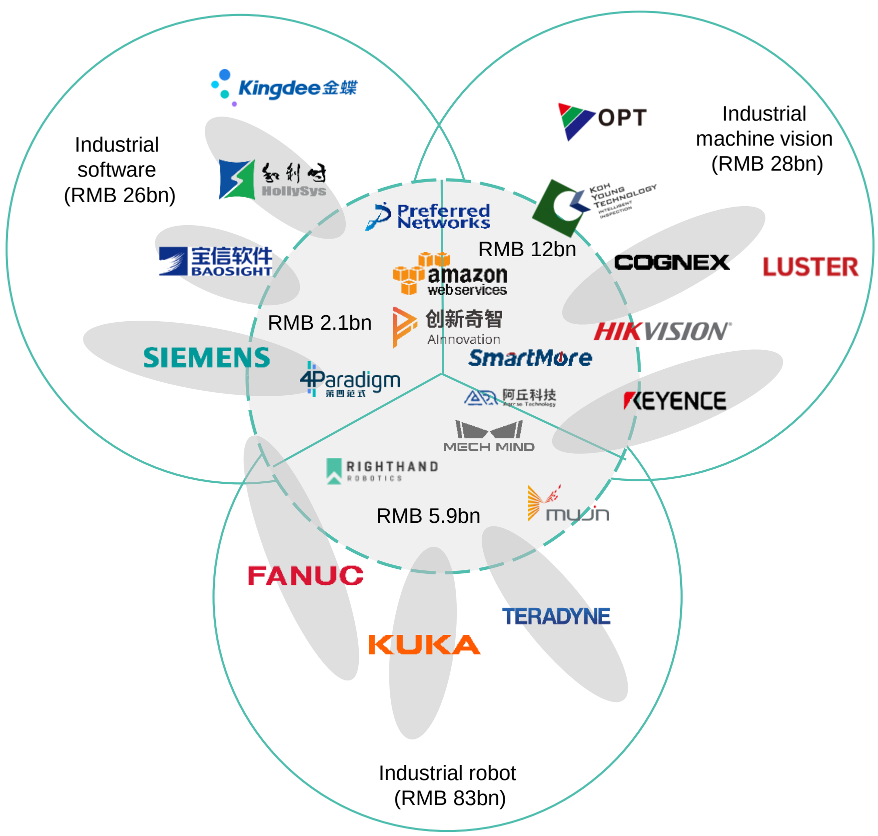
TAM

AI adoption in manufacturing is in the very early stage, and the market is still small, with an estimated global market of USD1.2bn in 2020 (see Exhibit 303). AI-enabled functions are currently a small portion in the three underlying markets of industrial machine vision, industrial software, and robotics.

Despite its small size, the global addressable market is anticipated to grow rapidly at a CAGR of >50% to USD11bn by 2025, based on our estimates (see Exhibit 303). AI-powered industrial machine vision is projected to account for 54% of the 2025 TAM, with a value of USD5.7bn, followed by AI-powered industrial software with 28% and AI-powered robot guiding with 18%. Use of AI in industrial software is still largely experimental and only plays a strengthening role, while AI inspection systems have started being implemented at scale. The China market in 2025 will reach RMB20bn (~USD3.1bn) (see Exhibit 302), representing 28% of the global opportunity.

These figures include the entire hardware and software value of AI-powered products, e.g., for robot guidance, the market size includes the robot and its AI trajectory planning software. Across the three underlying markets, 47% of the total value is estimated to come from the hardware portion of manufacturing AI solutions (see Exhibit 304). Excluding the industrial software segment, the portion of hardware value is even higher at 65%.

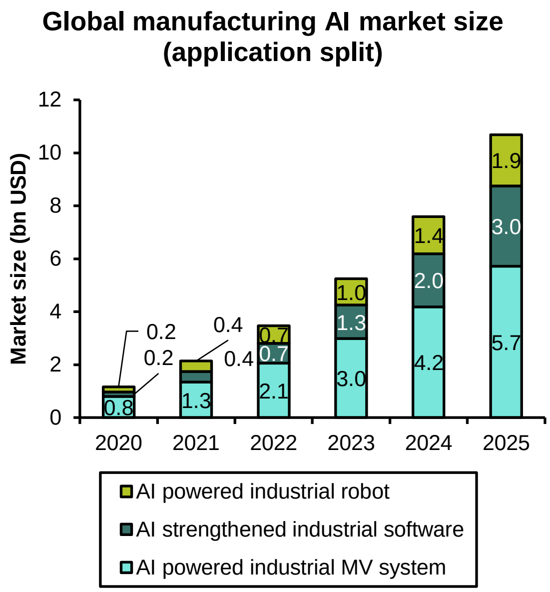
EXHIBIT 302: **AI in manufacturing TAM (circle in the middle) consists of three key underlying markets: industrial machine vision, robotics, and industrial software**



Note: Numbers in the circles indicate 2025 market size in China. The middle circle indicates the AI in manufacturing TAM.

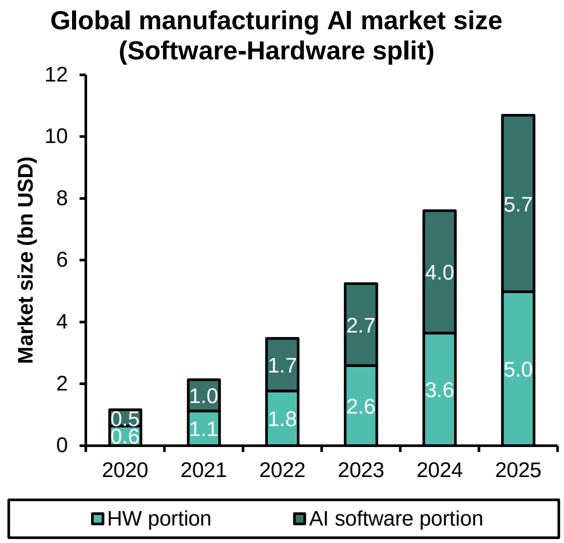
Source: MIR Databank, IRF, McKinsey, Cognex, Keyence, Autodesk, and Bernstein estimates and analysis

EXHIBIT 303: **We estimate global AI manufacturing TAM to reach USD11bn by 2025**



Source: MIR Databank, IRF, McKinsey, Cognex, Keyence, Autodesk, and Bernstein estimates (2020+) and analysis

EXHIBIT 304: **Almost half the TAM will likely be the hardware portion of AI solutions**



Source: MIR Databank, IRF, McKinsey, Cognex, Keyence, Autodesk, and Bernstein estimates (2020+) and analysis

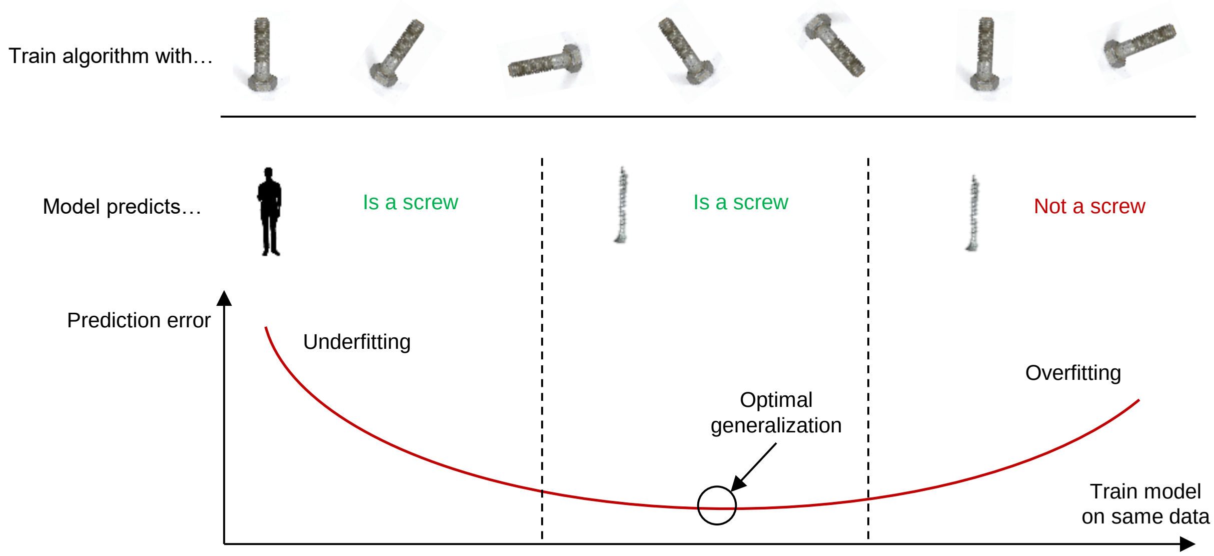
UNIQUE CHALLENGES IN MANUFACTURING

Implementing AI is demanding. Many challenges are common to all AI models; others are specific to using AI in manufacturing. Analyzing these challenges helps understand the success factors and differentiators later.

Optimal generalization is the most common challenge an AI model faces. When an AI model has insufficient training, it underfits, thinking, e.g., that things shaped remotely like a screw are actual screws. When it is trained too much, however, it overfits, defining a screw too narrowly based on what it has seen during training and discarding all other variations. Only at optimal generalization will an AI model recognize screws it has not seen previously, but also not include non-screws mistakenly (see Exhibit 305).

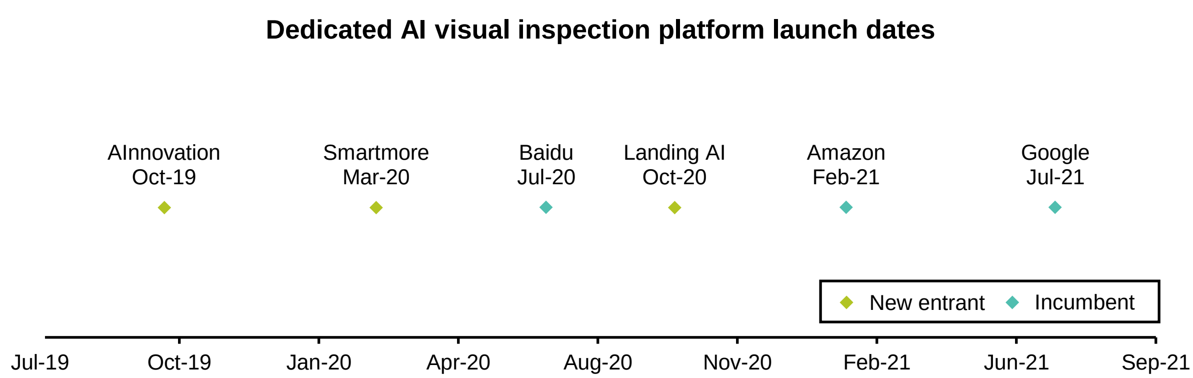
If generalization is a common challenge, why is AI adoption in manufacturing lagging much behind other verticals? And why, in the last couple years, does it seem to have suddenly taken off with many companies entering the space with technically and commercially viable offerings (see Exhibit 306)? It is because applying AI to manufacturing involves some unique hurdles, greatly aggravating the generalization challenge — we call them the data, model, and deployment problems (see Exhibit 307) and will discuss in detail next.

EXHIBIT 305: **Optimal generalization is a key challenge to AI models**



Source: Bernstein analysis

EXHIBIT 306: **Viable AI businesses in manufacturing have started emerging in the last two to three years**



Source: Company websites and Bernstein analysis

EXHIBIT 307: **There are unique challenges in applying AI to manufacturing**

Type	Data problem					Model problem		Deployment problem			
Challenge	Small database	Imbalanced classes	Missing values	Unlabeled samples	Noise	Varied tasks	Varied objects	Poor IT infrastructure	Lack AI skills	Black box risks	Data loop
Severity in manufacturing	**High**	**High**	Average	**High**	Average	Average	**High**	**High**	**High**	**High**	**High**
Severity in finance	Low	Low	**High**	Low	Average	Average	Low	Low	Average	Average	Average

Source: Bernstein analysis

Data problems

The data problems associated with manufacturing make achieving generalization harder (see Exhibit 308).

- **Small dataset:** While other sectors such as finance and digital have access to hundreds of millions of digital records on their subjects, manufacturing is often faced with datasets with only hundreds or even dozens of digital samples (see Exhibit 309). This makes AI algorithm training impractical without special techniques.

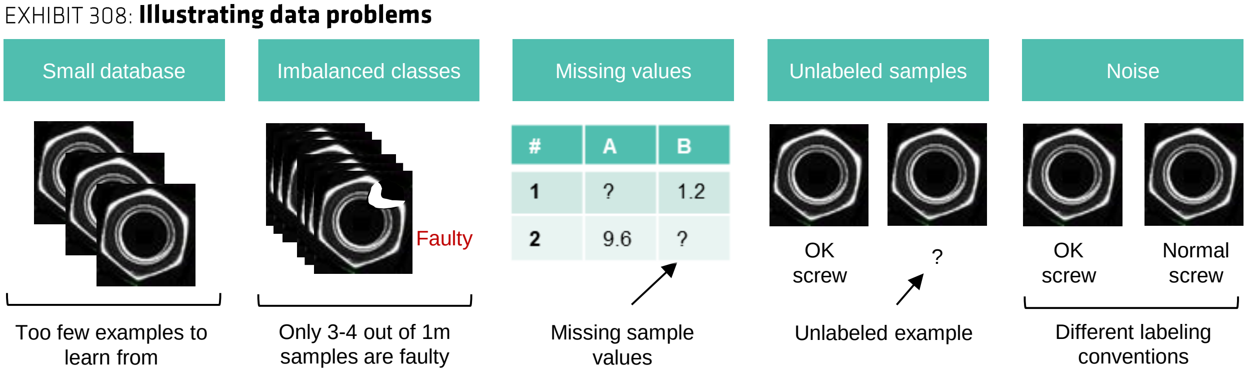
- **Imbalanced classes:** Many manufacturers adhere to Lean Six Sigma,[72] which by definition means defects fewer than four parts per million. With such rare defective parts, the dataset is said to be highly imbalanced, as the model will typically be exposed to overwhelmingly more non-defective parts than defective ones during training, making model generalization harder.

- **Missing values:** When values are missing for a specific sample, it has to either be discarded (reducing dataset size) or included with imputed values (introducing a bias). Both approaches make generalization more difficult.

- **Unlabeled samples:** It is one thing for a sample to miss values, but another to not know what the sample is (i.e., unlabeled). It is common in manufacturing to have photographic records of a part but no tag on what it is. As a result, a substantial amount of time and money is required to label all the samples manually before training can start.

- **Noisy data:** Noise can be in the form of noisy sensor measurements of a machine, image perturbations from a camera sensor, and inconsistencies in labeling. Because an AI model needs to "see" more examples to know which ones it should trust during training, the higher the noise levels, the higher the dataset size requirements (see Exhibit 310), aggravating the small dataset problem in manufacturing.

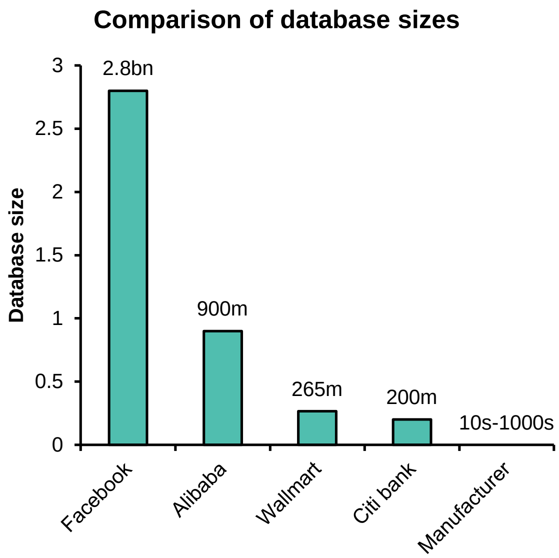
EXHIBIT 308: **Illustrating data problems**



Source: Bernstein analysis

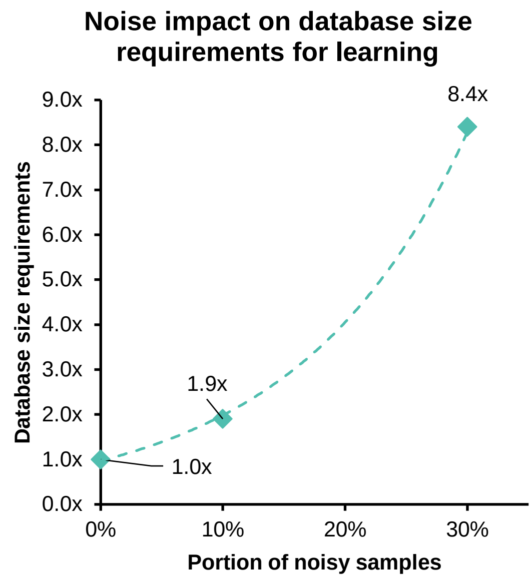
[72] Six Sigma is a quality management philosophy that attempts to keep the percentage of defective parts below six standard deviations of a normal distribution.

EXHIBIT 309: **Manufacturing has much smaller datasets for AI algorithms to work with**



Source: Company reports and Bernstein analysis

EXHIBIT 310: **Data noise increases the size requirement on datasets**



Source: Landing.AI and Bernstein analysis

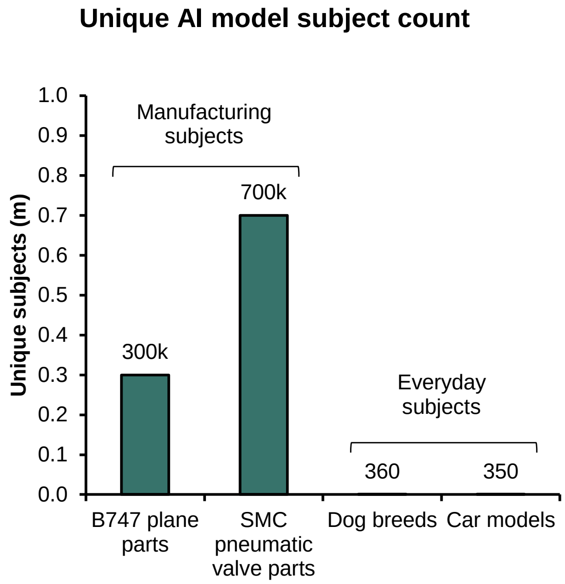
Model problems

Model problems arise when AI models have to deal with a wide variety of tasks and objects.

- **Varied objects:** Individual AI models are trained to recognize a class of similar objects. The more classes, the more the training data and unique model architectures are needed. In manufacturing, there are hundreds of thousands to millions parts variety, which is several orders of magnitude more than everyday items (see Exhibit 311). This challenge of large variety is in contrast to the small dataset challenge.

- **Varied tasks:** An AI model's architecture is geared toward a set of task aims, e.g., determining if the right number of screws are present in a box, evaluating whether screws do not exhibit any scraping defects, and verifying if screw dimensions are within given tolerances. Hence, the more task aims there are, the harder it is to develop a single model to cover all these aims simultaneously. Typically, inspecting for defects involves several models for simple objects such as bolts and nuts, but tens to hundreds of models for complex objects such as PCBs.

EXHIBIT 311: **Manufacturing subjects have much more variety than everyday subjects**



Source: SMC, "Air Transportation: A Management Perspective," and Bernstein analysis

Deployment problems

Deployment problems are related to AI model deployment in manufacturing enterprises.

- **Inadequate IT infrastructure:** Compared with other industries such as internet and finance, many manufacturing enterprises have poor IT infrastructure in the form of data silos[73] and low levels of digitalization (see Exhibit 312). As a result, it is hard to gather the necessary training data and connect the right devices together for successful deployment.

- **Lack of AI skills:** 40% of manufacturers have reported (The AI Skills Gap, 2019) that they lack the necessary skills to adopt AI on the shop floor. Deploying an AI model typically requires some level of in-house expertise to keep it operational and relevant throughout its life.

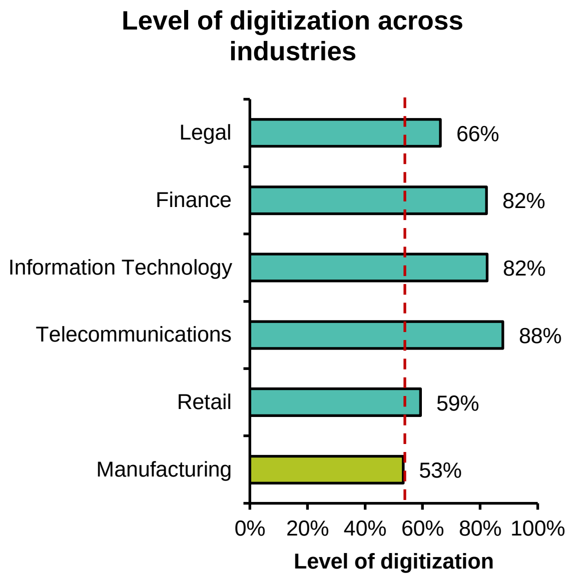
- **Black box risks:** Despite its touted superhuman capabilities, AI still makes obvious mistakes. Due to the nature of deep learning, successes and failures of an AI model are typically unexplainable, known as the black box problem. For critical tasks in manufacturing, backup solutions need to be in place.

- **Data loops and automated machine learning (AutoML):** Data loop (see Exhibit 313) is the dream of AI deployment, because it allows automated improvement of AI model performance when new or better data becomes available in use. In the real world, however, the deployment process is hardly automated. In Exhibit 313, data cleansing and tagging, parameter tweaking for algorithm training and model maintenance,

[73] Data silos form when datasets are separated across an organization because they are not connected or use different formats.

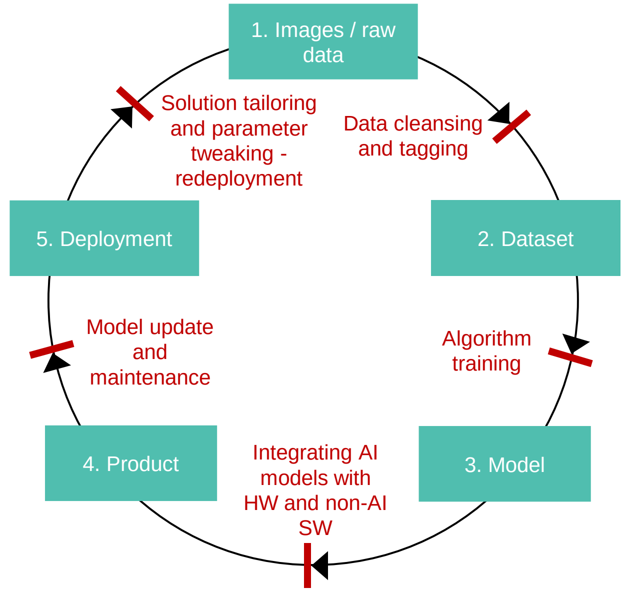
integrating AI model with HW/SW, and solution tailoring in redeployment are all labor intensive and process specific.

EXHIBIT 312: **Level of digitalization in manufacturing is below industries that have widely adopted AI**



Source: Tomasz Mucha, et al., Estimating firm digitalization: A method for disaggregating sector-level digital intensity to firm-level, MethodsX, Volume 8, 2021 and Bernstein analysis

EXHIBIT 313: **AI deployment is often labor-intensive; key steps are hard to automate**



Source: Google, PricewaterhouseCoopers (PwC), Mapi, and Bernstein analysis

SOLUTIONS AND DIFFERENTIATORS

With such daunting challenges, it requires more than generic deep learning algorithm know-how to bring AI to manufacturing. Many of these required capabilities have emerged only recently or are still under development, leading to the inflection of adoption we currently observe.

There are three broad capability building blocks in an AI manufacturing solution: hardware, software, and domain know-how. In each, we identify a unique differentiating factor as key to solving the AI manufacturing challenges associated with data, model, and deployment.

- **Hardware** is underappreciated. [74] A broad, specialized, and modular hardware portfolio is critical for delivering the best results facing the huge variety of manufacturing objects, processes, and problems.
- **Software** differentiation is less about deep learning backbone algorithms and more about model variety, model architecture and combination, and training methods to meet the small dataset challenge. They embody accumulated customer domain know-how.

[74] "Hardware phobia" is common in industrial investing. See "Surely you are joking, Mr. Analyst!" - Four maladies that hinder one's search for great industrial companies.

- **Automated deployment and commercial access** are key to scalability. Techniques such as automated machine learning to automate the deployment steps (as seen in Exhibit 313) allow efficient and scalable deployment and redeployment, and amplify a company's first-mover advantage and economy of scale.

In all three categories, and for software in particular, applying AI in manufacturing is like a LEGO building contest — the LEGO set is available, and the competition is about drawing the blueprints, choosing the right pieces, and building many LEGO projects.

These crucial differentiators manifest in different ways across the major applications areas (see Exhibit 314).

EXHIBIT 314: **Common and application-specific success factors in applying AI to manufacturing**

	Industrial machine vision	Robot guiding	Industrial software
Specialized and modular hardware	Advanced camera and laser sensing technology	Advanced 3D sensing	n.a.
	Broad SKUs	High performance robot	
	Extendability through modular design	Modular workcell setup	
Model variety and training techniques	Few-sample training techniques	Task agnostic algorithm architecture	Process agnostic architecture backbone
	Large "model zoo"	Compatability with many robot brands	Specialized model repository
	Integration of AI and rule-based vision	Process packages	
Deployment and commercial access	Understanding of customer process and imaging challenges	Integration of path planning and core robot control	Deep understanding of customer processes
	Commercial access	Commercial access	Commercial access
	AutoML	Data loop and shared learning	

Source: Bernstein analysis

Advanced and modular hardware

AI solution hardware needs to be sufficiently specialized. This requires a broad product portfolio because there is no one-product-fits-all for the huge varieties of manufacturing objects and processes, and it also needs to be modular to remain cost-efficient when SKUs multiply.

Keyence exemplifies this success factor. We have previously discussed the breadth (~3,000 SKUs) and innovative nature of its portfolio (20-30% of revenue from new products every year; 70% of new products being "industry first").[75] Another important aspect of Keyence's products is their modularity (see Exhibit 315). For example, a manufacturer may be looking to inspect nuts for surface defects across two production lines. In this case, the optimal solution would be an IV-3 Series sensor-only head (multiple production lines), monochrome (single-color object), and standard field of view (FOV) (small

[75] See Keyence: The (true and false) secret sauce.

object) setup, with a polarizing filter (shiny metal object), specific attachment mount, and amplifier (sensor only).

EXHIBIT 315: **Within a *single* product series, Keyence's modular products have enough varieties to serve each individual manufacturing application**

Note: Example is the IV-3 Series with built-in AI from Keyence.

Source: Keyence and Bernstein analysis

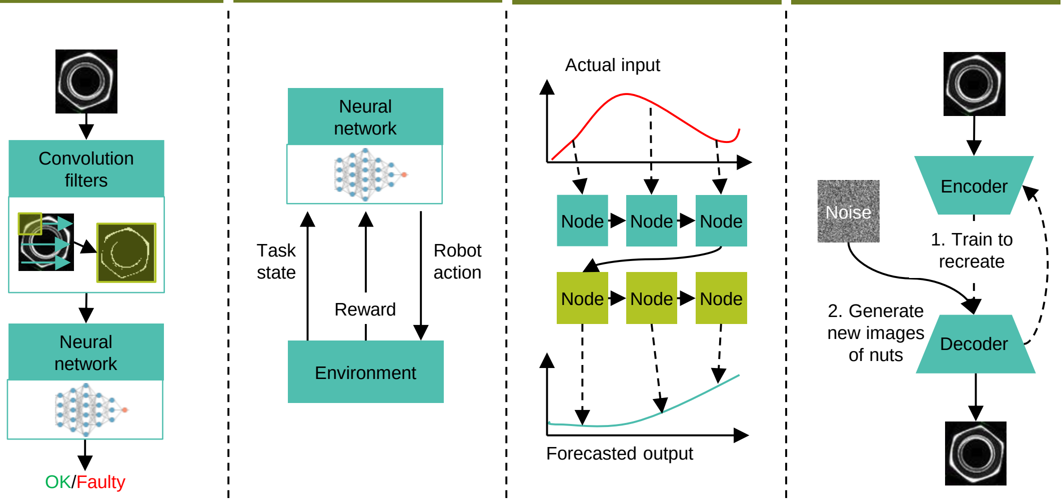
Model variety and training methods

AI software needs to have application-specific model architectures and be tweaked to create a wide range of applications. The deployment process in Exhibit 313 needs to be as automated as possible.

AI involves many types of algorithms that function on fundamentally different mechanisms and learning methods — the same way the word "sensing" involves such different sensory mechanisms as seeing, hearing, etc. Therefore, the selection of AI algorithm type, based on actual application, is the first level of differentiation. As Exhibit 316 illustrates, in industrial machine vision, convolutional neural networks (CNNs) with supervised learning are commonly used for feature identification, because convolutional filters amplify features of interest. In robot guiding, reinforced learning is the main approach for path planning, because in this application, actions have clear reactions. In process optimization and condition monitoring, the key aim is to forecast future outcomes, which makes recurrent neural networks (RNNs) the ideal architecture, as it predicts future sequences based on existing sequences. In generative design, variational auto encoders (VAEs) with unsupervised learning are the go-to approach, because they are taught how to generate new examples. Because of this, a leading player in one manufacturing field is not necessarily leading in others.

EXHIBIT 316: **Different manufacturing applications require different AI architectures and learning methods**

AI algorithm	Model	**Convolutional Neural Network (CNN)**	Neural Network (NN)	**Recurrent Neural Network (RNN)**	**Variational Auto Encoder (VAE)**
	+ Learning method	Supervised learning	**Reinforced learning**	Supervised learning	Unsupervised learning
	Main purpose	Understand what it is	Plan a future action	Predict a future outcome	Generate new data
	Key application	Machine vision inspection	Robot path planning	Production output forecasting	New design generation



Note: The types of architectures used for different applications are not fixed and exceptions to the rules can be found.

Source: Bernstein analysis

Once the appropriate AI architecture is chosen, it needs to be further tailored to a specific application. To illustrate this, we examine a single application — defect inspection using machine vision (see Exhibit 317). Under the overall CNN architecture, further customization is achieved with the choice of additional building blocks, how they link together, as well as training order and techniques.[76]

In this illustrative example, the architecture building blocks include (1) a feature extractor, such as ResNet, which is a CNN; (2) a region proposal network that suggests regions of interest; and (3) a segmentation network to identify the defect, such as Fast R-CNN. Differentiation is not about inventing new building blocks and revolutionizing deep learning

[76] Large proprietary datasets can in theory be a differentiator, but they are rarely available. A model can be pretrained on non-manufacturing and non-proprietary datasets to learn the basic capabilities of recognition and segmentation. The application-specific datasets are used during the final training step — in the same way that a toddler will only need to see one picture of a car to recognize it, because they have already mastered general recognition skills during the first few years of their life. However, the more you expose it to such defects, the more of an expert it will become.

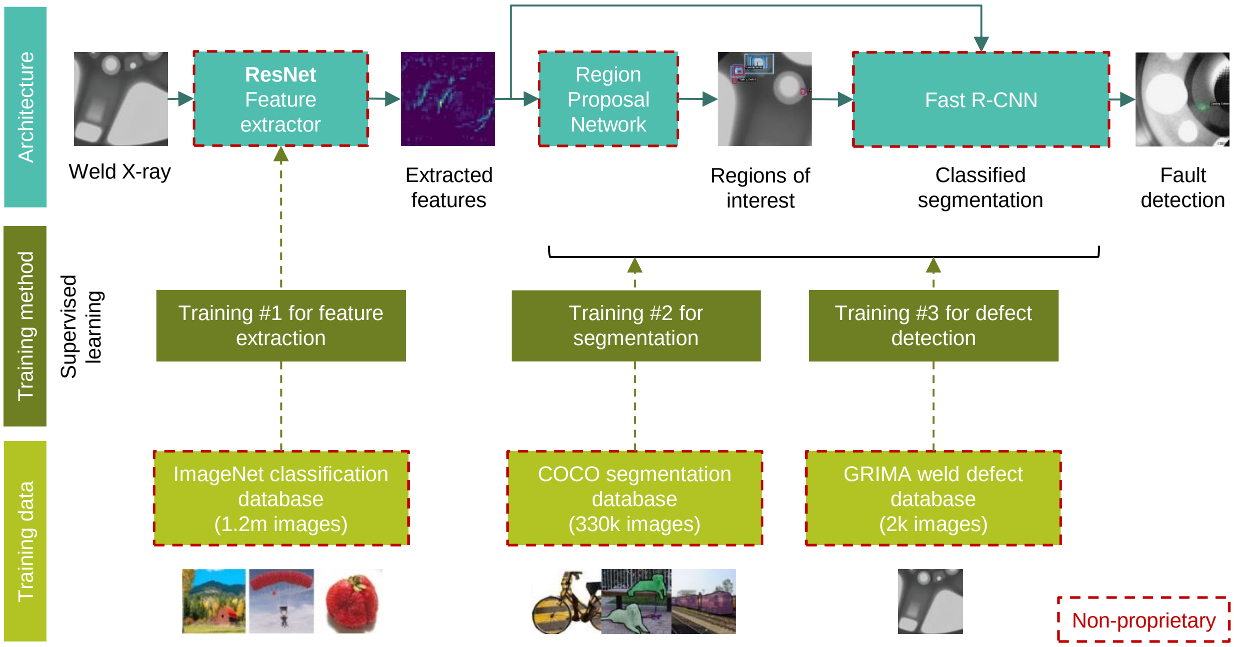
backbone; these building blocks and backbone algorithms are openly shared as academic publications for others to improve upon (see Exhibit 318 and Exhibit 319). Hence, developing an application-specific algorithm is similar to drawing the blueprint and putting the right LEGO pieces together instead of inventing LEGO pieces.

Training technique is another important aspect of differentiation, especially when dealing with the small dataset challenge in manufacturing. The techniques illustrated in Exhibit 321 have proved instrumental to the recent progress of AI adoption in manufacturing. Transfer learning allows the core of a model that was trained on one object to be reused to recognize a different object (see Exhibit 317); continuous learning is similar, but it develops a single model that can recognize multiple different objects simultaneously by forcing the model to retain previous recognition capabilities; prototype learning learns from small datasets by defining a "prototypical" object that is used as reference for comparison; representation learning reduces visual information to a domain-invariant space to recognize objects regardless of what domain they are from.

In many cases, domain know-how is important to the choice of model combinations and training techniques. For example, experience in manufacturing workpieces allows one to know that segmentation algorithms often work better for fault detection in manufacturing than the more popular classification algorithms (see Exhibit 320). This domain know-how leads to the correct choice of models and training techniques, applying which repeatedly results in a large model repository to deal with the very large task and object variety in manufacturing. Even startups typically need to have hundreds of AI models to do business in just a few verticals, and the inspection of a single object may involve several to tens of correctly chosen models. Counting the AI models and other software and hardware modules, the number of LEGO pieces approaches 2,000 at AInnovation. Equipment domain know-how is also important, as it allows integrated innovation across hardware, equipment control software (non-AI), and AI software (see Exhibit 327).[77]

[77] After Cognex acquired ViDi, it took a couple of years to fully integrate the deep learning software from ViDi into Cognex's machine vision platform VisionPro. Once done, the integrated function and user interface become a distinct strength.

EXHIBIT 317: **Illustrating the building blocks of a defect detection deep learning algorithm**



Ways to improve/customize algorithm:

Architecture

- Add architecture blocks
- Modify architecture blocks
- Modify framework

Training method

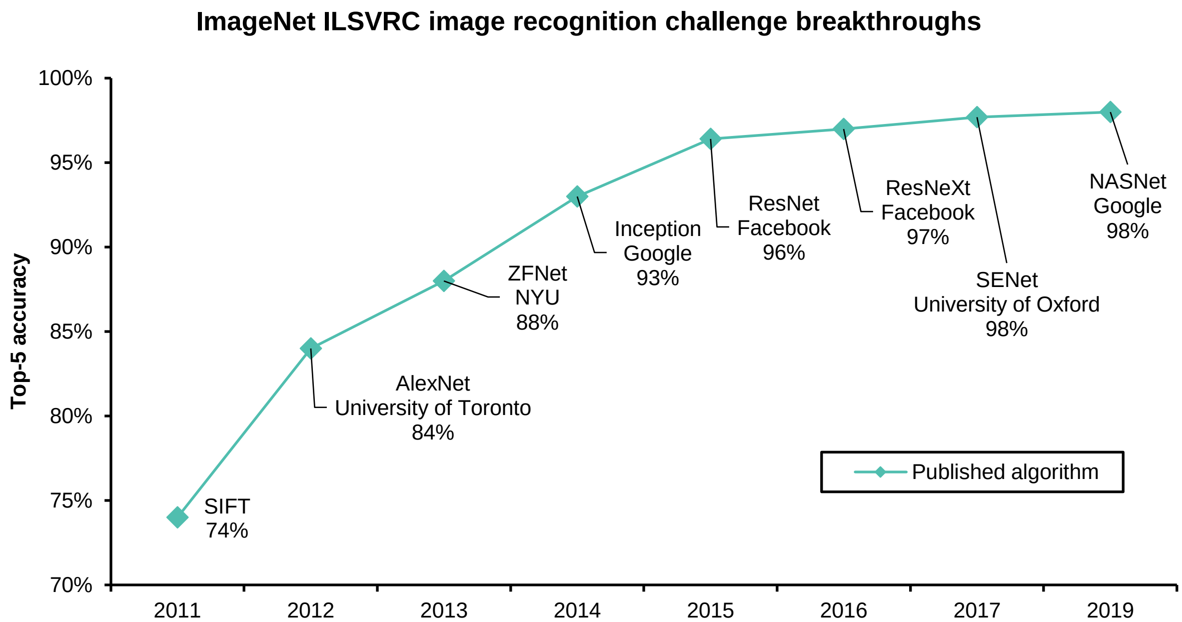
- Switch training method
- Modify training order
- Modify training objective

Training data

- Use larger data sets
- Use proprietary data

Source: Ferguson MK, et al. Detection and Segmentation of Manufacturing Defects with Convolutional Neural Networks and Transfer Learning. Smart Sustain Manuf Syst. 2018; 2:10 and Bernstein analysis

EXHIBIT 318: **Image recognition algorithm backbones are developed by key research institutions and openly shared for reference**



Source: ILSVRC and Bernstein analysis

EXHIBIT 319: **All AI manufacturing players use leading image recognition backbones; thus, there is little differentiation at this level**

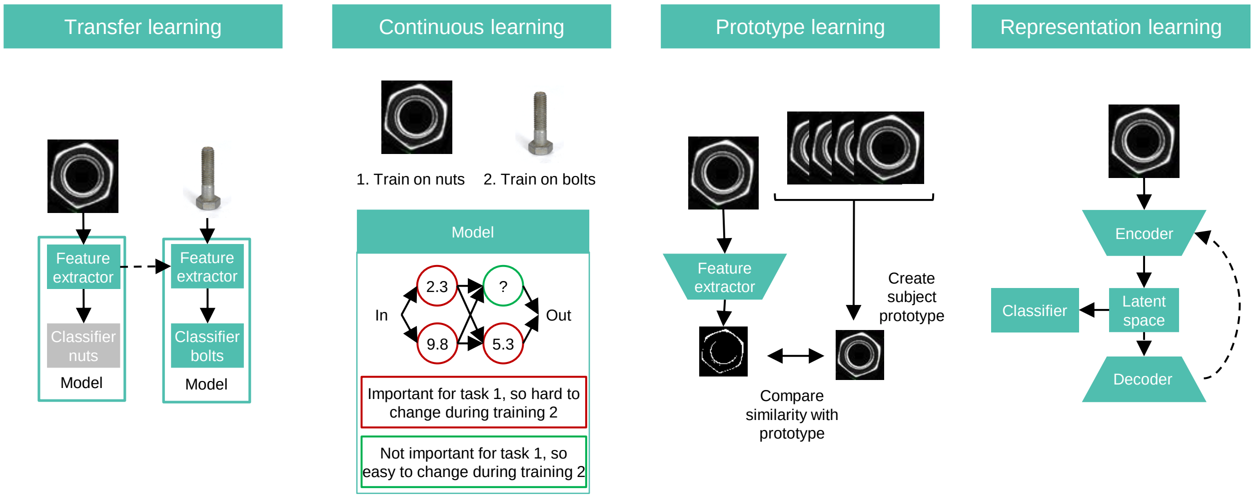
Vision backbone algorithm	AInnovation	Smartmore	MVTec	Baidu	Google	Amazon
ResNeXt (Facebook)		x		x		x
VAE (Google)			x			
SE- ResNet (University of Oxford)	x					
NasNet (Google)					x	

Source: Bernstein analysis

EXHIBIT 320: **Segmentation algorithms work better than classification algorithms for fault detection**

Source: Bernstein analysis

EXHIBIT 321: **Special learning techniques are developed to tackle the challenge of small datasets**



Source: Bernstein analysis

Automated deployment and commercial access

Automated deployment is critical for efficient and scalable deployment and redeployment facing the huge variety of AI tasks in manufacturing.

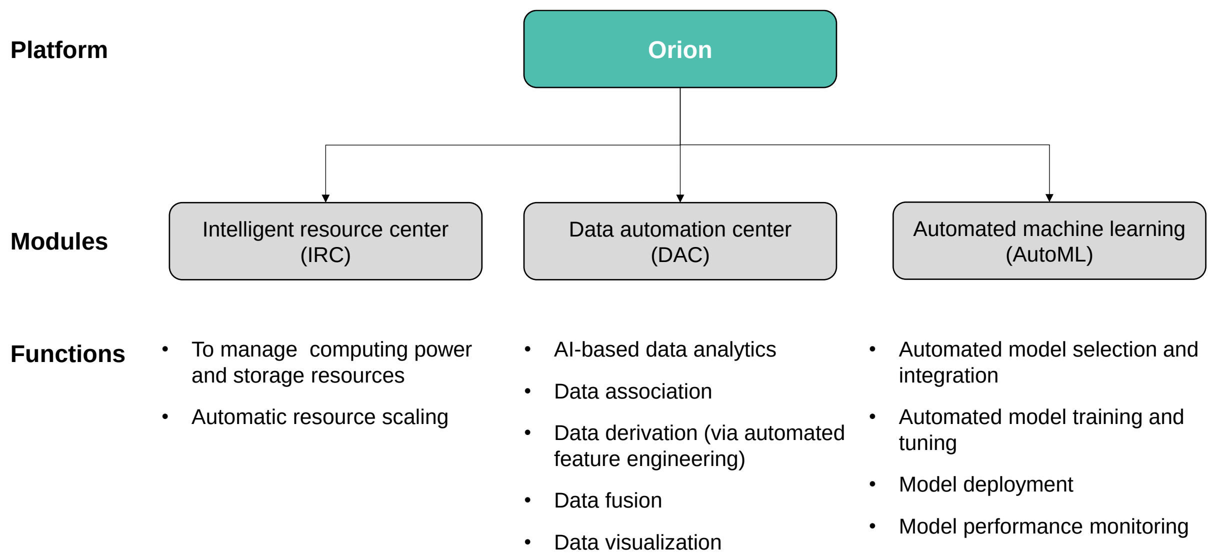
One could not overemphasize the importance of automation in AI deployment. Automated deployment and data loops are the dream of AI companies — they shorten the deployment time, lower deployment costs, and allow automated improvement of AI model performance when new or better data becomes available for use. In the real world, however, the deployment process (see Exhibit 313) is hardly automated. An automated deployment platform, e.g., AInnovation's Orion (see Exhibit 322), automates the following important steps:

- Data cleansing, data structuring, and data fusing (combining various data sources with different formats) before model training.
- Selecting the optimal combination of models (from a reservoir of hundreds to thousands) for a specific task.
- Training models with the prepared data and as new data becomes available for use.
- Tuning model parameters (e.g., the weight of each selected model) for optimal output; monitoring model performance to repeat the tuning process as necessary (less capable companies do this by stationing an army of engineers at customer sites for manual model tuning).
- Resource (computing power and storage) scaling.

Furthermore, commercial access reinforces domain know-how, and helps expand model repository and accumulate proprietary training data to unlock economies of scale in solutions development and deployment.

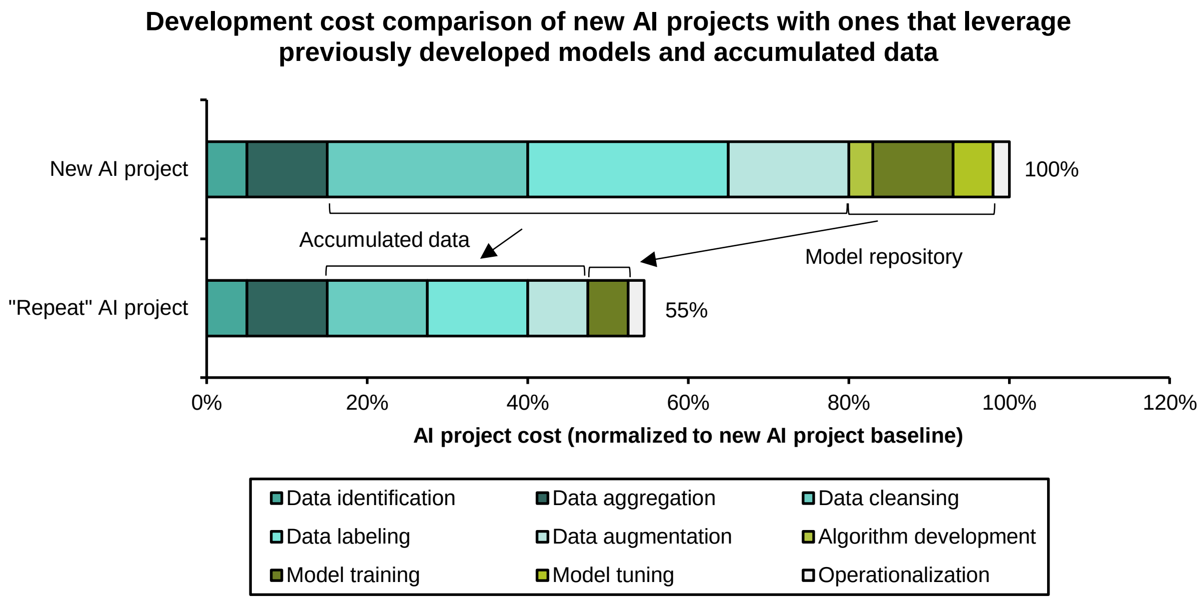
Companies with wide commercial access serve a wide range of tasks and many manufacturing customers with similar needs. As a result, they are more likely to build a large model repository and proprietary datasets that can be reused for future projects, thereby reducing AI model development costs (see Exhibit 323). Although the model development time only represents 18% of the total time spent on software engineering, it can be reduced by >70% if algorithms and model training methods are reused. Moreover, by reusing existing datasets, the time-consuming data cleansing, labeling, and augmentation steps can be at the very least halved, resulting in an overall reduction of 45% in overall development cost. To better understand why data processing occupies such a large portion of development time, we examined the cost of labeling by outsourcing it (Google and Amazon) or using in-house labor with third-party software (SuperAnnotate) (see Exhibit 324). Labeling one million images (with a single label per image) with 1,000 object classes costs USD720-870k for segmentation type labels, which are commonly used in manufacturing applications.

EXHIBIT 322: **AInnovation's Orion platform goes a long way to automate critical steps in deployment and redeployment**



Source: AInnovation prospectus and Bernstein analysis

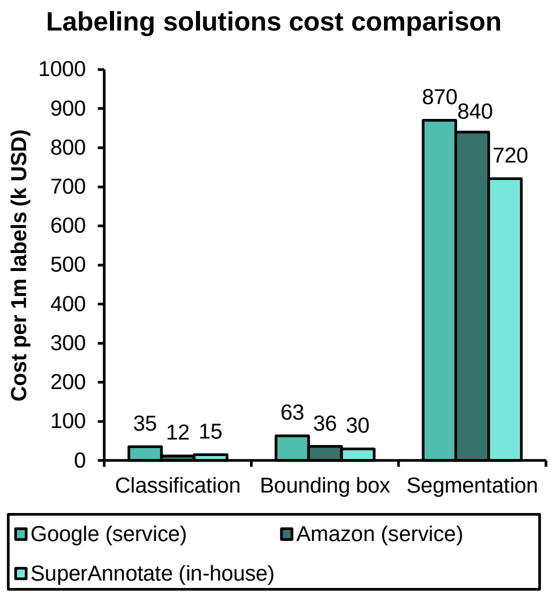
EXHIBIT 323: **Broad commercial access can unlock economies of scale because cost is substantially lower in redeploying similar AI solutions**



Note: An average enterprise AI project uses 20 software engineers (full-time equivalent) (Dimensional Research).

Source: Dimensional Research, Cognilytica, and Bernstein estimates and analysis

EXHIBIT 324: **Labeling is a labor-intensive and expensive process**



Source: Google, Amazon, G2, and Bernstein estimates and analysis

WHO IS WINNING?

Many players are entering the field of AI in manufacturing, including manufacturing incumbents, software giants as AI architects, and startups as AI product developers (see Exhibit 325). Against the key differentiators discussed in the previous section, we assess the strengths and weaknesses of the three aforesaid player categories as follows (see Exhibit 326):

- **Manufacturing incumbents**, such as Siemens, FANUC, and Keyence, are hardware-first developers, using AI as a booster to their offering in the respective field. Compared with the other two categories of players, manufacturing incumbents have natural strengths in advanced hardware, hardware-software (HW-SW) integration, AI software and equipment core software integration (see Exhibit 327), access to "unlimited" customers and their latent needs, and manufacturing domain know-how that guides solution development. These players' AI software skills (in-house or through external partnership; see Exhibit 328) focus on product and application development, instead of fundamental architecture research. FANUC, for example, has increased its R&D intensity twofold in recent years, with AI software engineers being a key area of investment. On everything AI-related, FANUC also partners with Preferred Networks, a Japanese company it invested in in 2018. In industrial machine vision, Keyence and Cognex have shown notable AI expertise, the former through organic development and the latter through two acquisitions.

- **AI architects** are mostly software giants such as Google. Their AI offerings consist of mostly algorithms and models, leaving hardware and integration to customers or third parties. AI architects innovate on the algorithm front. Google, e.g., leads in novel algorithms for segmentation (see Exhibit 329). This is certainly an edge but probably an overrated one, because the limitation is also clear: without breadth and depth in hardware and manufacturing domain know-how, it can only offer relatively standardized models to solve a limited set of common problems, e.g., defect detection of certain easy-to-image objects.

- **AI product developers** are typically AI startups that either offer HW-SW integrated products customized for specific applications (e.g., Innovation and Mech Mind) or provide customized models on third-party hardware (e.g., Aqrose). Their expertise in manufacturing varies greatly, and a key differentiator is commercial access and manufacturing domain know-how. The better ones actively build both, allowing them to expand the repository of models and HW-SW integrated products (see Exhibit 327), and start enjoying economies of scale through the reuse of these models and products. Lacking that, however, many AI startups in this category suffer from limited model variety and customer base and, consequently, disabling cost inefficiency. As a result of these differences, adjusted SG&A as a percentage of revenue shows >2x variation among the AI startups.[78]

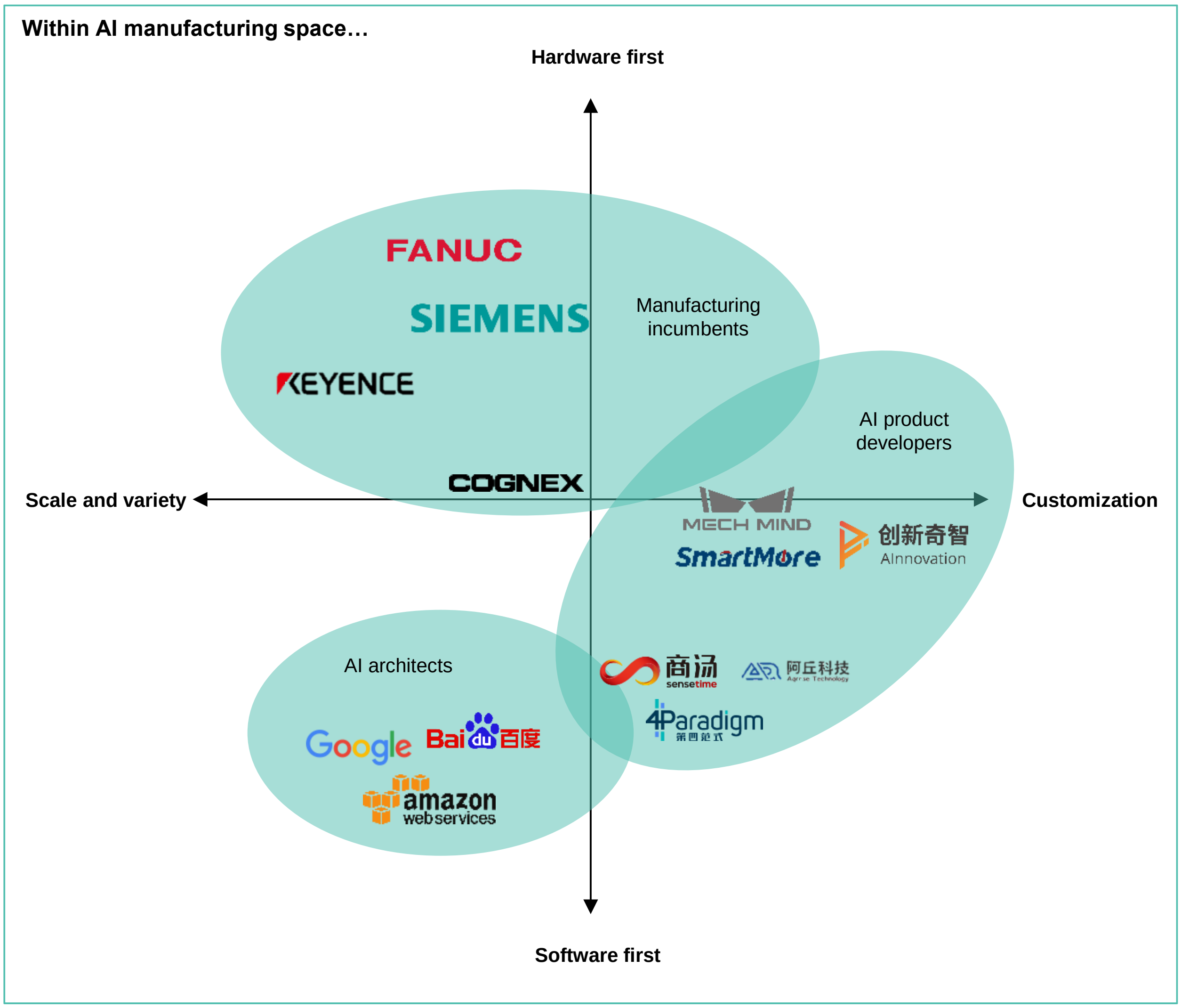
Instead of seeing one category as the ultimate winner, we believe that for a decade or longer, the AI needs in manufacturing will be diversified enough to offer distinct opportunities to all three. Pushing the TAM boundary is the main theme, and competition across them will only remain a backdrop. In machine vision, as Exhibit 331 illustrates, Keyence will likely continue focusing on broadly used manufacturing objects, each with limited types of defects, and on versatile vision products that can serve hundreds of thousands of customers without further tailoring; AInnovation will likely seek the

[78] See AInnovation IPO: Nine more months of operating data, and a key debate on technology.

opportunity of customized flagship projects that are potentially scalable; Google, Amazon, and Baidu will likely carve out a niche of low-throughput, hardware-agnostic defect inspection problems as their sweet spot.

Exhibit 331 also sheds light on an interesting comment many vision companies (AI or non-AI) have made at least once: "we did for our customer what Keyence could not." Most of the time, the examples were true, but the intended inference that "we have superior technology than Keyence" is not. The Keyence business model repels customization.[79] If a problem is too niche, or current technology does not support a standardized solution, Keyence would patiently wait until the problem becomes sizable and suitable.

EXHIBIT 325: **Three key categories of AI players in manufacturing**



Source: Company websites and Bernstein analysis

[79] See Keyence: The (true and false) secret sauce.

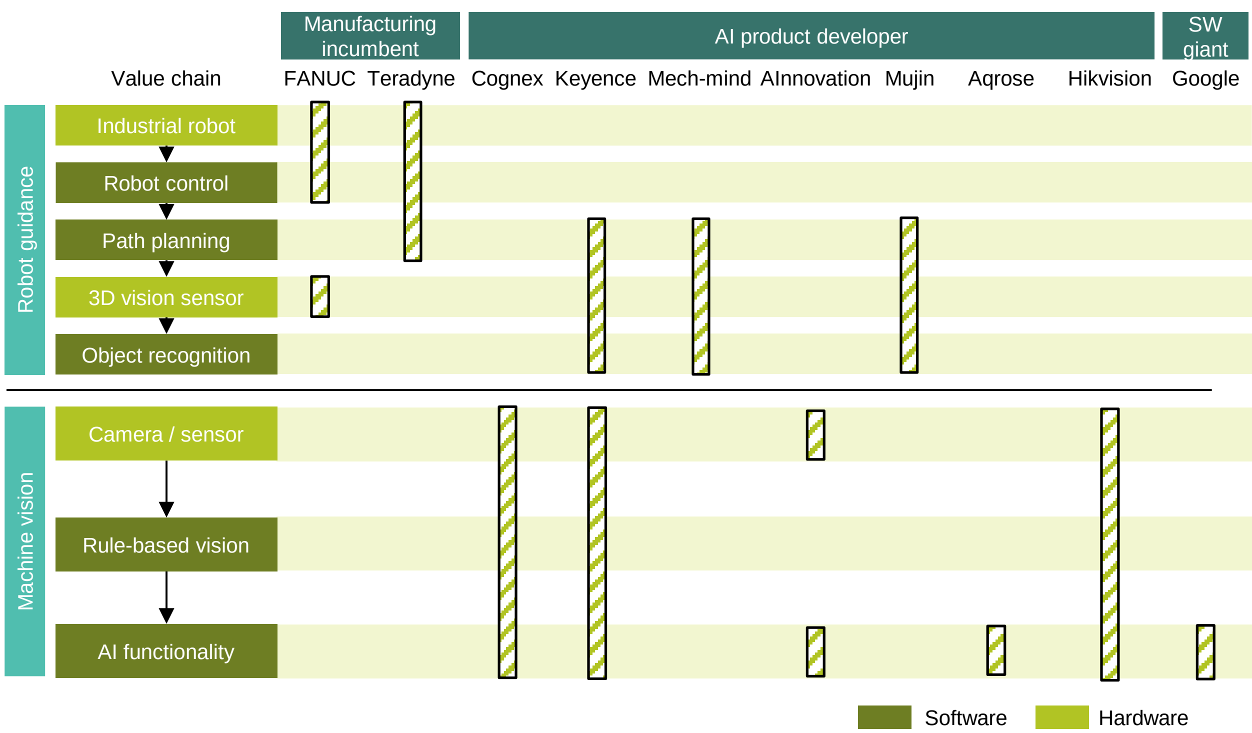
EXHIBIT 326: **Who is leading in each success factor for AI in manufacturing?**

	Industrial machine vision		Robot guiding		Industrial software	
	Differentors	**Best example**	**Differentors**	**Best example**	**Differentors**	**Best example**
Hardware	Advanced camera and laser sensing technology	*Keyence*	Advanced 3D sensing	*Keyence, FANUC, Mech-Mind*		
	Broad SKUs	*Keyence*	High performance robot	*FANUC*	n.a.	*n.a.*
	Extendability through modular design	*Keyence*	Modular workcell setup	*FANUC, Teradyne, Keyence*		
Software	Few-sample training techniques	*Google / AInnovation*	Task agnostic algorithm architecture	*FANUC, Mech-Mind*	Process agnostic architecture backbone	-
	Large "model zoo"	*AInnovation / Aqrose*	Compatability with many robot brands	*Keyence, Mech-Mind*	Specialized model repository	*Siemens*
	Integration of AI and rule-based vision	*Keyence / Cognex*	Process packages	*FANUC, Teradyne*		-
Deployment	Understanding of customer process and imaging challenges	*Keyence / Cgonex / AInnovation*	Integration of path planning and core robot control	*FANUC, Teradyne*	Deep understanding of customer processes	*Siemens / Autodesk*
	Commercial access	*Keyence / Cognex*	Commercial access	*FANUC, Teradyne, Keyence*	Commercial access	*Siemens / Autodesk*
	AutoML	*Google / AInnovation*	Data loop and shared learning	*FANUC*	AutoML platform	*Siemens/ 4Paradigm*

Note: MV stands for machine vision.

Source: Bernstein analysis

EXHIBIT 327: **Having AI software capability is often not enough; integration of AI function with hardware and non-AI software is important in a solution**



Source: Bernstein analysis

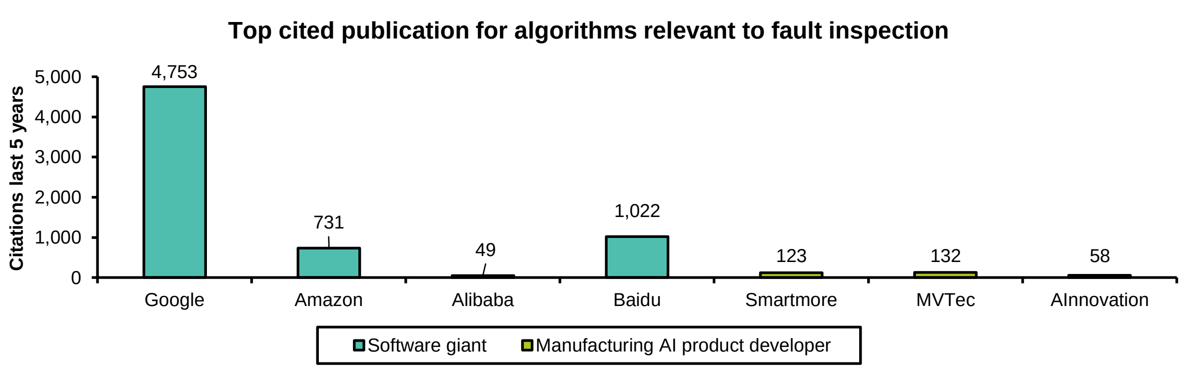
EXHIBIT 328: **Manufacturing incumbents have been investing for AI capabilities**

	Application	AI-related acquisitions	AI-related investments	AI partnerships
ABB	Robotics	-	-	Covariant ai (2020)
Kuka		-	-	Huawei (2016) Intel (2018)
FANUC		-	Preferred Networks (8% stake in 2018) R&D intensity increased two-fold since 2018	Nvidia (2016) Preferred Networks (2018) Soft Robotics (2020) Plus One Robotics (2020)
Teradyne		Energid (2018)	-	Sepro (2019)
Yaskawa		-	-	Dorabot (2019)
Kawasaki		-	-	Dexterity (2020)
Mitsubishi		-	-	Realtime Robotics (2019)
Keyence	Industrial machine vision	-	Industry-leading inhouse capability	-
Cognex		ViDi Systems (2017) SUALAB (2019)	-	-

Note: Keyence and Cognex are added for completeness.

Source: Company websites and Bernstein analysis

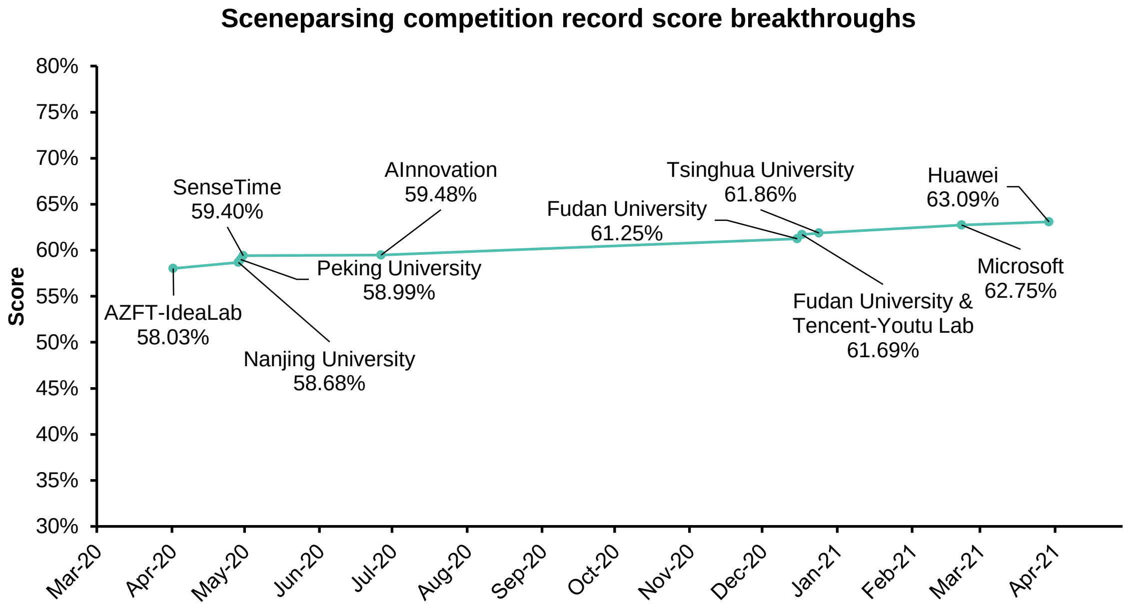
EXHIBIT 329: **Software giants lead in algorithm innovation...**



Note: Backbone image recognition algorithms were excluded. The search criteria were "zero/few-shot learning" and "semantic/image/instance segmentation," both highly relevant to fault detection.

Source: Google Scholar and Bernstein analysis

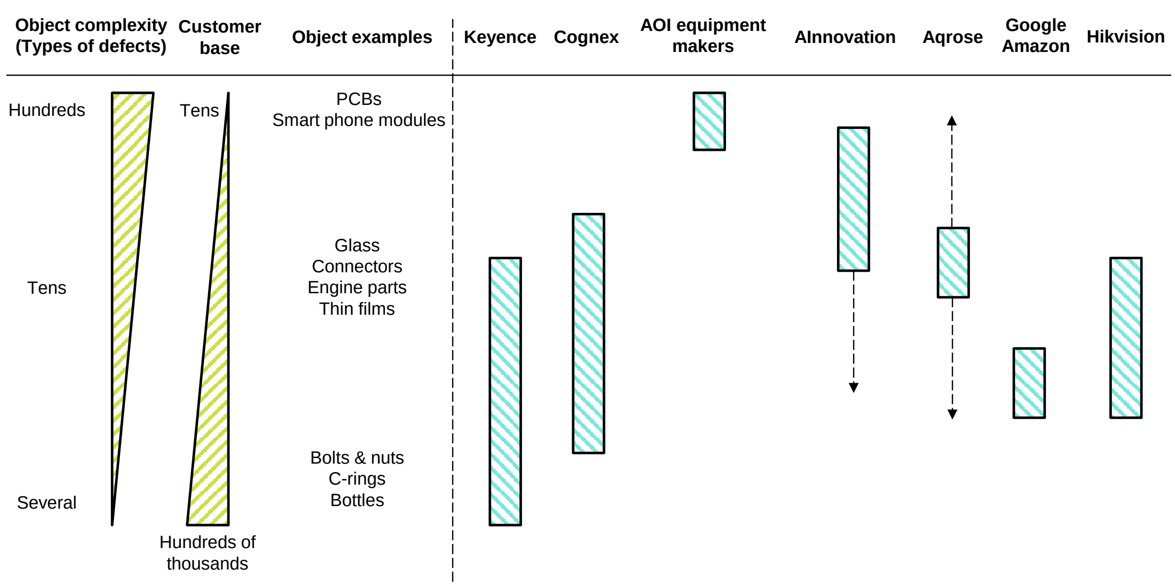
EXHIBIT 330: **...however, real-world performance of algorithms alone is hardly differentiating**



Note: Anonymous submissions were omitted.

Source: MIT and Bernstein analysis

EXHIBIT 331: **Machine vision players' strategies: tailoring or broad customer base?**



Source: Bernstein analysis

Pay-per-product vs. pay-per-use

As a result of their differences, AI manufacturing players use different revenue models (see Exhibit 332):

- Software giants, such as Google, do not provide any hardware or integration services and typically adopt **pay-per-use** pricing.
- Manufacturing incumbents, such as Keyence, offer a wide range of SKUs of ready-to-use hardware with embedded AI functions, all sold on a **pay-per-product** basis.
- AI product developers, such as AInnovation, use mixed models. Their products are typically more customized than manufacturing incumbents. As a result, they may use **pay-per-project and pay-per-use** models that suit the higher customization cost.

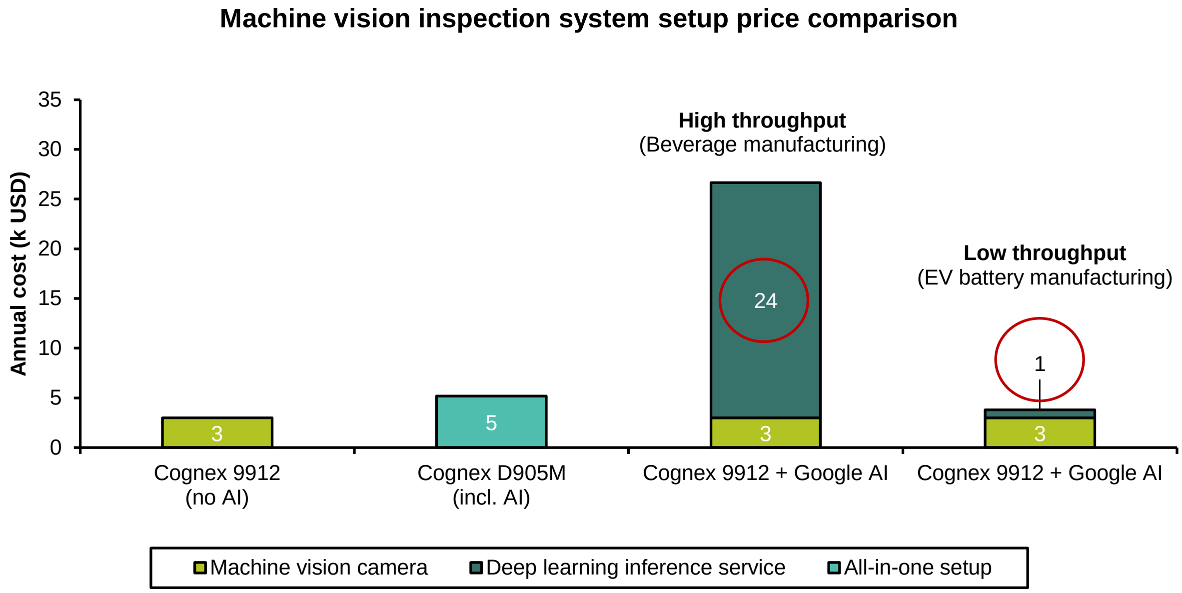
These business models have their respective sweet spots (see Exhibit 333). In high-throughput (short cycle time and many images) scenarios, standardized products, such as Cognex's AI-powered D905, offer a clear cost advantage over pay-per-use services from Google or Amazon Lookout for Vision. When throughput is low (long cycle time and few images), the pay-per-use model can be more cost-effective but only moderately. Finally, pay-per-project solutions can be the natural choice when such needs are just emerging and solutions are developed for the first time.

EXHIBIT 332: **Comparing the AI inspection offering from the three categories of AI players**

Player type	AI architect	AI product developer	Manufacturing incumbent
Example company	**Google**	**AInnovation**	**Keyence**
Client receives	Inference model	Inspection machine and customized inference application	Machine vision system with broad-function inference model
Options available	Minimal	Fully tailorable to project needs	Wide range of ready-to-use options
Deployment	On-premise or in-cloud	On-premise or in-cloud	In-camera or on-premise
Integration	3rd party	AInnovation	Keyence
Claimed selling point	Best-in-class algorithms	Solving previously unsolvable problems	Ready-to-use, multi-function, robust performance
Pricing	*Pay per use* Fixed: model training (per hour) Variable: inference (per image)	*Pay per project & use* Fixed: model dev. and HW Variable: inference (if in cloud)	*Pay per product* Fixed: camera hardware

Source: Google, AInnovation, Keyence, and Bernstein analysis

EXHIBIT 333: **Pay-per-use pricing is attractive only for low-throughput items**



Note: Cycle times for beverage and EV battery manufacturing are 2s and 60s, respectively.

Source: Applied Controls, Google, and Bernstein estimates and analysis

A NOTE ON TWO AI STARTUPS

Compared with software giants, are they handicapped by not being in the forefront of algorithm innovation? Are they better off choosing the path of manufacturing incumbents (focusing on the variety of HW-SW integrated solutions and depth of domain know-how) or the path of AI architects (focusing on novel AI algorithms)? The debate will continue, but we are strong believers of the former path. When an AI startup's aspiration is to become "the AI version of Cognex," we think it is at least on the right path and has a much better chance of success than if it aspires to become "the Google in manufacturing." Hoping to skip or outsource most of the hard work in Exhibit 313 and focusing on the single element of algorithm training may work in some niches for a few software giants, but not broadly in manufacturing or for startups. Furthermore, being the first in introducing a new algorithm provides only a temporary and limited edge because algorithm know-how is much more readily shared than other elements in the solution. It is also limited because algorithm is only one element in the overall solution and the real-world performance of algorithms alone is hardly differentiating (see Exhibit 330).

In the next section, we dive into AInnovation, a recent IPO in this field. Here, we briefly discuss two other Chinese AI startups that we believe are highly promising in the vision and robotic guiding fields, respectively.

Aqrose

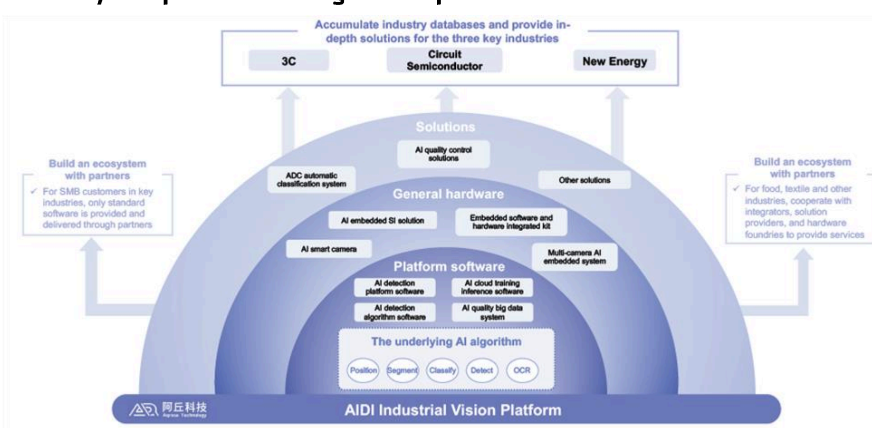
Aqrose, an AI startup founded in 2017, focuses on applying AI and machine vision technologies to industrial inspection fields. To date, its AI product has landed in 180+ factories, including dozens of industry benchmark customers, including Apple, CATL, Foxconn, Luxshare, Goertek, LY iTech, LG Chem, and Kinwong/Tripod/SCC.

Approximately 10% of manual labor in manufacturing is in visual inspection, or 35 million workers in China. In certain companies such as Apple supply chain, this number goes up to 20-30% of all workers. At present, each set of Aqrose's vision system replaces two to three inspection workers on average, and Aqrose has helped Luxshare to reduce worker numbers by 1,500+. Company founder and CEO, Mr. HUANG Yao, estimated that the TAM for Aqrose exceeds USD10bn in electronics and semiconductors.

Aqrose prices its AI software 10-20% below Cognex's VisionPro/ViDi and also competes on customization and services. Huang believes that in AI-based inspection, Aqrose is already ahead of other machine vision players such as MVTec and Hikvision, and OPT is further behind. Aqrose acknowledges Cognex's strength in having rule-based and AI algorithms as one integrated software package (VisionPro). To compete in the near term, Aqrose has made its software easy to be integrated with other vision software; in the medium term, it will likely develop its own rule-based vision software.

For all players in this field, a key challenge is to strike the fine balance between customization and scale, and a path from the former to the latter. Aqrose's strategy is a three-layered product offering (see Exhibit 334): its platform software (AIDI) is the most scalable, targeting experienced integrators and machine developers. The company believes it is critical to have this layer to address the diversified "long tail" manufacturing customer needs in China; the middle layer is "general-purpose AI products," similar to what Keyence offers, ready to use and targeting users across many industries; the third layer is customized product solutions for specific inspection tasks, e.g., an AI-based AOI machine for PCB inspection, or individual customers (e.g., Apple). The company believes that for startups, a common pitfall is to jump to "generalization" too early, hoping to offer just algorithms and have other people "do the hard work" — they fail to build the domain know-how to become relevant in manufacturing. On the other hand, if a company only has customized solutions, it will find it very difficult to scale up, and the addressable opportunity is limited to a small fraction of the overall AI in manufacturing field. The optimal approach is to first go from customized solution to standardized products in order to build a solid foundation for commercialization, and only after that to develop platform software to reach the long tail and scale up.

EXHIBIT 334: **The three-layered product offering from Aqrose to tackle the customization vs. scale challenge**



Source: Aqrose

Mech Mind

Mech Mind, a 3D vision and robotic guiding startup founded in 2016, is devoted to drive the ubiquity of intelligent robots. The company has developed 3D cameras, 3D vision algorithms for identification and inspection, and robotic guiding and autonomous path planning platforms. In 2021, Mech Mind sold ~2,000 units of its products to 550 clients, and the company's founder and CEO, Mr. SHAO Tianlan, expected shipment to triple in 2022.

Mech Mind believes that autonomous functions (e.g., bin picking) are the next big thing in robotics. 3D vision and robot path planning algorithms together allow robots to tackle unstructured tasks, whose paths cannot be pre-programmed. Compared to the robot that costs USD30k on average, the additional cost of adding autonomous functions is just several thousand dollars. The vision-guided robotic solution is much more flexible and saves cost compared to a customized machine to handle the same task. According to Shao, the global shipment of 3D vision + AI-equipped robots was less than 500 units in 2017 and the number has grown ~20x over the last four years. He estimated that in the medium term, the TAM for this new type of robot application is as big as the current robot operational stock and, in the long term, it can be one to two orders of magnitude bigger. But this requires continued improvement of vision and robotic technologies. As of now, 95% of the potential TAM remains too challenging for a robot to handle, Shao estimated.

Mech Mind prides itself on having the broadest and deepest "technology stack" in autonomous robot guiding, while its competitors such as RightHand, Dexterity, and Photoneo only cover one-third to half its technology stack. Mujin, the well-known Japanese startup, for instance, does not have its own 3D vision products. Compared to Keyence's 3D vision guiding products, Mech Mind's price is less than one-third, we learned.

Similar to Aqrose, Mech Mind adopts a hardware-software integrated product strategy, believing it is key to success. It also stresses the importance of offering "standardized" products as the enabler of scalability. Mech Mind's products can be deployed with minimal customization across most customers. In addition to robot guiding, Mech Mind is also exploring its 3D vision+AI in defect inspection.

AINNOVATION: NOT YOUR AVERAGE UNICORN

COMPANY HIGHLIGHTS

Qingdao AInnovation Technology Group Co., Ltd (青岛创新奇智科技集团股份有限公司) is an enterprise AI solutions provider founded in 2018 in China. It is one of the youngest AI startups and became listed in January 2022. The company's mission is to empower businesses with AI technology by helping them optimize costs, operational efficiency, and decision-making. AInnovation's AI offerings serve three broad customer verticals:

- **Manufacturing** (52% of 2021 revenue) is the company's largest vertical and strategic focus. Currently, its major customers in the segment are in metallurgy, energy & power, automotive production equipment, OLED panels and semiconductors, consumer electronics, and engineering and construction.

- **Finance** (32% of 2021 revenue) offerings include intelligent data center infrastructure and operation, intelligent hybrid cloud management, and data governance to help financial institutions enhance their IT and data infrastructure.

- **Others** (16% of 2021 revenue) include customers in retail, IT, and other industries. AInnovation addresses customers' broad "automation" needs beyond production (e.g., product lifecycle and supply chain management).

Compared with other AI startups, e.g., the well-known "AI Four Dragons" and 4Paradigm, AInnovation is unique in many important aspects (see Exhibit 335):

- Its vertical focus is distinctively manufacturing, a huge and less-crowded field, while most other AI startups focus on public security, consumer, and finance.

- Its AI technology covers both branches of major applications: image (including industrial machine vision and video surveillance) and structured data. Many industrial and enterprise applications, as we will see, are developed by fusing both technology branches.

- Its business model starts with and focuses on AI-based solutions and products, the opposite of first-generation "research-oriented" AI startups that were founded on a deep learning framework and platform, and only tried to find commercial applications later. This difference is analogous to whether one holds a beautiful hammer and looks everywhere for a few nails or sees many nails first and then makes a hammer.

- Its commercially oriented business model is strengthened by its technical architecture and the profile of its leadership team:

  - AInnovation's core offerings are asset-based solutions (ABS) and their more standardized version, rapidly deployable products (RDP). The company's technology platforms are in the background as underlying AI infrastructure for model training and tackling the engineering challenges in scalable development and deployment (see Exhibit 336).

  - AInnovation's top team is well-balanced with an AI expert (CTO) and seasoned business executives (CEO and CRO). CEO Hui XU's experience as an enterprise technology service executive at IBM, SAP, Microsoft, and Wanda is pivotal to AInnovation's chosen path.[80] By comparison, most other AI startups' top teams are packed with "researchers" (see Exhibit 337).

AInnovation is backed by Sinovation Ventures, the largest shareholder of the company. The company's CEO, Mr. Hui XU**,** holds 10.25% shares of the company (see Exhibit 338).

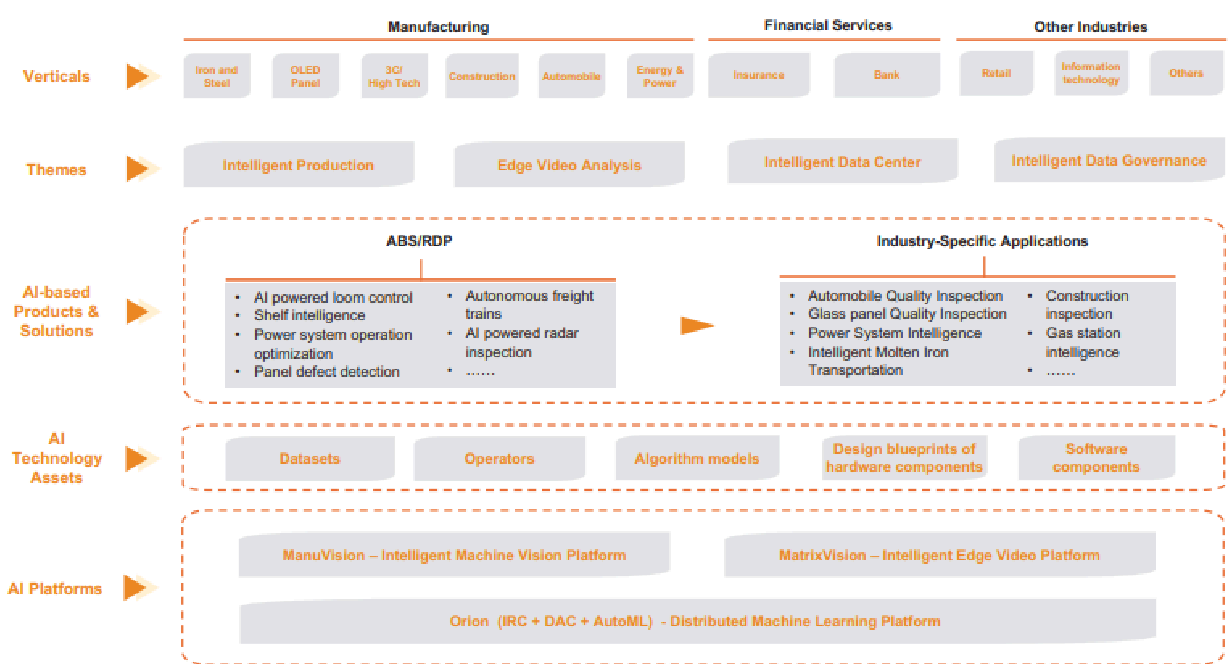
[80] His background is very similar to Mr. XU Ximing, Hikvision's SVP and Enterprise Business Group (EBG) head. Video-based enterprise digitalization is a key opportunity for both AInnovation and Hikvision's EBG. See Hikvision: "We are no longer just about security" - its accelerated transformation to capture digital enterprise opportunities and Hikvision: Video beyond surveillance and security - many breakthroughs and a well-executed transformation.

EXHIBIT 335: **AInnovation is a unique AI for manufacturing play among AI unicorns**

Company	Vertical focus (Revenue contribution)					Technology focus			Starting point		Top team		Year Founded
	Manufacturing	Finance	Other enterprises	Public	Consumer	Industrial vision	Video surveillance	Structured data	Deep learning framework and platform	Smart solutions and products	Scientists	Businessmen	
AInnovation	52%	32%	16%			+	+	+		+	CTO	CEO; CRO	2018
Megvii	7%	65%			28%		+		+		CEO; CTO; SVP; Chief Scientist		2011
SenseTime			17%	40%	43%		+		+		Founders; CEO; Chief Scientist		2014
Yitu				90%	10%		+			+	CEO; Chief Architect; Chief Innovation Officer		2012
Cloudwalk		++	+	+	+		+	+		+	Chairman; Deputy GM	Deputy GM	2015
4Paradigm		++			+			+	+		CEO; Chief Scientist; SVP	President	2014

Source: AInnovation IPO prospectus and annual report, company websites and prospectus, and Bernstein analysis

EXHIBIT 336: **AInnovation's AI assets, offerings, and target verticals**



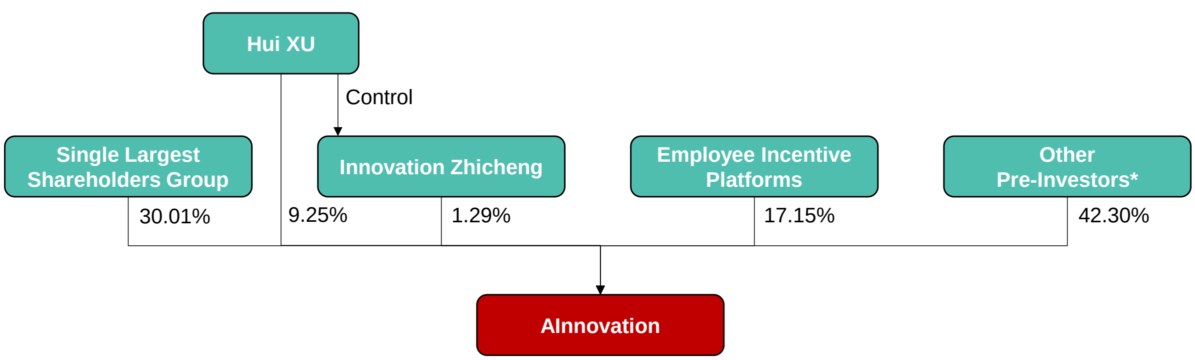
Source: AInnovation IPO prospectus and Bernstein analysis

EXHIBIT 337: **AInnovation's top team has balanced technical and commercial expertise**

Name	Name (Chinese)	Position	Age	Shareholding ratio	Education background	Work experience
Hui XU	徐辉	Chief Executive Officer	48	11.10%	Bachelor's degree in electronic engineering; EMBA	IBM, 1996-2009 SAP, 2009-2013 Microsoft, 2013-2016 Wanda Internet Technology Group, 2016-2018
Fa'en ZHANG	张发恩	Chief Technology Officer	40	2.61%	Bachelor' s degree in software engineering; Master's degree in computer software and theory	Microsoft China, 2008-2010 Google Information Technology (China) Co., Ltd., 2010-2015 Baidu China, 2015-2018
Jun CAO	曹钧	Chief Financial Officer	49	No info	MBA	More than 20 years of experience in finance and technology industry, including Investment Banking at Morgan Stanley, Barclays Capital, and UBS Shanghai Zhaoyou Information Technology Co., Ltd. before joining Ainnovation
Tao HE	何涛	Chief Revenue Officer	51	7.44%	Bachelor's degree in Russian	Wanda Department Stores, 2007-2013 Shanghai Red Star Macalline Business Management (Group) Co., Ltd., 2013-2015 Chongqing Zhida Tianya Business Management Co., Ltd., 2015-2017 Southern China of Wanda Information Technology Co., Ltd., 2017-2018
Lei XIAO	肖磊	Director of investment and finance	33	No info	Bachelor's degree in law; Master's degree in civil and commercial law	COFCO Land Management Co, Ltd., 2012-2014 Shoutai Jinxin (Beijing) Equity Investment Fund Management Co., Ltd., 2014-2020

Source: AInnovation IPO prospectus and Bernstein analysis

EXHIBIT 338: **AInnovation's shareholding structure**



Note: (1) The single largest shareholders group comprises Sinovation Ventures, Sinovation Ventures Yucheng, Mr. Wang Hua, and Ms. Tao Ning (26.24%, 1.68%, 1.68%, and 0.42%, respectively); (2) Other pre-investors include Chengwei Evergreen, Sinovation Ventures Funds, Hongxi Investment, Hongyue Investment, Honger Investment, Huasheng Fund, Jiaxing Yilang, Huangshan SAIF, SAIF Haohai, Chuangzhi Fund, Guohe Fund II, Ronghui Capital, Huaxing Zhihong, Wufang Tianya, Qianhai Puzheng, Yinfeng Rongjin Investment, Yunhai Zhicheng, Shanghai Lanyue, and SVF II Zeal.

Source: AInnovation IPO prospectus and Bernstein analysis

TAM

AInnovation's technology and product development focus is on areas where AI is already a proven tool or showing strength (see Exhibit 339).

AInnovation's business scope and TAM is illustrated in Exhibit 340. In the broadest sense, the company generates revenue from China's enterprise IT and automation capex (>RMB500bn p.a.). Within that, its relevant market consists of four distinct parts: industrial machine vision, industrial software, enterprise video digitalization,[81] and IT for finance,

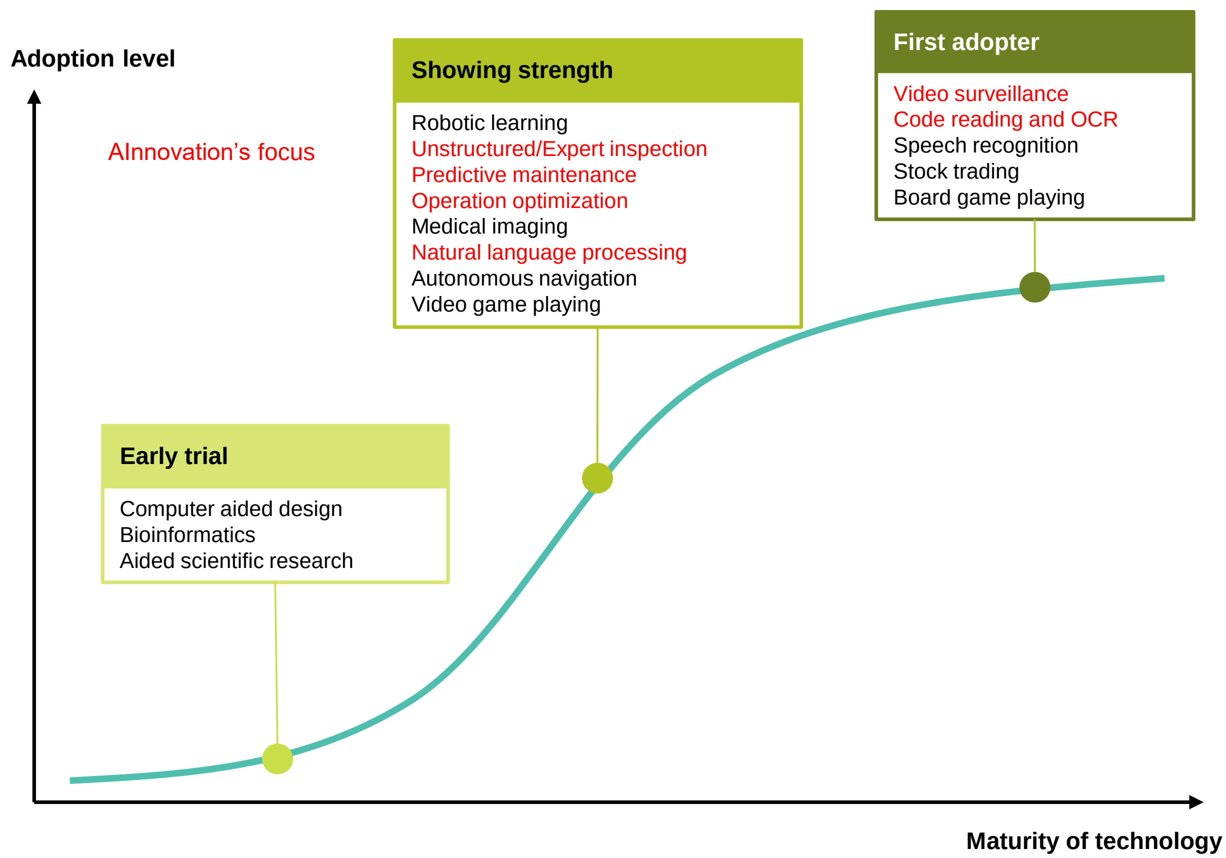
[81] This is part of the RMB160bn China video surveillance market. We estimate the segment to be RMB50bn in 2021 by excluding from the overall video surveillance market the entire public security segment and security surveillance applications within the enterprise segment.

adding up to RMB162bn p.a. The direct TAM is an inner "circle of AI" within these relevant markets, amounting to RMB20-30bn in China today, and projected to grow to RMB80-RMB90bn by 2025 and RMB180-RMB190bn by 2030 (see Exhibit 341). Compared with its current size of just under half a billion RMB, AInnovation has a practically unlimited TAM to play in. This TAM is bigger than the AI in manufacturing TAM discussed earlier in the chapter, because it has segments.

AInnovation is an AI-focused company, but in each of the relevant markets it also competes with industry incumbents, whose level of AI exposure varies (see Exhibit 340). While we see constant expansion of the "circle of AI," we do not believe it will engulf the majority of the relevant markets — as we wrote in 2017 and still believe today, deep learning is a multiplier, serving to strengthen and expand the scope of conventional technologies rather than a disruptor substituting conventional technologies. Therefore, AInnovation's success is not necessarily challenging the respective industries' incumbent leaders such as Keyence, Cognex, and Hikvision.

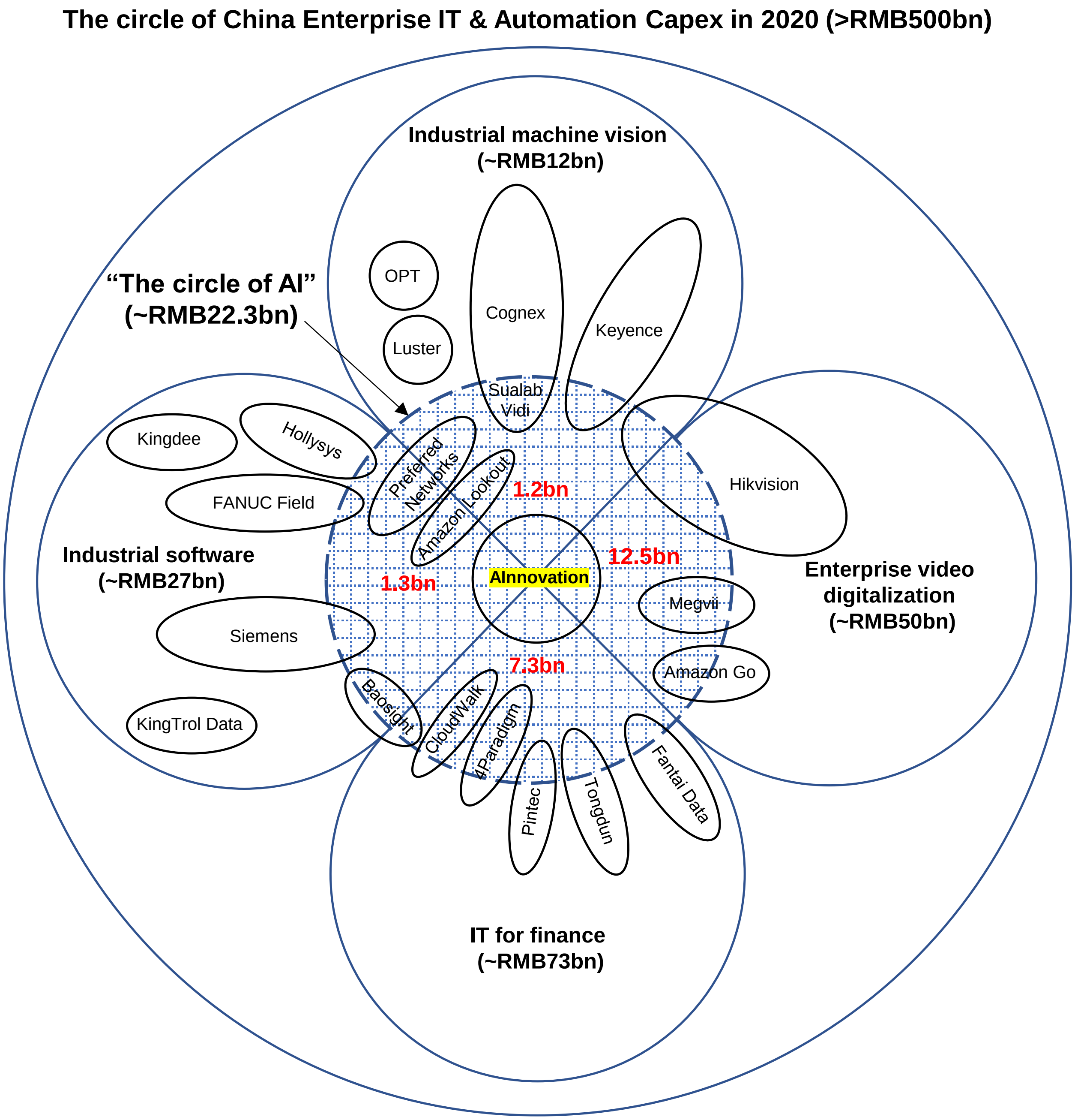
Considering the overlap of TAM and similarity in business models, we see AInnovation not as a peer to China's "AI Four Dragons" (see Exhibit 335), but as a (mini) hybrid of Keyence, Baosight, and Hikvision's enterprise and automation segments.

EXHIBIT 339: **AInnovation focuses on industrial and enterprise applications where AI is first adopted or is showing strength**



Source: Bernstein analysis

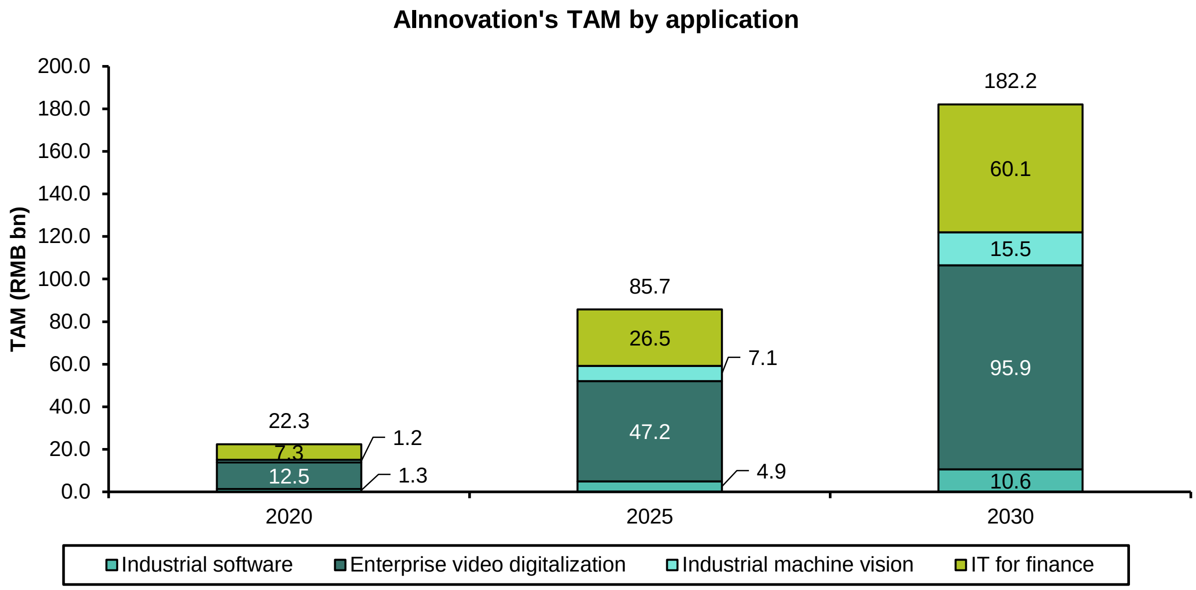
EXHIBIT 340: **AInnovation's TAM (the circle of AI) and four relevant markets**



Note: We cover Keyence, Cognex, Hikvision, FANUC, and Hollysys. Amazon is covered by the Bernstein US Internet team. The rest are not listed or not covered by Bernstein.

Source: AInnovation IPO prospectus, MIR Databank, CMVU, company websites, and Bernstein estimates and analysis

EXHIBIT 341: **We project AInnovation's China TAM to reach ~RMB86bn by 2025 and ~RMB182bn by 2030**



Source: MIR Databank, CMVU, AInnovation prospectus, and Bernstein estimate and analysis

STRATEGY AND DIFFERENTIATION

Since its inception in 2018, AInnovation has successfully introduced several blockbuster AI products and solutions, won industry-leading customers, and reached RMB462mn of revenue in 2020. It now serves customers in iron & steel, display panel, 3C (computers, communications, and consumer electronics)/high tech, automotive, insurance, banking, retail, etc. It has a scalable growth formula (see Exhibit 342):

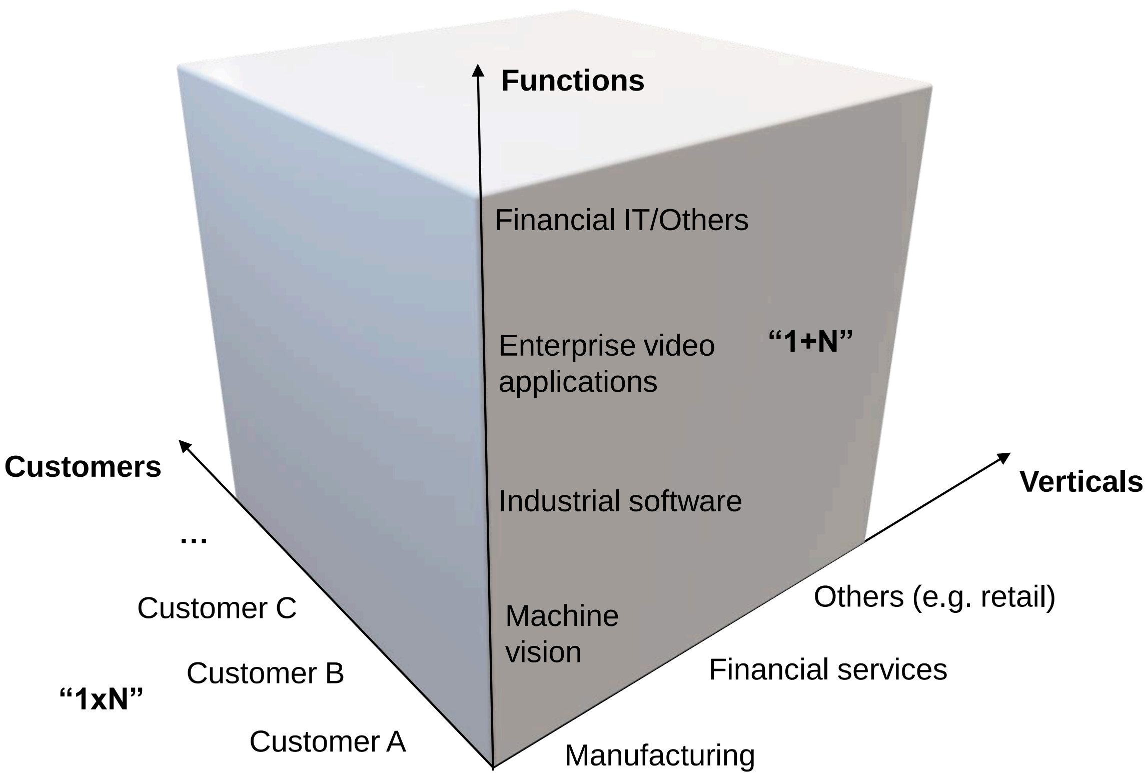
- **"1+N":** Repurchase from company's expanding AI product portfolio by existing customers.
- **"1xN":** Adoption of existing AI products by an expanding customer base with similar needs.

On the customer front ("1xN"), part of AInnovation's progress is evidenced by the companies it serves. The list now includes Baosteel, CIMC, Zong Shen Power, China Tiesiju Civil Engineering Group, and Tincere. AInnovation also serves, through contract manufacturer Yee Tung Group, major global fashion brands such as A&F, Polo Ralph Lauren, and Vans. Clearly, adoption began from top players in each vertical, and these top player user cases will help push adoption downward.

On the product front ("1+N"), AInnovation's approach is highly methodical (see Exhibit 343). Starting from its two major branches of AI capabilities in image (including machine vision and video) and structured data, the company develops an AI application toolbox. The tools of this toolbox are mapped to numerous industry verticals to identify high ROI, and scalable AI solutions and products. Therefore, "1xN" is a relentless effort to grow both dimensions and fill the blank cells of Exhibit 343. Exhibit 344 to Exhibit 347 are some examples of the company's industrial AI offerings.

While the customer approach is top-down, the product approach is characteristically bottom-up. On both fronts, AInnovation is demonstrating impressive early success, thanks to the technical and commercial acumen of its balanced top team. From 2019 to 2020, the number of manufacturing customers (measuring "1xN") increased by 50% (see Exhibit 348) and average sales per key customer (measuring "1+N") almost doubled (see Exhibit 349).

EXHIBIT 342: **AInnovation's growth formula: "1+N" and "1xN"**



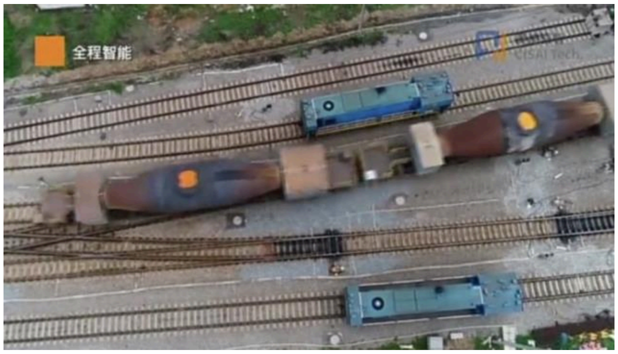
Source: AInnovation prospectus and presentations, and Bernstein analysis

EXHIBIT 343: **"1+N": Filling the expanding matrix (showing examples of where AInnovation's offerings currently cover)**

Functions \ Verticals		Manufacturing							Financial services		Other industries	
		Iron and steel	Display panel	3C/ High tech	Construction	Automobile	Energy & Power	Others	Insurance	Bank	Retail	Others
Industrial software	Automated logistics system	Molten iron transportation										
	Data visualization			Motion system disgnosis			Wind power operation and maintenance	Motion system diagnosis				
	Predicative maintenance											
	Supply chain management										Supply chain management	
	Energy usage management system	Energy management										
	Enterprise resource planning (ERP)	ERP system										
	Others											
Enterprise video applications	Facial/object identification	Molten iron transportation					Wind power operation and maintenance				Smart container	Crowd identification; Smart city AI; Escalator monitoring
	Behavior detection											
	Guiding (e.g. AGV/AMR)											
	Remote control/operation											
Machine vision	Quality inspection	Steel roll inspection	Liquid crystal semiconductor production	Defect detection; Laptop cover inspection; Connector inspection	Glass inspection	Components inspection and assmbly verification		Magnetic tile inspection; Furniture plate inspection; Magnets inspection				Apparel inspection
	2D/3D Measurement				Engineering radar inspection							
	Guiding							Sorting machine guiding system; Filature vision system				
	OCR / ID	OCR mobile terminal										
	Signal processing				Engineering radar inspection							
IT and data governance	Text/image recognition											Resume parsing; Training&examination system
	Natural language processing											
	Operation data analysis	IIoT data governance							Data center/Data governance and application			
	Process automation								Data governance and application			
	Data storage and maintenance	Data center/Hybrid cloud management										

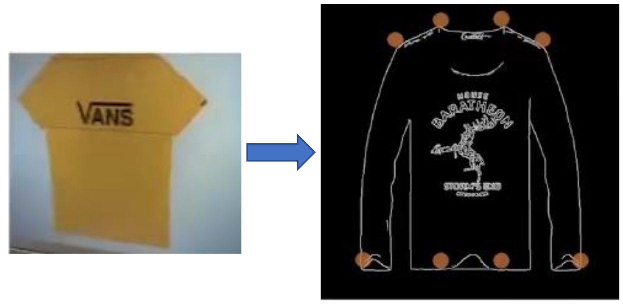
Source: AInnovation prospectus and presentations, and Bernstein analysis

EXHIBIT 344: **Intelligent molten iron transportation system saves cost by RMB8.5mn p.a.**



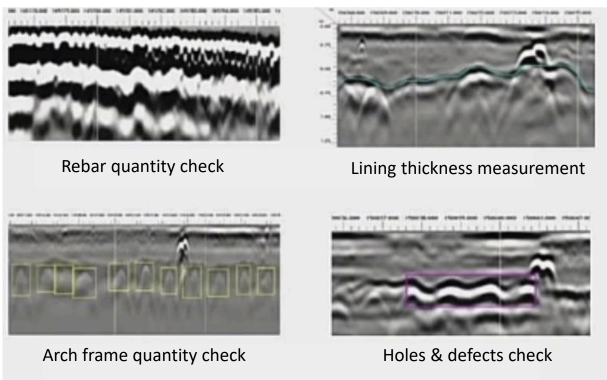
Source: AInnovation presentations

EXHIBIT 345: **Dimension and defect inspection in apparel making raises efficiency by 7x and cuts 95% labor in inspection**



Source: AInnovation presentations

EXHIBIT 346: **Tunnel engineering radar inspection improves accuracy by 20x vs. manual inspection**

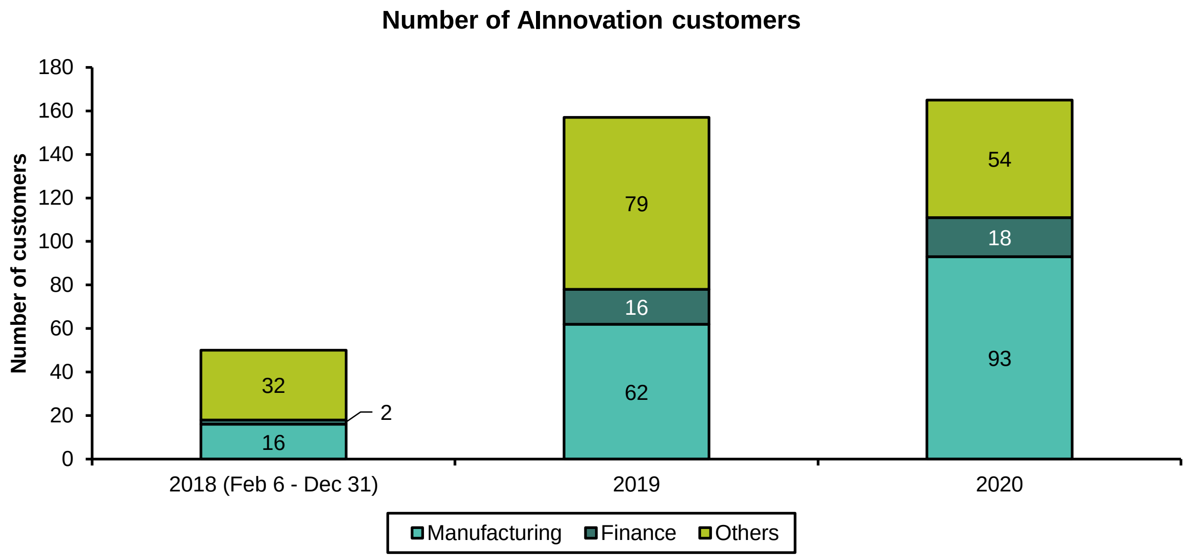


Source: AInnovation presentations

EXHIBIT 347: **Motor assembly inspection achieves detect precision of 100%**

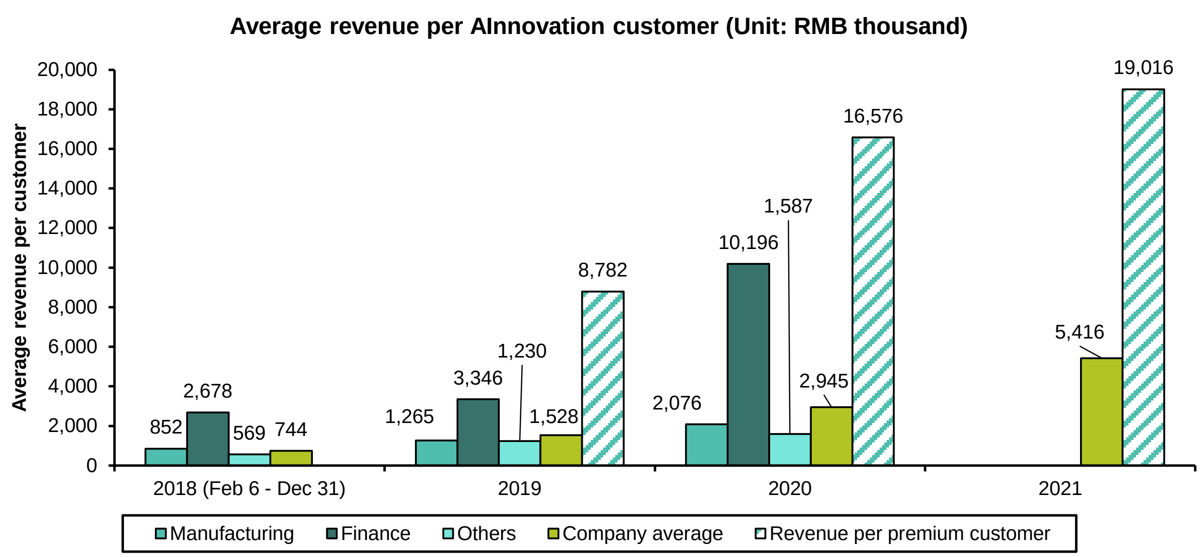
Source: AInnovation presentations

EXHIBIT 348: **AInnovation's customers in its first three years**



Source: AInnovation prospectus and Bernstein analysis

EXHIBIT 349: **Average revenue per AInnovation customer**



Source: AInnovation prospectus and annual report, and Bernstein analysis

The 1xN and 1+N strategies seem logical and straightforward, but it is not the path most AI startups have chosen (see Exhibit 335). Instead of developing a product portfolio bottom up with real users and their ROI in mind, AI startups often hope to do it top down — developing and perfecting a platform of framework algorithm (a splendid "hammer") then looking for applications ("nails") opportunistically. We call this top-down product approach the "internet-mentality pitfall." A platform may sometimes be the most powerful thing in a B2C sector; however, it is outright overrated in manufacturing.[82]

Most automation system integrators, though, fall into the other extreme. Their business is so bottom up that each project is a painstakingly customized solution. The required time and cost for constant customization prevents them from growing out of silos to achieve scalability. This is the "pitfall of system integrators."

AInnovation steers clear of both pitfalls by taking the road traveled by Keyence and Hikvision: solutions → products → platform (optional), in that order (see Exhibit 350). These two formidable industry leaders excel with large, innovative, and fast-evolving products, which, abundant in SKUs (tens of times in numbers vs. a typical competitor), are used without much customization by thousands of customers. Only very recently has Hikvision started building platforms, not changing but extending and further strengthening its product-centric strategy. [83] Keyence has deemed introducing platform offerings unnecessary.

When an entire industry/technology is young, it needs tailored solutions to make the technology relevant and bring initial adoption. For Keyence and Hikvision, this phase was decades ago. For AInnovation and AI, customized solutions are still important to establish relevancy. But the key to scalability is to standardize solutions to become modular products. In choosing R&D focuses, AInnovation assesses whether that critical step is practical, and its current offering consists of ABSs and their more standardized version, RDPs.

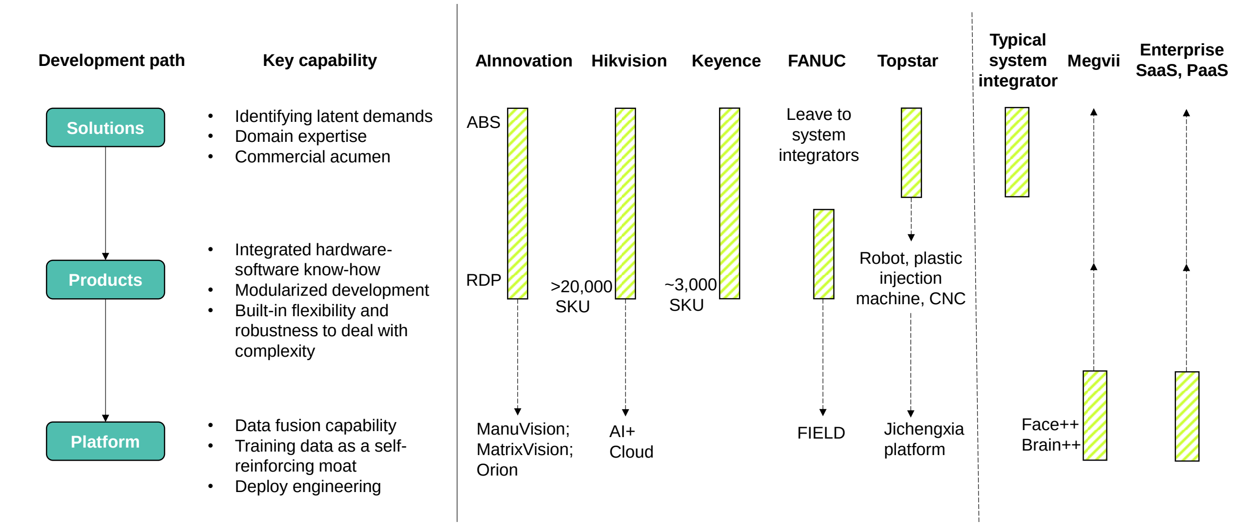
Two other companies in Exhibit 350 are worth mentioning. FANUC, also taking a product-centric approach and adding platforms only recently, decided from early days to leave "solutions" completely to external integrators, therefore maximizing scalability. Topstar (not covered) started as a system integrator, but has made it a key strategy to modularize its solutions, become a product company, and grow out of the pitfall of system integrators.

AInnovation's AI technology assets, including datasets, operators, algorithms, trained models, hardware/software modules, and deployment architecture (ManuVision for industrial vision, MatrixVision for edge video, and Orion for distributed machine learning; see Exhibit 336) form a self-reinforcing loop (see Exhibit 351). This loop helps AInnovation build a moat from economy of scale and enjoy the first-mover advantage in manufacturing. As deployment broadens, training datasets and software/hardware modules all expand, and trained models not only perform better but also multiply in numbers in the "model zoo." With adequate AI techniques such as transfer learning, new models are "bred" from old ones for adjacent applications with minimal additional training required, thus leading to diminishing cost for "1+N." One recent innovation by the company is called zero-shot instance (ZSI) segmentation, which allows AI models trained on seen data to be used for unseen data (see Exhibit 352),[84] a powerful tool in the typical manufacturing environment,

[82] See this fun note: "Surely you are joking, Mr. Analyst!" - Four maladies that hinder one's search for great industrial companies.
[83] See Hikvision: Full speed and five platforms toward AIoT and digital enterprise.
[84] For example, in industrial machine vision, a model trained by ZSI on images of knifes can be deployed, with no additional training, to inspect forks, thus expanding the application quickly and efficiently.

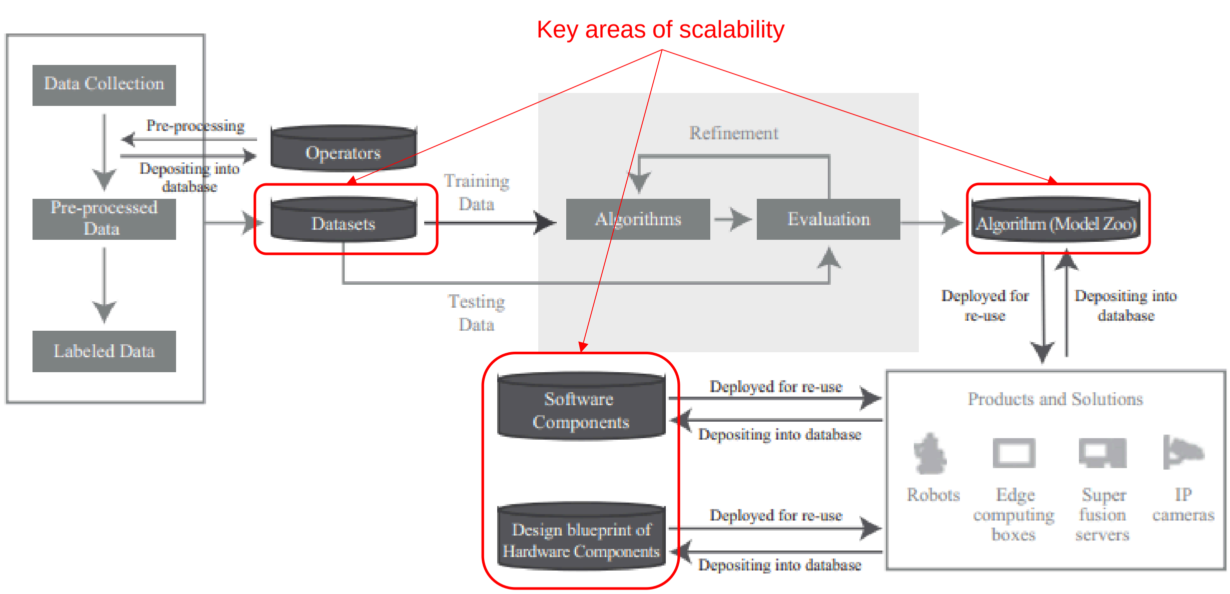
where digitalization is incomplete, workpiece complexity is extremely high, and labeled data is scarce.

EXHIBIT 350: **"Internet mentality pitfall," "system integrator pitfall," and the winning path in industrial tech (Keyence, Hikvision, and AInnovation)**



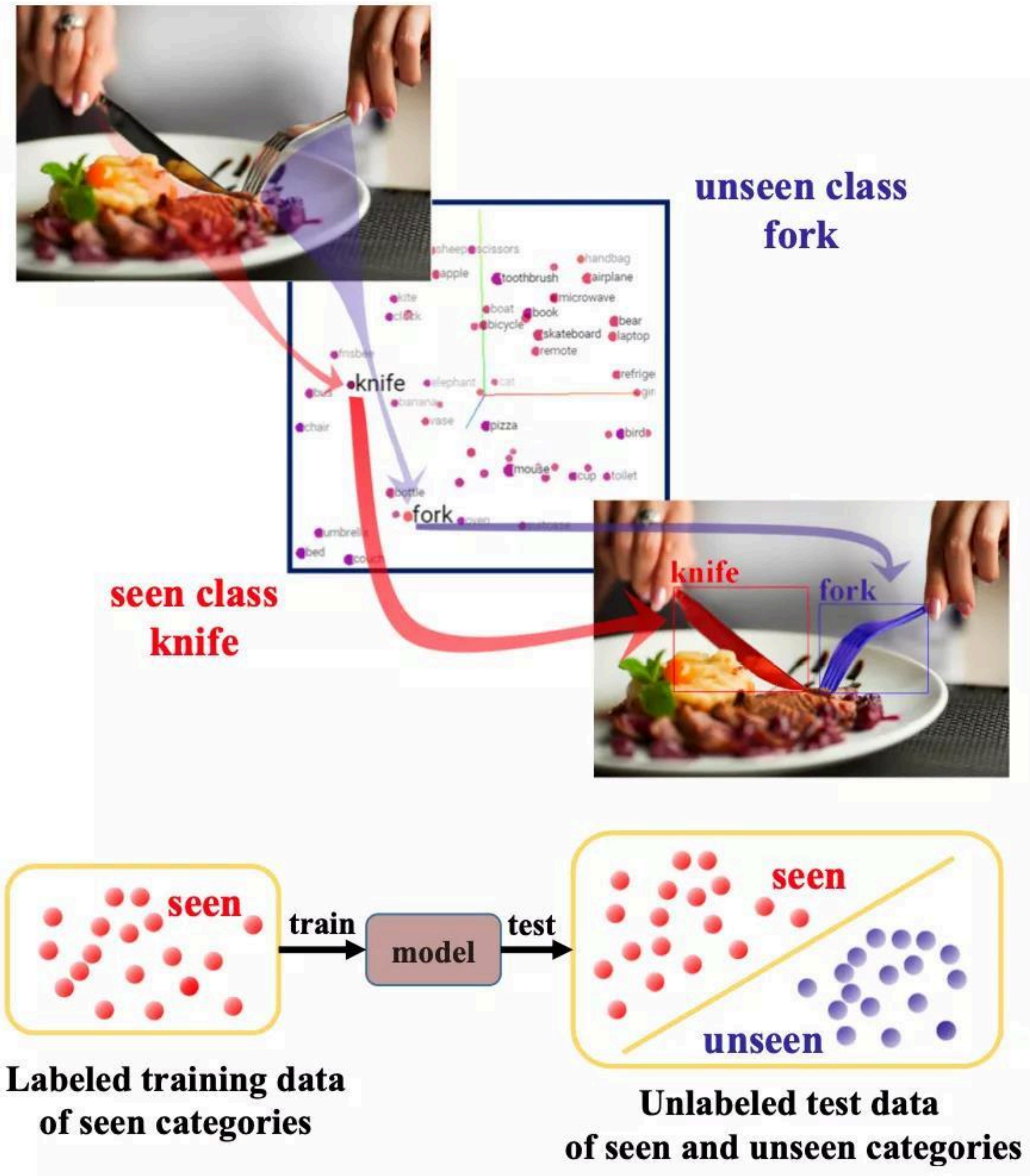
Source: AInnovation prospectus and Bernstein analysis

EXHIBIT 351: **AInnovation's self-reinforcing loop of AI assets leads to strong first-mover advantage in manufacturing**



Source: AInnovation prospectus and Bernstein analysis

EXHIBIT 352: **AInnovation's ZSI: a model trained on seen data (images of knives) can be directly applied to unseen data (images of forks) with no additional training**



Source: AInnovation and Bernstein analysis

AINNOVATION'S TECHNOLOGY DIFFERENTIATION

Through many discussions with investors, we understand that the central debate regarding AInnovation is whether it is differentiated in AI technology. While the bulls (us included) see the company's hardware-software integrated offering, its commercial acumen, and its business-technology balanced top team as an important moat, the bears see the company as a mere system integrator disguised as an AI company. We take this opportunity to directly address this issue. In our view, *having all the good things around AI does not dilute* *one's strength in AI*. From a pure AI technology perspective, we believe the company is differentiated in:

- Having a large and quickly expanding AI model zoo, tailored to manufacturing tasks. Model variety is critical because in manufacturing, not only are there a huge variety of objects, but also each object may have several different types of defects. There is no one-size-fits-all AI model. In 2H21, the company's model classes increased by ~50% (see Exhibit 354). We want to see this pace of model zoo expansion to continue for at least several more years.

- Manufacturing-dedicated, reusable AI assets, including datasets, data operators (allow the fusion of different formats of data), algorithms, models, software modules, and hardware design blueprints (see Exhibit 351 and Exhibit 353), allowing modularized development of products and solutions with diminishing costs. These AI assets carry the domain know-how accumulated in each project and are also the source of economy of scale.

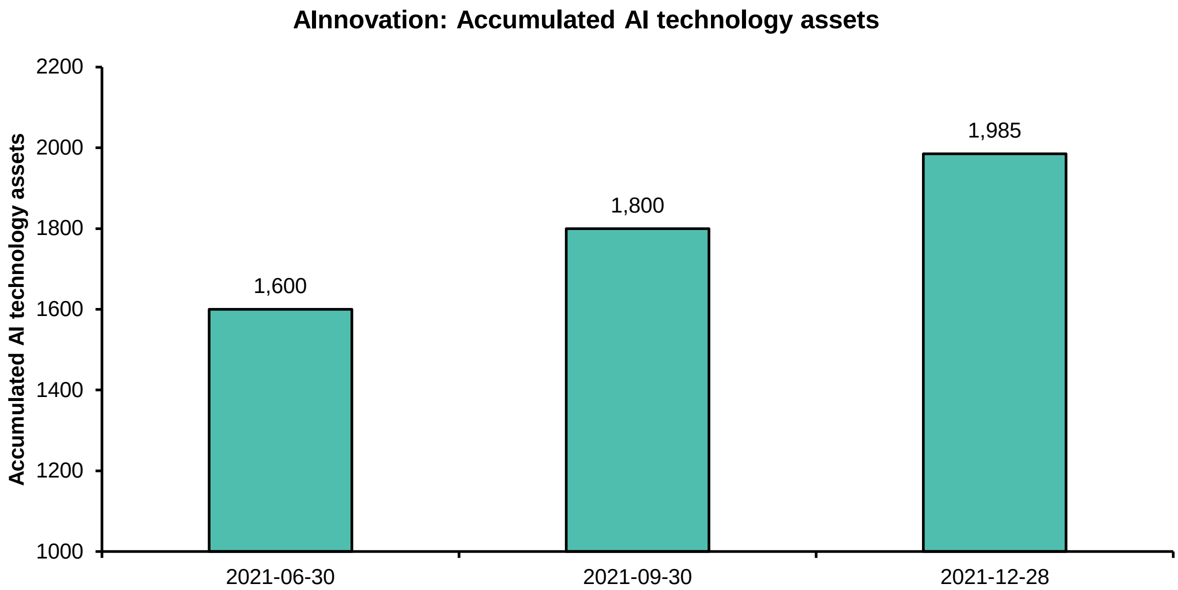
- Being among the leading AI algorithm innovators to tackle the small sample-size and large object variety challenges, which are characteristic in manufacturing. Just now, we described how transfer learning and AInnovation's ZSI technique allow a model trained on seen data (e.g., images of knives) to be directly applied to unseen data (e.g., images of forks) with no additional training. Here we show that AInnovation is also among the top performers in scene-parsing algorithms, a critical technique for machines to "understand" images and videos (see Exhibit 330).

- Being a leading practitioner of automated machine learning,[85] critical for efficient and scalable deployment and redeployment facing the huge variety of AI tasks in manufacturing (see Exhibit 322).

AInnovation differentiates with its strong engineering capabilities to drive AI adoption. In the three-layered AI product framework (see Exhibit 334), AInnovation starts from the top layer (customized product solutions), but has a clear vision to go down to the standardized product layer as its chosen path toward scalability. Although not selling standalone software like Aqrose does, AInnovation has developed vision and machine learning platforms as part of its technology moat. Chosen areas of focus and stance on standalone software are different between AInnovation and Aqrose, but the understanding of priorities and path toward scalable commercialization is similar: (customized) solution first, (standardized) product, platforms as an enabler. Compared to other AI startups, AInnovation has deeper solution know-how, broader AI application scope (beyond small feature inspection), and its relationship with flagship customers is an important first-mover advantage that can fuel future growth.

[85] See a short video explaining the automated machine learning concept by following this link: https://www.microsoft.com/zh-cn/videoplayer/embed/RE2Xc9t?autoCaptions=zh-cn.

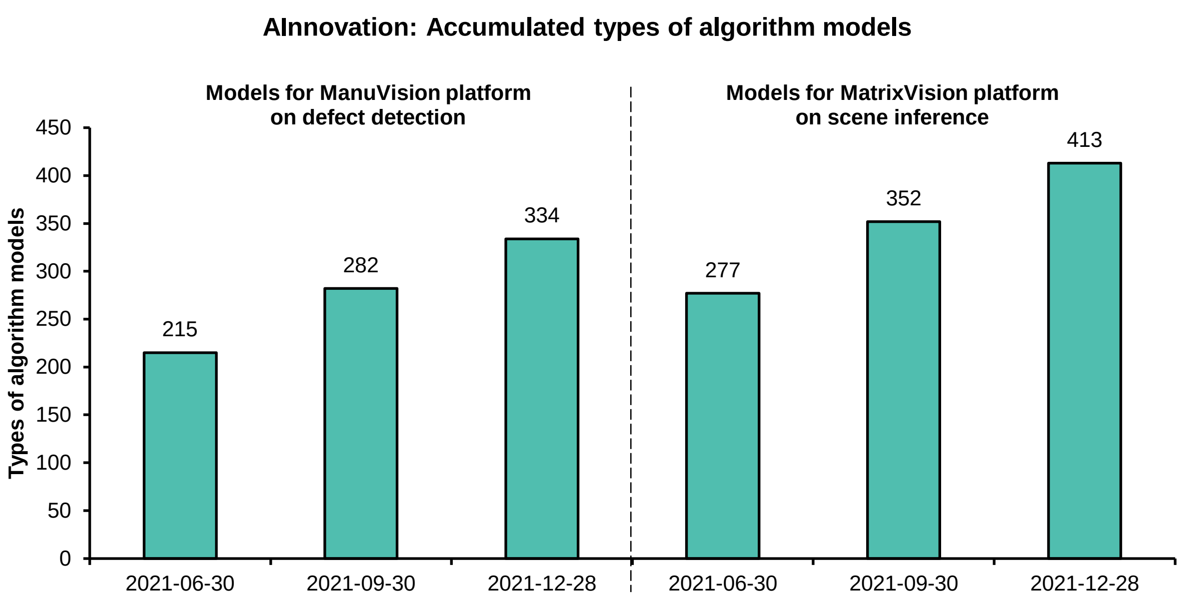
EXHIBIT 353: **AInnovation is quickly expanding its AI technology assets**



Note: AI technology assets include datasets, operators, algorithm models, design blueprints of hardware components, and software components.

Source: AInnovation prospectus and Bernstein analysis

EXHIBIT 354: **AInnovation has developed a large and quickly expanding model zoo**



Source: AInnovation prospectus and Bernstein analysis

ECONOMICS

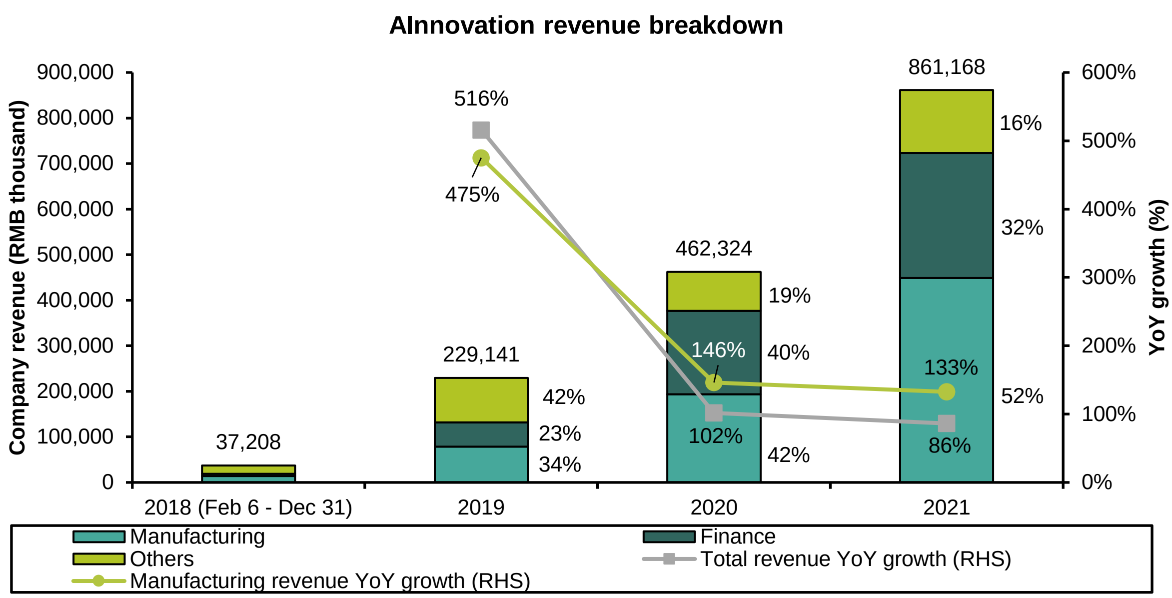
AInnovation recorded revenue of RMB861.2mn in 2021, up 86.3% yoy (see Exhibit 355). Even as the company's scale increased, the manufacturing segment growth accelerated: it was up 133% yoy in 2021, with contribution increasing to 52.2% (from 42% in 2020).

AInnovation is the largest Chinese AI company in manufacturing (see Exhibit 356), and the strong growth in 2021 strengthens its leading role. We are further encouraged to see the company's breakthrough in key manufacturing verticals. In addition to well-known molten-iron transportation projects with major steelmakers, the company has also made breakthroughs in the automotive and high-tech/3C supply chain. These two verticals contributed 51% to AInnovation's 2021 revenue in manufacturing (up from 20% in 2020; see Exhibit 357).

Being an AI play, AInnovation chooses not to be a pure software company, but builds its moat on hardware-software integration — another key trait of success in manufacturing and of differentiation from other AI startups. This choice resulted in lower GP margin of ~30% after a brief period in 2018 when it was mostly software sales, but it is a matter of scale: its less AI-focused incumbents in AInnovation's relevant market are generating 40-80% GP margins (see Exhibit 358). GP margin expanded 190bps in 2021. We believe this trend will continue, and the steady-state GPM is 45-50% for AInnovation's chosen hardware-software integrated solution model

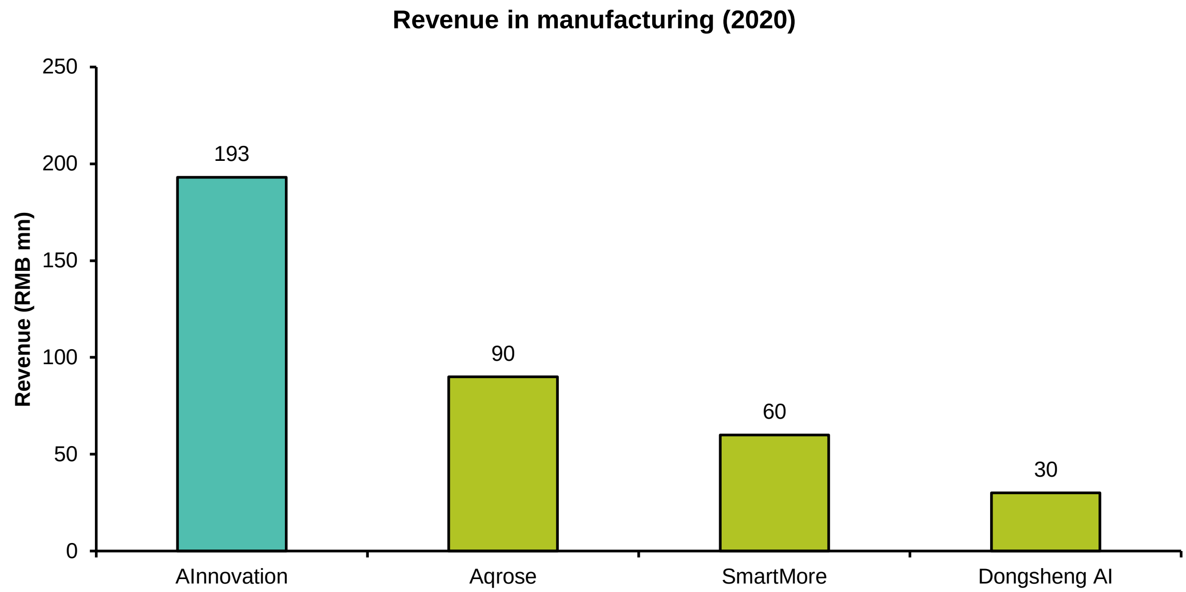
At this early stage the company is understandably loss-making, but is already demonstrating economy of scale: adjusted operating loss narrowed from -33% in 2020 to -25% in 2021 (see Exhibit 359), driven by quickly decreasing operating cost intensity (see Exhibit 360). Thanks to its commercial access and product-centric strategy, AInnovation's R&D and SG&A efficiency, as well as revenue per employee (see Exhibit 361), are two to three times higher than other AI startups, and continue to improve. At scale, we see a steady-state margin profile comparable with or higher than its less AI-focused peers.

EXHIBIT 355: **AInnovation's revenue grew 86% yoy in 2021; manufacturing segment hiked by 133% yoy**



Source: AInnovation prospectus and annual report, and Bernstein analysis

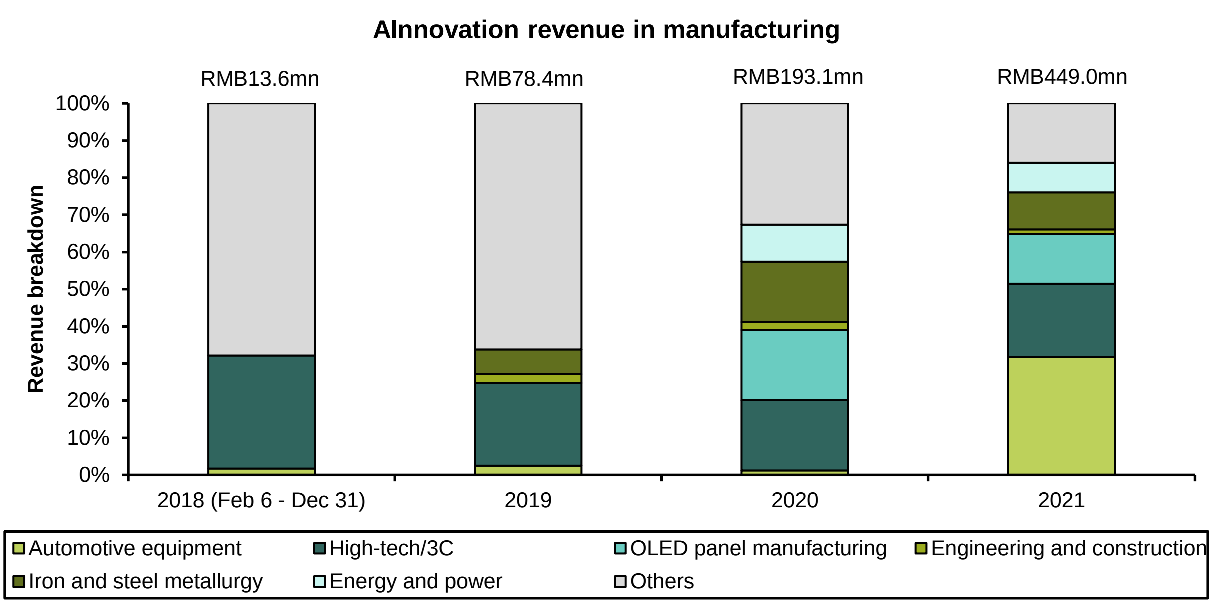
EXHIBIT 356: **AInnovation is the leading Chinese AI player in manufacturing**



Note: Aqrose is a computer vision based AI solutions provider with business covering the logistics and manufacturing sectors; SmartMore is a computer vision based AI solutions provider focusing on manufacturing and ultra HD video; Dongsheng AI is a computer vision based AI solutions provider focusing on manufacturing.

Source: AInnovation prospectus and Bernstein analysis

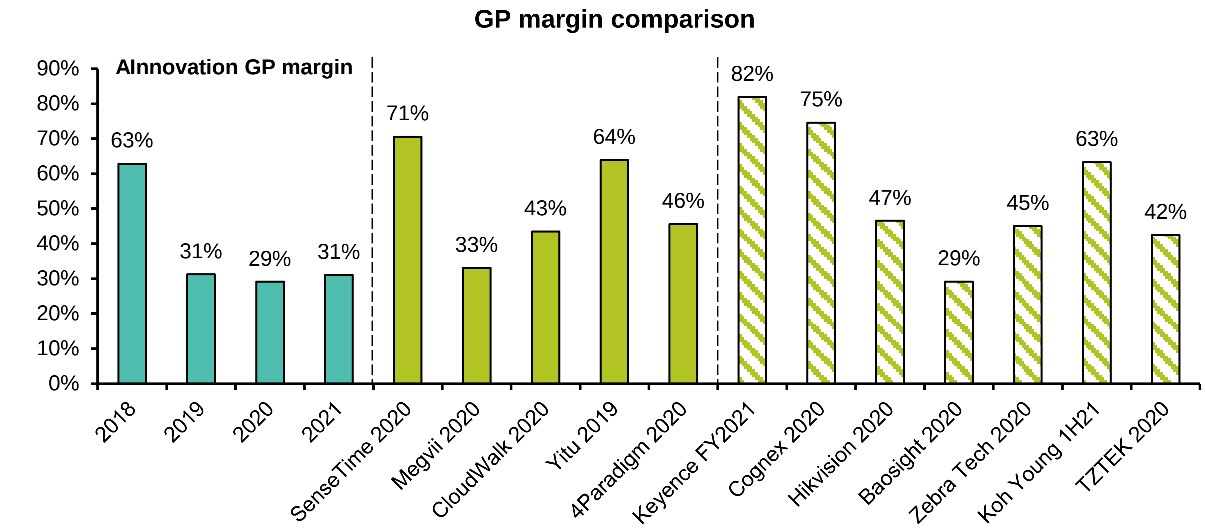
EXHIBIT 357: **Two verticals with the largest TAM, automotive and high-tech/3C, saw significant increase in contribution in 2021**



Note: Others mainly include textile manufacturing, food production, communication equipment manufacturing, and other verticals in manufacturing industry.

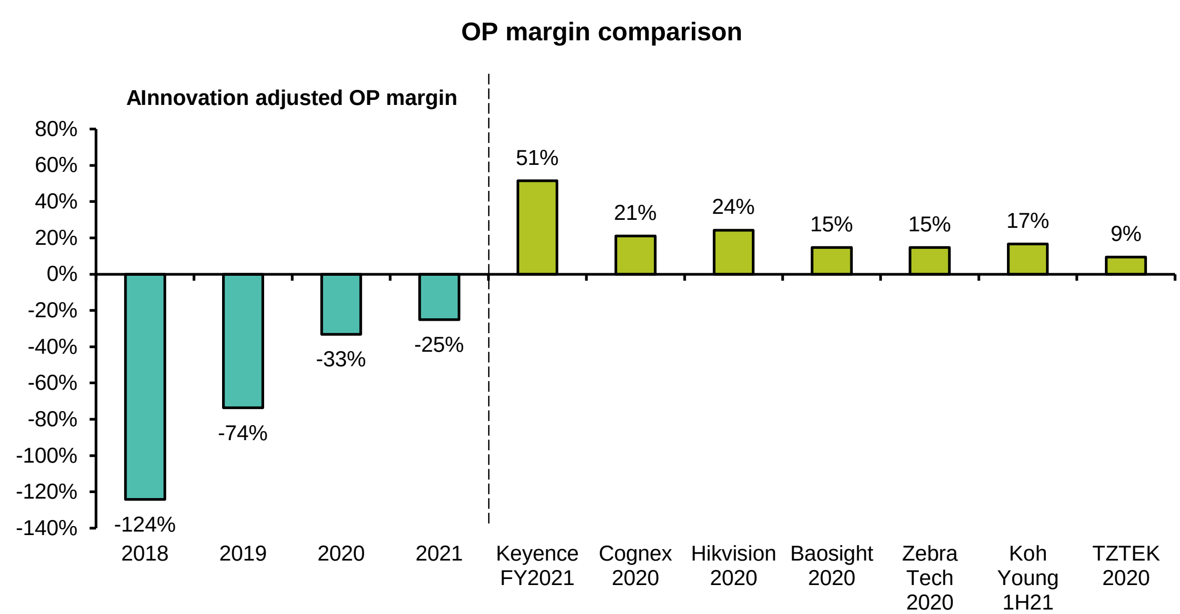
Source: AInnovation prospectus and annual report, and Bernstein analysis

EXHIBIT 358: **AInnovation's GPM improved to 31%, consistent with management guidance of 100-200bps annual improvement**



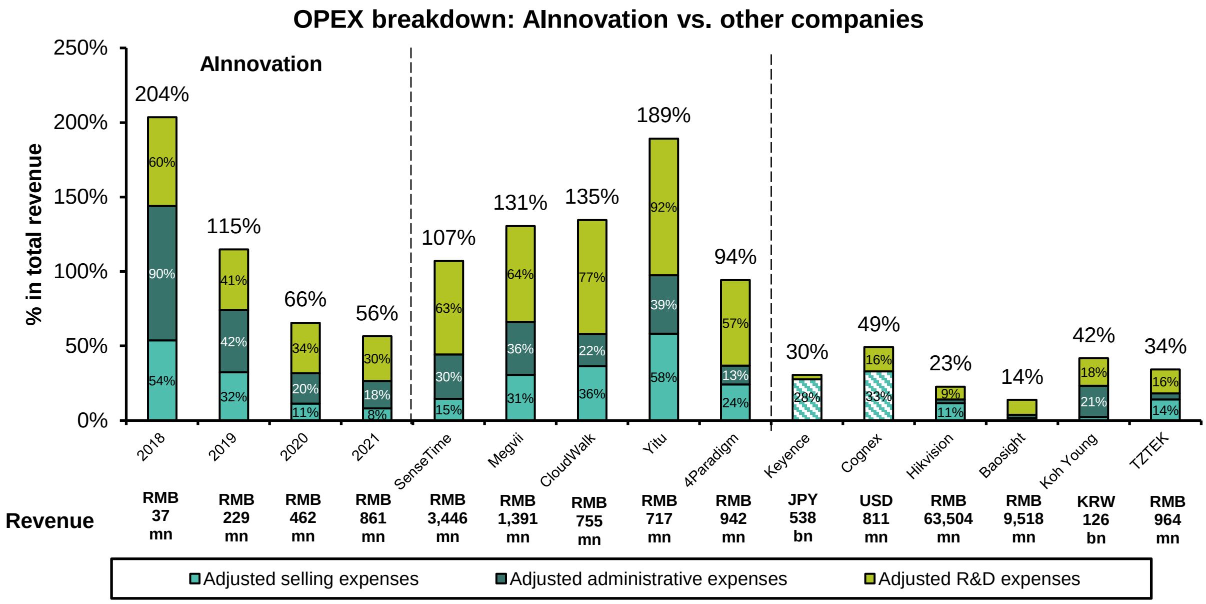
Source: AInnovation prospectus and annual report, Bloomberg, company websites and prospectuses, and Bernstein analysis

EXHIBIT 359: **AInnovation is burning much less money than a typical AI startup — operating loss is narrowing quickly**



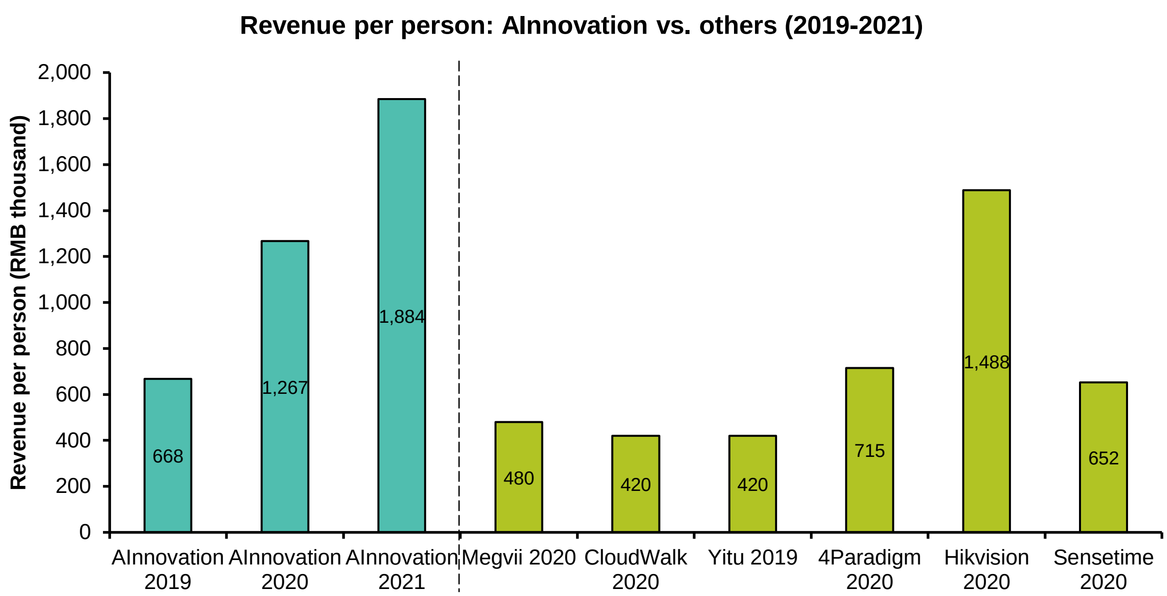
Source: AInnovation prospectus and annual report, Bloomberg, and Bernstein analysis

EXHIBIT 360: **AInnovation's opex efficiency continues to improve; at much smaller scale, it is already much more efficient in opex than other AI startups**



Source: AInnovation prospectus and annual report, company websites and prospectus, and Bernstein analysis

EXHIBIT 361: **AInnovation's revenue per employee is 2-3x that of other AI startups**



Source: Bloomberg, AInnovation prospectus and annual report, company websites and prospectus, and Bernstein analysis

I. REQUIRED DISCLOSURES

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We use EV/EBITDA multiple as the primary valuation method. We set the target multiple referencing previous cycles but adjust for secular or competitive trends that we believe are moving multiples higher or lower across multiple cycles. We use discounted cash flow (DCF) as reference for the company's long-term intrinsic value. As we move along the different stages of a cycle, the time-dependent target price may deviate from the DCF-implied value.

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- Market-Perform: Stock will perform in line with the market index to within +/-15 pp
- Underperform: Stock will trail the performance of the market index by more than 15 pp

Not Rated: The stock Rating, Target Price and/or estimates (if any) have been suspended temporarily.

Autonomous brand

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* These figures represent the number and percentage of companies in each category to whom Bernstein and Autonomous provided investment banking services.

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