AUTOMATION, EMPLOYMENT, AND RESHORING: CASE STUDIES OF THE APPAREL AND ELECTRONICS INDUSTRIES

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I. INTRODUCTION

Much of the discussion of the impact of automation on employment has focused on developed countries. Yet, for developing countries, a key concern is the prospect of "reshoring" or "nearshoring"—the opposite of offshoring—in which production particularly of labor-intensive manufactures shifts from developing back towards developed countries. These shifts in the global division of labor are enabled by automation in such critical industries as apparel and electronics, that have provided developing countries with strategic entry points into global markets and employ large numbers of workers. For example, the more readily and cheaply that apparel, sewing, and electronics assembly can be automated, the less readily can developing countries retain their competitive advantage based on lower labor costs. For lead firms in global supply chains, reshoring would provide the considerable advantages of lower transport costs, as well as shorter lag times between design, production, and final sales, enabling more just-in-time production. While there is not at present an *overall* trend towards reshoring, recent empirical studies find evidence that the increased use of robotics and other automation technologies in developed countries is associated with reshoring.[1]

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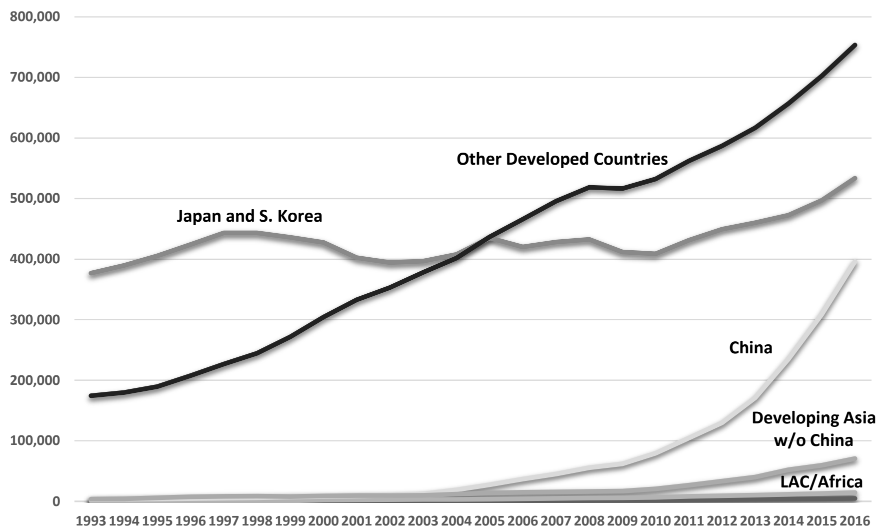
1. Bernhard Dachs, Steffen Kinkel & Angela Jager, *Bringing It All Back Home? Backshoring of Manufacturing Activities and the Adoption of Industry 4.0 Technologies* (MPRA, Paper No. 83167, 2017); Marius Faber, *Robots and Reshoring: Evidence from Mexican Local Labor Markets* (WWZ, Working Paper 2018/27, 2018); Astrid Krenz, Klaus Prettner & Holger Strulik, *Robots, Reshoring and the Lot of Low-skilled Workers* (CEGE, Discussion Paper 351, 2018).

The concern for developing countries is heightened when one considers the figures for risk of potential automation in different occupations via a method developed by Carl Benedikt Frey and Michael Osborne and applied in theirs and other widely-cited studies.[2] The purported risk of potential automation by computer-controlled equipment in the next ten years or so is 99% for hand sewers, 89% for sewing machine operators, and 95% for electrical and electronic equipment assemblers. These figures are high because the occupations are classified as being comprised largely of routine work that is judged to be more amenable to automation. Since developing countries have much higher shares of such occupations than developed countries, the method inevitably yields the result that the country-wide share of jobs at high risk (70% or greater) of potential automation is considerably higher in developing than developed countries.

Yet, computer-controlled automation is not particularly new, and developing countries have always had higher shares of routine work than developed countries. If technological feasibility were the decisive consideration, then more production would be (or would soon be) automated in developing as opposed to developed countries. Most typical of computer-controlled automation are robots, whose diffusion has been facilitated by rapidly expanding capabilities and falling costs. But, as Figure 1 shows, the geographical distribution of robots is highly concentrated in developed countries and, more recently, in China—suggesting that technological feasibility is not the decisive consideration.

2. Carl Benedikt Frey and Michael Osborne, *The Future of Employment: How Susceptible are Jobs to Computerisation?* (Oxford Martin Programme on Technology and Employment, 2013), a revised version of which was published in 114 TECH. FORECASTING & SOC. CHANGE 254 (2017); Jae-Hee Chang and Phu Huynh, *ASEAN in Transformation: How Technology is Changing Jobs and Enterprises* (Bureau for Employers Activities, Working Paper No. 9, 2016); WORLD BANK, WORLD DEVELOPMENT REPORT 2016: DIGITAL DIVIDEND (2016).

Figure 1: Global Unit Stock of Industrial Robots, 1993-2016



Source: International Federation of Robotics, 2017.

The authors of these studies clearly state that their results refer to the probability that a job *could be* automated, whereas they are often misrepresented or misunderstood as the probability that a job *will be* automated. These are two fundamentally different things: for while the former is purely a technological consideration, the latter is also an economic consideration, depending on the relative costs of labor and automation technologies, and ultimately, on whether investing in new automation technologies is at least as profitable as existing alternatives. Since applying this method to different countries is entirely driven by differences in the distribution of workers among occupations, the gap between the probability that a job *could be* automated and the probability that a job *will be* automated is systematically larger in countries with lower labor costs. In other words, equating *could be* with *will be* is particularly problematic for developing countries. Moreover, a method developed by Melanie Arntz *et al*. that more fully accounts for the variety of tasks within occupations yields much lower estimates than Frey and Osborne's method of the country-wide share of jobs at high risk of potential automation.[3]

In contrast with these prior studies, the ambition of this paper is not to look at all occupations and industries within a country to provide a country-wide assessment, useful as that general approach may be in its own right. Rather, we provide more in-depth case studies of the apparel and electronics industries, in which we focus on the companies that are makers and users of industrial robots and other automation technologies. This provides more of a shop floor perspective on the technological bottlenecks to the use of automation in these industries. We have noted that these industries have been strategically important for developing countries, and they have also experienced extensive offshoring of production in recent decades. We also focus on these industries, because they illustrate challenges to the automation of seemingly routine work, as well as the technological bottlenecks that are specific to each.

This paper argues that technological feasibility is not the decisive consideration in the diffusion of new automation technologies. The paper also argues that the high figures for the risk of potential automation noted above appear overstated and do not adequately convey the considerable technological bottlenecks involved in automation in the apparel and electronics industry, particularly for sewing operations and the assembly of electronics components. Tasks that may appear routine for humans may in fact be very difficult for machines. Moreover, the skills involved in sewing and electronics assembly may be underestimated, perhaps in part the result of the tendency to equate low pay with low skill. There may be a gender dimension to this as well, as production workers in these industries are disproportionately female, and there are studies showing that occupations with high shares of women workers are devalued.[4]

The paper next presents the case studies of the apparel and electronics industries, looking at the global distribution of employment and exports among leading developed and developing countries, patterns of offshoring and reshoring, as well as industry-specific discussions around reshoring, and the use of robots among leading countries. Central to the case studies are the descriptions of recent technological developments, illustrating how companies are wrestling with challenges, particularly in sewing operations and the assembly of electronics components, in contrast to the production of electronics components. The case studies contain their own

3. Melanie Arntz, Terry Gregory & Ulrich Zierahn, *The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis* (OECD Social, Employment and Migration Working Paper No. 189, 2016).

4. E.g., Asaf Levanon, Paula England & Paul Allison, *Occupational Feminization and Pay: Assessing Causal Dynamics Using 1950-2000 U.S. Census Data*, 88 SOC. FORCES 865 (2009).

conclusions, and the paper closes with more general observations about the impact of automation on employment and the global division of labor.

II. THE APPAREL INDUSTRY

The apparel industry has experienced extensive offshoring from developed to developing countries in recent decades, and is also one of the most important industries as regards integration into global supply chains, along with the automobile and electronics industries.[5] Table 1 gives a sense of the extent of offshoring in the last fifteen years, from developed to developing countries, particularly in Asia. The table shows exports for and numbers of formal employees in the industry for the world's top ten apparel exporters, accounting for 87% of global apparel exports as of 2015. For the eight developing exporters shown in the upper panel of the table, apparel exports totaled $287 billion in 2015 and employment increased from 6.5 million in 2000 to 15.5 million around 2015. China is by far the most important among these eight in terms of exports and employment, accounting for 61% of their exports as of 2015 (67%, if one includes Hong Kong) and with its share of employment holding steady at about 50% over these years.

For 2015, apparel exports for the European Union (EU) totaled $112 billion—second only to China—compared to $6 billion for the United States. The much larger volume of exports from the European Union 28 than the United States is striking, suggesting that EU producers have been much better at holding their own in global markets than their counterparts in the United States.[6] Yet employment has dropped sharply in both the EU and the United States since 2000: by 42% in the former and 66% in the latter. While in 2000, the European Union 28 and United States accounted for 30% of employment in the industry among these ten exporters, this plummeted to just 9% around 2015, a massive compositional shift in employment in such a short span of time.

5. Timothy Sturgeon and Olga Memedovic, *Mapping Global Value Chains: Intermediate Goods Trade and Structural Change in the World Economy* (UNIDO, Working Paper 05/2010, 2011)

6. It may be the case, however, that this reflects a higher share of imported intermediates embodied in EU 28 than U.S. apparel exports.

Table 1: Exports and Formal Employees in Top 10 Apparel Exporters

	Exports, 2015 US$, billions	Formal employees, 2000[1]	Formal employees, around 2015[2]
China	175	3,284,000	7,661,200
Bangladesh	26	1,037,310	2,827,468
Vietnam	22	511,364	2,314,288
Hong Kong, China	18	28,200	11,650
India	18	469,195	1,342,454
Turkey	15	164,212	563,593
Indonesia	7	761,183	787,782
Cambodia	6	203,612	N/A
Total: Developing	287	6,459,076	15,508,435
EU 28	112	2,279,365	1,314,928
US	6	498,472	167,223
Total: Developed	118	2,777,837	1,482,151

Sources: WTO, World Trade Statistical Review, 2016; Refers to SITC 84: Articles of apparel and clothing accessories, and does not include footwear.
UNIDO, INDSTAT2, 2017: Refers to ISIC (rev. 4) 14 and 15: Wearing apparel, fur, leather, leather products and footwear.
Note 1: Bangladesh, 1998.
Note 2: China, 2014; Bangladesh, 2011; Vietnam, 2014; Hong Kong, China, 2015; India, 2015; Turkey, 2015; Indonesia, 2015; EU 28, 2015, except Ireland, 2012; Malta, 2011; Slovenia, 2014; US, 2015.

In spite of these trends, there is considerable interest in the prospects for reshoring as well as nearshoring in the apparel industry. A study by consulting firm A.T. Kearney documented over 700 cases of reshoring to the United States in recent years, 12% of these for the apparel industry.[7] Similarly, the U.S.-based Reshoring Initiative documented 75 cases of reshoring to the United States for the textile and apparel industries from 2007 to 2015, resulting in the creation 3,226 jobs.[8] Yet, this does not mean that there was more reshoring than offshoring in the industry—that is, that there was *net* reshoring, in terms of either production or employment. It is instructive in this regard to consider more long-run employment trends in the U.S. industry. From around 1.5 million employees in the 1960s, employment has dropped sharply to well under 200,000 employees in recent years (UNIDO, 2017). This decline resulted in a shortage of skilled operatives as well as technicians to maintain sewing machines, which is argued by industry insiders to be one of the key impediments to reshoring to the United States.[9]

7. A.T. KEARNEY, THE TRUTH ABOUT RESHORING: NOT WHAT IT'S CRACKED UP TO BE (2014). The apparel industry ranked third among industries in this regard. Other industries in the top four were electrical equipment, appliances and components, at 16%; transportation equipment, at 14%; and computers, and electronics at 11%.

8. Robin Anson, *Editorial: Reshoring—A Renaissance for the Textile and Apparel Industries in Advanced Economies or a Passing Fad?*, 180 TEXTILE OUTLOOK INT'L 4 (2016).

9. *Id.*

Yet, a number of reasons have been advanced in favor of reshoring, particularly in light of rising labor costs in many developing countries. These include the potential for reduced transport costs and delivery times, less surplus inventory sold at discounts as production becomes more just-in-time, closer proximity to designers, improved product quality, reduced corporate social responsibility risk, and improved brand image.[10] The last of these are particularly important for luxury brands, for which part of their cachet is their association with a particular country, such as Burberry in the United Kingdom and Brooks Brothers in the US, both of which have reshored apparel production in recent years for this reason.[11] Might such examples of reshoring be spearheading a trend that could significantly affect the overall global division of labor in the industry? One study based on interviews of members of the U.S. Fashion Industry Association in 2014 suggests not, concluding that "it is not realistic to expect a substantial return of apparel manufacturing in the United States at least in the near future."[12] This contrasts sharply with the findings of a survey of apparel sourcing executives and managers, as well as industry participants, undertaken in 2018, featured in the McKinsey and Company report *Is apparel manufacturing coming come?* The survey found that "79 percent of respondents in our survey believe that a step change in nearshoring for speed is highly/somewhat likely by 2025."[13] In terms of the nearshoring of production for sales to the North American market, much of this was expected to be in Central America, but survey respondents replied that they expected fully 30% of such production to be in the United States. The report argues that the economic viability of such nearshoring and reshoring depends critically on the use of new automation technologies in apparel production.

How the dynamic between automation and reshoring plays out depends on the potential of new automation technologies in the industry and the extent to which these could address concerns about the shortage of skilled operatives (in the United States, if not the European Union 28) as well as overcome developing countries' competitive advantage based on lower labor costs. There are a number of potentially relevant technological developments in the industry in this regard, including automated fabric cutting and apparel

10. *Id*.

11. Paul Davidson, *Some apparel manufacturing 'reshoring' to USA*, USA TODAY (July 4, 2013), https://www.usatoday.com/story/money/business/2013/07/04/some-apparel-manufacturing-returns-to-us/2454075/; Pamela Robinson & Linda Hsieh, Reshoring: *A Strategic Renewal of Luxury Clothing Supply Chains*, 9 OPERATIONS MGMT RESEARCH 89 (2016).

12. Sheng Lu, Reshoring Apparel Manufacturing in the United States? Perspectives from Branded Manufacturers and Marketers (BM&M*)*, INT'L TEXTILE & APPAREL ASS'N ANNUAL CONFERENCE PROCEEDINGS, Nov. 2015, at 2.

13. MCKINSEY & COMPANY, IS APPAREL MANUFACTURING COMING HOME? NEARSHORING, AUTOMATION, AND SUSTAINABILITY—ESTABLISHING A DEMAND-FOCUSED APPAREL VALUE CHAIN 8 (2018).

knitting, seamless garments, and 3-D printing. We focus on automated sewing, as it has received the most attention in the industry.

III. AUTOMATION IN THE APPAREL INDUSTRY

While the automobile and electronics industries have been leaders in terms of adopting new automation technologies, particularly robotics, the apparel industry has been a laggard. This is suggested by a summary of a roundtable discussion of over twenty-five apparel sourcing executives hosted in 2016 by the consulting firm McKinsey and Company: "Advances in virtual design, digital printing, robotics, and automation are transforming the way companies in many industries design and make their products. Yet . . . the majority of participants felt that the apparel industry is at a very early stage in terms of adopting these approaches."[14]

The impression of the apparel sourcing executives is confirmed by data from the International Federation of Robotics database. Shown in Table 2 are the number of robots sold in the textiles, apparel, and footwear industries in the ten countries with sales of ten or more robots in any given year between 1993 and 2016. As the database does not provide more detailed breakdown, textiles are grouped together with apparel and footwear, and so the table overstates the use of robots in apparel and footwear, the subject of this study. This is all the more so in that the production of textiles generally lends itself more readily to automation than the production of apparel and footwear, and so a disproportionate share of robots is likely to be in textiles. One must also bear in mind that some of these robots are used in ancillary operations, such as packaging, rather than in direct production.

14. MCKINSEY & COMPANY, THE STATE OF FASHION 2017 44 (2016).

Table 2: Country Unit Sales of Industrial Robots in Textiles, Apparel and Footwear: 1993-2016

	United States	China	Japan	South Korea	Taiwan, China	Germany	Spain	France	Italy	Denmark
1993	0	0	0	0	1	60	12	5	3	0
1994	0	0	0	0	1	139	0	9	29	0
1995	0	0	0	0	13	0	0	7	22	0
1996	0	0	1	0	1	0	0	13	50	1
1997	0	0	12	0	50	18	4	18	50	7
1998	0	0	7	0	0	44	8	10	68	9
1999	0	0	16	0	40	19	12	9	21	21
2000	0	0	12	0	0	28	1	1	46	18
2001	0	0	6	0	0	31	25	7	27	12
2002	0	0	2	0	0	0	10	10	41	5
2003	0	0	10	21	0	0	15	7	25	8
2004	0	0	2	0	0	0	28	4	22	6
2005	0	0	0	12	0	6	1	3	25	9
2006	0	0	6	0	0	10	1	1	23	5
2007	2	2	1	0	0	11	1	0	26	1
2008	7	0	4	1	0	6	10	3	13	3
2009	0	0	0	0	0	14	0	3	0	0
2010	2	6	4	0	0	62	0	2	38	8
2011	11	3	5	0	3	63	1	14	39	37
2012	16	1	0	0	1	19	2	3	16	11
2013	16	1	4	0	174	31	2	8	20	18
2014	20	157	3	2	33	14	1	2	19	22
2015	36	101	6	0	0	23	0	0	33	0
2016	39	133	9	0	0	10	0	0	59	0

Source: International Federation of Robotics, World Robotics, 2017;
Refers to ISIC (Rev. 4) 13, 14 and 15: Textiles, wearing apparel, fur, leather, leather products and footwear.

These qualifications noted, compared with Table 1, China is the only developing country among the top ten apparel exporters that also features in Table 2, and indeed the only developing country in Table 2, aside from Taiwan, China. Sales of robots in China were negligible before 2014, but over 100 robots were sold in these industries each year from 2014 to 2016, a considerably greater number than any other country. In contrast, in both 2015 and 2016, no robots were sold in South Korea, Taiwan, Spain, France, or Denmark. Italy has seen fairly stable annual sales of robots going back to 1994, whereas annual sales have been more variable, though still significant, in Germany. Finally, the United States has seen steady sales increases from 2011 to 2016, though this peaked at just thirty-nine robots in 2016. In sum, while there is significant variation among countries in the sales of robots in the textiles, apparel and footwear industries, these are dwarfed by sales in the automotive and electronics industries.

Why are there so few robots in the apparel industry? Though the cutting of fabrics has been automated to a considerable extent, sewing continues to be predominately done by the familiar process of workers manipulating pieces of fabric by hand through stand-alone sewing machines.

Wages tend to be low in the industry—creating less incentive to automate—but a fundamental impediment is technical. This results from the pliability of fabrics, pieces of which need to be accurately aligned before they are sewn, something the human hand and eye can readily accommodate, but which poses daunting challenges for automation. This challenge is exacerbated by the vast range of apparel products, the rapid changes in product demand (witness fast fashion), the varied properties of different fabrics, and the range of sizes in which any given product must be produced. The implication is that Frey and Osborne's estimates for relevant occupations may be too high, with the qualification that technical developments two decades hence are difficult to anticipate.

To address this issue, we next consider how three companies endeavoring to sew with robots are dealing in very different ways with common technological challenges. These are Sewbo, SoftWear Automation, and Grabit. This enables one to come to a clearer sense of the technological bottlenecks involved than is possible by a global assessment of hundreds of occupations, valuable as that approach may be in its own right. At the same time, a high degree of automation is possible in apparel sewing, even when fabric handling is largely done by hand. In this regard, we also look at MAICA, a company producing semiautomated machinery to sew shirts.

A. Sewbo[15]

Sewbo's approach makes use of conventional, off-the-shelf collaborative robots and sewing machines. Its innovation is not with automation machinery, but rather in the treatment of pieces of fabric, making them temporarily rigid with a water-soluble chemical. After being treated with the chemical, the stiffened pieces of fabric can be provisionally joined with an ultrasonic welder (commonly used to join plastic parts) in preparation for sewing or directly manipulated through a sewing machine by a robotic arm with a suction cup hand. After being sewn, the article of clothing is then rinsed in water, removing the stiffening chemical. In short, Sewbo's approach is to make pieces of fabric similarly manipulable to pieces of metal, thus making apparel sewing akin to a conventional assembly operation that is able to take advantage of the ready reprogrammability of state-of-the-art collaborative robots. Such reprogrammability could, in principle, accommodate the rapidly changing demands of the fashion industry.

15. Sources for Sewbo: SEWBO, http://www.sewbo.com/; Signe Brewster, *A Robot That Sews Could Take the Sweat out Of Sweatshops*, MIT TECHNOLOGY REVIEW (September 22, 2016), https://www.technologyreview.com/s/602423/a-robot-that-sews-could-take-the-sweat-out-of-sweatshops/; Ananya Bhattacharya, *We're Getting Closer to Clothing Made Entirely by Robots*, QUARTZ (October 9, 2016), https://qz.com/788587/were-getting-closer-to-clothing-made-entirely-by-robots/; Parija Kavilanz, *This Robot Makes a T-Shirt from Start to Finish*, CNN MONEY (October 11, 2016), https://money.cnn.com/2016/10/11/technology/robots-garment-manufacturing-sewbo/.

Sewbo claims to be the first company to sew a complete article of clothing, a basic T-shirt. There are some intrinsic limitations to Sewbo's approach in that it cannot work with material that would be damaged by soaking in water nor with waterproof fabric. One textiles and apparel researcher has also expressed reservations about the economic viability of the Sewbo approach, given the costs of the extra steps involved in treating fabrics as well as of chemicals and water. As recently as 2016, Sewbo was literally a one-man operation, yet it also had a pilot project with Bluewater Defense, which produces uniforms for the U.S. military. Important in this regard are rules dating from 1941 requiring that the U.S. Department of Defense purchase uniforms produced in the United States. Such considerations can make attractive investments in sewing robots that would not be otherwise profitable, at least for this sizeable captive market, especially in light of the relatively high labor costs, as well as the scarcity of skilled operatives in the United States.

B. SoftWear Automation[16]

SoftWear Automation is a collaboration with the Georgia Institute of Technology and was supported by an over one million USD grant from the

16. Sources for SoftWear Automation: SOFTWEAR AUTOMATION, http://softwearautomation.com/; The Economist, *Made to Measure: A Robotic Sewing Machine Could Throw Garment Workers in Low-Cost Countries Out of a Job*, ECONOMIST: TECH. QUARTERLY (May 28, 2015), https://www.economist.com/technology-quarterly/2015/05/28/made-to-measure; Kiran Stacey & Anna Nicolaou, *Stitched Up by Robots: The Threat to Emerging Economies*, FINANCIAL TIMES (July 18, 2017), https://www.ft.com/content/9f146ab6-621c-11e7-91a7-502f7ee26895; BOSS Editorial Team, *Sewbots are Coming to a Closet Near You*, THE BOSS MAGAZINE (August 15, 2015), https://thebossmagazine.com/sewbots-are-coming-to-a-closet-near-you/; Lyndsay McGregor, *Are Sewbots the Solution to North America's Lack of Skilled Seamstresses?*, SOURCING JOURNAL (November 16, 2015), https://sourcingjournal.com/topics/technology/are-sewbots-the-solution-to-north-americas-lack-of-skilled-seamstresses-38276/; Gabe Fenigsohn, *The Sewbots are Coming…*, TECHNOSKEPTIC (August 17, 2016), https://thetechnoskeptic.com/sewbots/; Christian Scibetta, *Will Sewbots Bring Denim Manufacturing Back to the US?*, SOURCING JOURNAL (September 14, 2016), https://sourcingjournal.com/denim/denim-brands/walmart-announces-sewbots-automated-jean-machines-cs-96864/; Mark Allinson, *Sewbots Prepare to Take Millions of Jobs off Humans in Clothes Manufacturing Sector*, ROBOTICS & AUTOMATION NEWS (October 1, 2016), https://roboticsandautomationnews.com/2016/10/01/sewbots-prepare-to-take-millions-of-jobs-off-humans-in-clothes-manufacturing-sector/7566/; Bhattacharya, *supra* note 15; Marc Bain, *A New T-Shirt Sewing Robot Can Make as Many Shirts Per Hour as 17 Factory Workers*, QUARTZ (August 30, 2017), https://qz.com/1064679/a-new-t-shirt-sewing-robot-can-make-as-many-shirts-per-hour-as-17-factory-workers/; David Grossman, *This Automated Sewing Robot Can Make Shirts Basically by Itself*, POPULAR MECHANICS (August 31, 2017), https://www.popularmechanics.com/technology/robots/a28021/automated-sewing-robots/; Leonie Barrie, *China Firm to Make T-Shirts in The US Using Sewbots*, JUST-STYLE (September 1, 2017), https://www.just-style.com/news/china-firm-to-make-t-shirts-in-the-us-using-sewbots_id131563.aspx; Erico Guizzo, *Your Next T-Shirt Will Be Made by a Robot*, IEEE SPECTRUM (January 5, 2018), https://spectrum.ieee.org/robotics/industrial-robots/your-next-tshirt-will-be-made-by-a-robot; Christopher Quinn, *Look, No Hands: Atlanta Startup Reinvents T-Shirt with Sewbot*, ATLANTA JOURNAL-CONSTITUTION (March 21, 2019), https://www.ajc.com/business/economy/machines-drive-textile-industry-comeback-bid-south/bLEbIZ3Lrm8anMnYoxjVoL/.

U.S. Department of Defense, whose vested interest in the development of sewing robots is noted above. In contrast with Sewbo, SoftWear Automation designs and builds robots specifically for sewing—Sewbots, the company calls them. The company deals with the challenges posed by the pliability of fabrics through the development of sensors and accompanying visual enhancement software that count individual threads and intersections of threads in fabric. These sensors enable its robots to guide fabrics through conventional sewing machines with a high degree of precision, and the company has also developed robotic sewing machines. Between different sewing operations, pieces of fabric are conveyed along flat surfaces by hovering over small air jets or being slid by robotic arms. SoftWear Automation's systems are able to import files from commonly used pattern design software, facilitating just-in-time product customization and changeovers.

The company's robots are able to perform discrete sewing operations, such as sewing buttonholes or two pattern pieces of denim jeans. The company claims, though, that full-line automation for jeans and button-up shirts is in the offing and has reportedly received $2 million from Walmart for a project to automate the production of jeans. Referring specifically to SoftWear Automation, Walmart's optimistic assessment is that sewing robots will result in "the reshoring of apparel manufacturing in the U.S., and other high labor markets, cutting lead times to consumers, creating in-demand, highly-skilled jobs, and freeing manufacturers from the endless search for low-wage labor."[17]

A key development for SoftWear Automation is the use of its sewing robots in a T-shift factory that will reportedly open in the United States in late 2019. Tianyuan Garments, a large Chinese contract manufacturer producing primarily for Adidas, has reportedly invested $20 million in this factory, which will produce T-shirts in twenty-one fully-automated production lines supplied by SoftWear Automation. It is claimed that costs per T-shirt will rival those of T-shirts produced in such low wage countries as Bangladesh. Yet, this depends on the number of T-shirts produced in a given amount of time, and here, published estimates vary widely. While the production lines may be fully automated, it is also reported that the factory will create 400 jobs ancillary to sewing T-shirts. Even if direct production costs were higher than in low wage countries, the other significant cost and time advantages associated with reshoring noted above could more than offset this, though these may hold less for relatively standardized, low-cost items like T-shirts. The potential implications of its sewing robots for reshoring and the structure of global supply chains is one of SoftWear Automation's selling points, with its website stating that: "SoftWear's fully

17. Scibetta, *supra* note 16.

automated Sewbots allow manufacturers to SEWLOCAL™, moving their supply chains closer to the customer while creating higher quality products at a lower cost." Also telling is the closing caption to the company's demonstration video for T-shirt production: "Redesigning the textile supply chain."

C. Grabit[18]

Grabit developed a robotic hand that uses electroadhesion (a type of static electricity) and can pick up and handle a wider range of objects—including fabrics—than conventional robotic gripper or suction cup hands. When combined with a customized Toshiba Machine robot, Grabit's hand is reportedly able to arrange the pieces for a sports shoe upper 20 times faster than a human, after which the pieces are heat fused. Investors in Grabit include Nike and the Esquel Group, a large manufacturer of button-up shirts for the likes of Ralph Lauren and Tommy Hilfiger, that intends to use the technology to make collars and cuffs. Nike is reportedly installing about a dozen Grabit machines in shoe factories in China and Mexico. Nike's interest in Grabit is motivated at least in part by its interest in shifting production closer to customers in Europe and the United States, with an article in Bloomberg News noting that "Automation factors heavily into Nike's plan to move factories closer to the U.S." (Brustein, *op. cit.*).

D. MAICA[19]

MAICA is an Italian-based company that has been in operation since 1977 and specializes in manufacturing computer-controlled, semiautomated machinery to sew button-up shirts. MAICA was acquired by Jack Sewing Machine, a Chinese company, for €6.5 million in late 2017. According to MAICA's website, the company has four product lines, focusing on collars, cuffs, button fronts, and folding machines. Rather than attempting to overcome the challenges posed by the pliability of fabrics, as with Sewbo and

18. Sources for Grabit: GRABIT, https://grabitinc.com/; Joshua Brustein, *These Robots Are Using Static Electricity to Make Nikes*, BLOOMBERG (August 39, 2017), https://www.bloomberg.com/news/articles/2017-08-30/these-robots-are-using-static-electricity-to-make-nikes; Marc Bain, *Nike Is Investing in Robots that Use Static Electricity to Put Its Shoes Together*, QUARTZ (September 7, 2017), https://qz.com/1070240/nike-is-investing-in-grabits-robots-which-use-static-electricity-to-put-its-shoes-together/; TRR Editor, *Grabit Robots Use Static Electricity to Make Nikes Faster than Humans*, ROBOT REPORT (February 14, 2018), https://www.therobotreport.com/grabit-robots-make-nikes-faster-humans/.

19. Sources for MAICA: MAICA, http://www.maicaitalia.com/company-profile/; Editorial Team, *Jack Acquires MAICA to Develop Intelligent Manufacturing*, APPAREL VIEWS (October 27, 2017), http://www.apparelviews.com/jack-expands-its-intelligent-sewing-profile-by-acquiring-vi-be-mac/.

SoftWear Automation, the company's strategy is rather to work within these constraints, with workers hand-feeding fabrics into a series of machines that break down the shirt-making process into discrete steps. Each machine is specialized for each step, with some of the steps using conventional sewing machines integrated with MAICA's auxiliary machinery.

It might be thought that MAICA's semiautomated approach represents a transitional stage towards fully automated production, but there are good reasons to think otherwise. In Mercedes-Benz and BMW, for example, there has been an increased use of collaborative robots in recent years, with employees working side-by-side with these smaller, safer, and more readily adaptable robots.[20] One study of a BMW plant found that assembly lines with co-bots working alongside workers are more efficient than lines with either workers or robots alone, and this combination is also argued to be better able to accommodate the customized options demanded by customers. Co-bots are reported to soon become the largest selling type of industrial robot.[21] While MAICA's machines may not be robots in the strict sense, the approach of workers working alongside computer-controlled machines may represent a viable path for automation in the apparel industry, perhaps complementing more fully-automated approaches. In this sense, automation in the apparel industry may follow a more evolutionary rather than revolutionary path, based on incremental improvements and application to a wider range of apparel products. MAICA's approach also has the virtue of being market-tested, with their machines being used, for example, in a Zara factory in Portugal—and thus within the European fast fashion market—as well as a shirt factory in Sri Lanka, with each factory reportedly producing thousands of shirts a day. From the employment perspective, the labor-displacing effects and reshoring potential of such semiautomation may also be considerable, whether or not robots are utilized.

IV. APPAREL SUMMARY

The implication of Frey and Osborne's study and other studies using their method is that it is technologically possible for there to be massive job losses in the apparel industry in coming years resulting from computer-controlled automation technologies. In such a scenario, the competitive advantage of developing countries in terms of lower labor costs would be weakened, all the more so in light of the cost and time advantages resulting

20. Samuel Gibbs, *Mercedes-Benz Swaps Robots for People on Its Assembly Lines*, GUARDIAN (Feb. 26, 2016), https://www.theguardian.com/technology/2016/feb/26/mercedes-benz-robots-people-assembly-lines; Frank Tobe, *Why Co-Bots Will Be a Huge Innovation and Growth Driver or Robotics Industry*, THE ROBOT REPORT (Apr. 7, 2016), https://spectrum.ieee.org/automaton/robotics/industrial-robots/collaborative-robots-innovation-growth-driver.

21. Tobe, *supra* note 20.

from the closer proximity of production and consumption. There would be substantially reduced employment for a given quantity of apparel output, accompanied by the reshoring of production towards developed countries, alongside the persistence of production in large developing country markets, most notably in China. Even in the face of a rapidly growing market for apparel, the net effect of such sweeping labor displacement on global employment in the industry would appear negative, based on Frey and Osborne's extremely high estimates of the risk of automation in relevant occupations. In such a scenario, that is, the negative labor displacement effects of automation on employment at the task and establishment levels are unlikely to be offset by positive market expansion effects at the industry level. The possibility of such a scenario is also suggested by the views of management at Sewbo and SoftWear Automation.[22]

It is worth emphasizing that new automation technologies may have negative effects on workers, in addition to job loss. For the threat of automation can also be used to curtail workers' demands regarding working conditions and pay. An example is given in a 2018 article in the *Wall Street Journal*, in which a union leader in Bangladesh stated that factory owners threatened to automate jobs if workers would not agree to management's plans.[23]

In our discussion of MAICA, we suggested that the future of technology in the industry may well be represented by a more collaborative engagement between workers and machines, as also suggested by the increased use of co-bots in such firms as Mercedes-Benz and BMW. If this is true, then the prospects for employment in the industry would be very different. There still may be significant reshoring, but the net effect on global employment in the industry is less clear-cut. And contrary to the expectations about the need for higher-skilled workers noted above, the semiautomated approach may actually require fewer skills and less training than traditional sewing. Production line workers are, after all, largely involved in feeding fabrics into automated sewing machines. This is suggested, for example, by MAICA's website, which states, "A remarkable ease of use allows everyone to use them without difficulty, being able to explore all the features from the very first use."[24] At the same time, MAICA's equipment is all computer controlled, and there are more skilled jobs involved in setting up and adapting this equipment.

At the same time, it is important to emphasize that economic feasibility does not mean that the unit costs of *production* of automated

22. McGregor, *supra* note 16; Kavilanz, *supra* note 15.

23. Jon Emont, *The Robots Are Coming for Garment Workers. That's Good for the U.S., Bad for Poor Countries*, WALL ST. J. (Feb. 16, 2018), https://www.wsj.com/articles/the-robots-are-coming-for-garment-workers-thats-good-for-the-u-s-bad-for-poor-countries-1518797631.

24. MAICA, http://www.maicaitalia.com/company-profile/.

sewing need to be equal to or less than comparable goods produced in low-wage countries. For the closer proximity of production and consumption brings with it a host of other cost and time advantages that can offset higher unit costs of production. This is all the more so, insofar as closer proximity enables just-in-time production, characterized by leaner inventories and lesser reliance on the deep price markdowns that have plagued the industry.

V. THE ELECTRONICS INDUSTRY

Electronics generate more revenue than any other goods-producing sector, accounting for nearly one-quarter of traded manufactured goods globally, and employing an estimated over 18 million workers worldwide.[25] Limited need for co-location between engineers and production means a single product, such as a mobile phone, can contain parts from several firms across multiple countries. Greater tradability led to extensive offshoring, especially of lower value-added activities, such as assembly, towards lower cost countries. In the past quarter-century, Eastern Asia, especially China, and, more recently, South-Eastern Asia, have gained prominence as manufacturing centers, while high value-added core activities such as R&D remained in Western Europe and the United States.[26]

Table 3 shows formal employment and exports for the top ten exporters of electronic products in 2015. Accounting for over 90% of global electronics exports, these countries employed 14.5 million workers in the industry in recent years, over 80% more workers than in 2000. Trends evidence significant reshuffling of global production, with growing shares of exports and greater employment in middle-income countries. Combined, the five emerging countries' share of electronics exports increased from 26% to 58%, while their share of employment among the main electronics exporters expanded from 53% to 77%. China alone accounted for 47% of global exports in 2015, up from 15% in 2000, and employment nearly tripled.[27]

25. Leonhard Plank & Cornelia Staritz, *"Precarious upgrading" in electronics global production networks in Central and Eastern Europe: The cases of Hungary and Romania* (Capturing the Gains, Working Paper 31, Manchester, University of Manchester, 2013); Gale Raj-Reichert, *Promoting decent work in global supply chains: The electronics industry*, *in* SECTORAL STUDIES ON DECENT WORK IN GLOBAL SUPPLY CHAINS (ILO SECTOR, 2016); Timothy Sturgeon & Momoko Kawakami, *Global value chains in the electronics industry: Characteristics, crisis, and upgrading opportunities for firms from developing countries*, 4 INT'L J. TECH. LEARNING, INNOVATION AND DEV. 120 (2011).

26. Sturgeon & Kawakami, *supra* note 25; ILO, SECTOR. *Ups and downs in the electronics industry: Fluctuating production and the use of temporary and other forms of employment* (Issues paper for discussion at the Global Dialogue Forum on the Adaptability of Companies to Deal with Fluctuating Demands and the Incidence of Temporary and Other Forms of Employment in Electronics, Geneva, Dec. 9–11, 2014).

27. China includes Taiwan and Hong Kong.

Employment also increased manifold in Vietnam and Mexico, but whereas the share of exports rose for the former, it remained stable in the latter. Employment expanded, but the export share held steady in Thailand, while both declined in Malaysia. In contrast, the export share of the top high-income countries decreased from 67% in 2000 to 38% in 2015, and their share of employees contracted from 47% to 23%. Declines were most marked in the European Union, Japan, and the United States. Yet, there are concerns over the possibility of reshoring from emerging to high-income countries.

Table 3: Exports and Formal Employees in Top 10 Electronics Exporters

	Exports, 2015 US$, billions	Formal employees, 2000[1]	Formal employees, around 2015[2]
China (incl. Hong Kong and Taiw	935	3,507,848	9,868,596
Mexico	63	28,222	250,275
Malaysia	59	402,470	368,737
Vietnam	47	18,591	410,994
Thailand	35	214,103	297,630
Total: Developing	1,139	4,171,234	11,196,232
EU 28	322	1,254,444	1,092,970
US	141	1,008,717	943,767
Singapore	119	102,320	79,680
South Korea	110	327,218	546,357
Japan	60	989,846	627,677
Total: Developed	753	3,682,545	3,290,451

Sources: WTO, Statistical Database, 2017; Refers to SITC (rev. 3) 75, 76 and 776: Electronic data processing and office equipment, telecommunications equipment, integrated circuits, and electronic components.
UNIDO, INDSTAT2, 2017: Refers to ISIC (rev. 3) 30 and 32: Office, accounting and computing machinery; Radio, television and communication equipment.
Note 1: China, 2003.
Note 2: China, 2014; EU, 2015, except Ireland, 2012, and Slovenia, 2014, and excludes Luxembourg and Malta; Japan, 2013; Mexico, 2013; Thailand, 2011; Vietnam, 2014.

As electronics manufacturing has been pivotal in countries' economic development processes, reshoring could have important implications for future development prospects. At the same time, in electronics specifically, A.T. Kearney suggests that offshoring—to China and other Asian countries, as well as nearshoring to Mexico—continues to outweigh reshoring.[28] Ultimately, location choices made by profit-seeking entities are complex decisions that consider, among other factors, the potential of new automation technologies, and whether reshoring would trump emerging countries low-cost labor advantage. Importantly, the production of electronics involves distinct processes in the manufacture of

28. A.T. KEARNEY, *supra* note 7.

components and assembly of final products, each with unique technological needs and bottlenecks. This study focuses mainly on electronics assembly, as this is predominant in emerging and developing economies.

VI. AUTOMATION IN THE ELECTRONICS INDUSTRY

The electronics industry has been a leader in technology adoption. In 2015, 14.2% of all industrial robots sold globally was for the electronics industry, while the industry accounted for 13% of the total stock of industrial robots.[29] Research by the International Federation of Robotics (IFR) suggests that the electronics industry will continue to drive robot use in coming years and may surpass the automotive industry in the number of installed robots by 2021.[30]

Many of the jobs in electronics assembly are low-skill, repetitive jobs, often deemed most susceptible to automation, but nonflexible, high-cost robot solutions have constrained automation. The manufacture of electronic products necessitates handling small and fragile parts, put together in compact, tightly-packed products. In addition, rapid technological progress has led to short product life cycles. These bottlenecks create the need for adaptable and reusable robots fitted with force and vision sensors to improve the handling of miniaturized parts, allowing costs to be amortized over longer periods of time.

Increasingly, robot manufacturers are developing new solutions. Flexible robots are at the forefront of these trends, both in terms of traditional and collaborative robots (or co-bots). Flexible robots are typically a robotic arm with multiple axes of movement and interchangeable heads that can perform a variety of tasks.[31] In particular, co-bots are usually configured with a series of sensors that, together with flexibility of movement, allow for quick reprogramming and reconfiguration and remove the need for safety barriers between machines and workers. Vision sensors and high precision grippers allow for greater accuracy in the picking and placing of parts, permitting flexible feeding solutions in response to the challenges of unsorted presentation of parts, which remains a barrier to electronics manufacturing automation. In turn, force sensors are ever more important as electronics miniaturize and delicate parts need to be handled. Force sensors improve tactile feedback and allow robots to "feel" their way into assembly, adjusting

29. Electronics includes ISIC Rev 4 codes 260-63.
30. IFR, WORLD ROBOTICS 2018, INDUSTRIAL ROBOTS (2018).
31. Cory Roehl, *Know YourMmachine:Iindustrial Robots vs. Cobots*, UNIVERSAL ROBOTS (Oct. 12, 2017), https://blog.universal-robots.com/know-your-machine-industrial-robots-vs.-cobots; Andrew Shakely, *Hard vs. Flexible automation*, NUTEC GROUP (Dec. 19, 2014), https://www.nutecgroup.com/news/hard-vs-flexible-automation.

force in response to a dynamic assembly process, according to Christopher Blanchette, FANUC Robotics America Corp.[32]

Most leading robot manufacturers now offer collaborative robots, frequently targeting electronics assembly. In 2014, ABB launched YuMi, a two-arm co-bot designed specifically to handle small parts, such as mechanical components for smartphones, tablets, and other consumer electronics.[33] Kuka's LBR iiwa allows for the automation of complex assembly tasks and direct cooperation with workers, and is advertised as a solution to electronics manufacturing. Other firms such as Rethink Robotics and Universal Robots also produce and market co-bots specifically for use in the electronics industry.

These and other machinery manufacturers also continue to develop smaller and lighter traditional industrial robots for the electronics industry. In 2016, Kuka launched KR 3 Agilus, which involved Chinese electronics manufacturers in the development phase, with the intention to target electronics manufacturing in the Chinese and Asian markets.[34] Kuka's robot can, for instance, fasten screws with a diameter head of 1.4mm, common in mobile phones and other hardware, as well test keyboards, which is traditionally done manually by workers. There is also a new generation of four axes selective-compliance-articulated robot arms (SCARA) and other types of robots for use in electronics assembly.[35] This new generation of robots can increasingly perform tasks such as mounting small objects, gluing, setting very small screws in place, machine tending, and circuit board testing, among others.

A contraction in employment and an increased ratio of robots per thousand workers in the electronics industry of high-income countries—e.g. doubling in Europe and tripling in the United States between 2005 and 2015—suggests some automation has occurred in these countries.[36] In contrast, technology adoption has not prevented employment expansion in emerging countries, where both employment and robot usage have increased. Still, the use of robots in assembly remains limited. Production processes, technical challenges, and the state of automation in electronics is distinct

32. Bennett Brumson, *Robotics in Electronics*, ROBOTICS INDUS. ASS'N (June 8, 2011), https://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/Robotics-in-Electronics/content_id/2811.

33. Tanya Anandan, *Small assembly robots with big gains*, ROBOTICS INDUS. ASS'N (Sept. 28, 2015), https://www.robotics.org/content-detail.cfm/Industrial-Robotics-Industry-Insights/Small-Assembly-Robots-with-Big-Gains/content_id/5708.

34. Kuka Robot Group, *Robotic Automation in the Electronics Industry: Kuka Talks Trends*, YOUTUBE (Mar. 30 2017), https://www.youtube.com/watch?v=IwzUWLEgxvw&feature=youtu.be%20published%2030%20March

35. John Sprovieri, *Next-Gen SCARA Robots*, ASSEMBLY MAGAZINE (Apr. 2, 2018), https://www.assemblymag.com/articles/94230-next-gen-scara-robots.

36. It is worth noting that the top ten electronics exporters in 2015 accounted for over 95% of the global stock of robots in electronics that year.

between the manufacture versus assembly of components. A closer examination of the stock of robots in electronics by subsector reveals that although the stock of robots increased markedly overall, they are much more predominant in components.[37] Worldwide, there are over three times as many robots used in the production rather than the assembly of electronics components. Robots for the production of electronics components comprised 67% of all industrial robot purchases in the industry between 1996 and 2016. In 2016, such robots accounted for over 75% of the industrial robot stock in the industry. Moreover, assembly robots are highly concentrated in a few countries.

Table 4 shows annual purchases of robots for electronics assembly for the top ten largest markets in the period 1996-2016, all of which are amongst the top 2015 exporters in Table 3. Eight of the ten are high-income economies and the top three countries—namely Japan, South Korea and China, including Hong Kong and Taiwan—purchased 90% of robots for electronics assembly over these two decades. These economies drove the global stock of assembly robots to double between 2010 and 2015. The number of robots in middle-income exporters (except China) remains very limited and the industry remains labor-intensive.

37. Components relates to ISIC Rev 4 codes 260 (manufacture of electronic components and devices) and 261 (semiconductors, LCD, and LED) whereas assembly encompasses ISIC Rev 4 codes 262 (computers and peripheral equipment) and 263 (information and communications equipment domestic and professional without automotive parts), as defined in IFR, WORLD INDUSTRIAL ROBOTS 2017 (2017).

Table 4: Country Unit Sales of Industrial Robots in Electronics: 1996-2016

	China	Finland	Germany	Italy	Japan	Malaysia	South Korea	Taiwan, China	United Kingdom	United States
1996	0	3	0	50	5,836	0	0	0	35	0
1997	0	0	0	70	6,287	0	0	0	70	0
1998	0	0	0	15	4,503	0	0	0	10	0
1999	0	42	0	17	4,915	0	0	0	21	0
2000	0	67	0	68	5,070	0	0	0	67	0
2001	0	52	0	89	980	0	649	0	5	0
2002	0	22	0	79	212	0	0	0	10	0
2003	0	22	77	77	42	0	491	0	11	0
2004	0	20	92	62	669	0	626	0	11	0
2005	0	123	136	8	3,041	0	49	0	4	0
2006	0	2	59	2	1,850	0	1,473	0	4	0
2007	0	2	154	1	863	0	677	0	8	0
2008	0	0	20	0	659	0	806	0	0	16
2009	56	0	50	21	198	49	715	115	2	84
2010	12	3	87	13	1,200	320	1,075	214	0	58
2011	114	8	53	8	1,388	202	2,948	80	3	55
2012	439	9	120	29	908	209	2,739	699	1	198
2013	1,669	2	91	7	747	216	2,158	2,542	2	234
2014	1,937	2	103	35	1,284	19	914	3,461	23	136
2015	2,309	0	161	0	1,686	0	4,544	0	0	400
2016	2,735	0	24	0	630	0	4,908	0	0	72

Source: International Federation of Robotics, World Robotics, 2017;
Refers to ISIC (Rev. 4) 262 and 263: Computers and peripheral equipment, information and communications equipment domestic and professional without automotive parts.

To better understand the state of the industry and how it has evolved in the past few years, we explore publicly available information on two large players. Looking beyond task and occupation-based automation risk assessments, our examination of developments in Hon Hai Precision Industry (i.e. Foxconn) and Samsung Electronics' production strategies allows us to get a better grasp on the extent to which technology has been adopted in electronics assembly and whether there are signs of a rearrangement of global production.

A. Foxconn[38]

Foxconn is the world's largest electronics contract manufacturer, with over 1 million workers employed. The company's interest in automation

38. Sources for Foxconn: Gulveen Aulakh, *Foxconn's Next India Facility to be in Navi Mumbai*, ECON. TIMES, Nov. 4, 2016; Gulveen Aulakh, *Committed to investing $5 billion in Maharashtra: Foxconn*, ECON. TIMES, Feb. 17, 2018; BAIN & COMPANY, LABOUR 2030: THE COLLUSION OF DEMOGRAPHICS, AUTOMATION AND INEQUALITY (2018); David Barboza, *Before Wisconsin, Foxconn vowed big spending in Brazil. Few jobs have come*, N.Y. TIMES, Sept. 20, 2017; Alain Clapaud, *Robots*

led it to announce in 2011 plans to deploy 1 million robots in the following three years and, by 2015, it had an estimated 50,000 robots in operation. The push towards automation continues. Foxconn's handbook for the 2018 general shareholder's meeting revealed plans to invest over $300 million in Internet of Things, artificial intelligence, and robotics research in the next five years. There have also been reports of significant technology-driven layoffs. A recent study by Bain & Company reports that Foxconn replaced 60,000 factory workers with robots due to declines in robot prices and higher wages in China, though there is skepticism as to whether these were indeed related to automation. Foxconn's general manager for automation technology, Day Chia-peng, stated in a recent interview: "The majority of our production lines employ a mix of automated stations and manual operations for the various process steps and we expect this to remain the case for the foreseeable future." This suggests that significant technological bottlenecks in assembly remain and that instead of full automation, new technologies will lead to teams of robots and workers, as in the examples of MAICA and BMW discussed above.

Although the majority of its production capacity is in China, Foxconn has taken steps to invest in production in high-income countries. In July 2017, Foxconn signed a Memorandum of Understanding (MoU) with the Government of Wisconsin in the United States, announcing plans to invest $10 billion and create up to 13,000 jobs. It is, however, unclear whether the plans will materialize. In early 2019, it was reported that Foxconn was reconsidering plans to build an LCD display factory, citing high costs of assembling television screens in the United States and suggesting it would instead invest in an R&D facility. At the same time, the firm has also made plans to continue to invest in emerging economies. For instance, in August 2015, Foxconn signed a MoU with the Maharashtra Government in India, to invest $5 billion, creating a minimum of 50,000 jobs within five years. Early 2018 reports indicate the promise had not yet concretized, even though the firm invested in other parts of the country. More recently, in 2019, several news articles report Foxconn is making further investments in India and will start to produce iPhones in the country.

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will do 70% of the work in Foxconn factories by 3 years, 4EREVOLUTION (Mar. 1, 2015), http://www.4erevolution.com/en/foxconn-robots-2018/; THE ECONOMIST INTELLIGENCE UNIT, THE AUTOMATION READINESS INDEX: WHO IS READY FOR THE COMING WAVE OF AUTOMATION? (2018); Julia Horowitz, *It's official: Foxconn will get $3 billion to build a plant in Wisconsin*, CNN (Sept. 19, 2017), https://money.cnn.com/2017/09/18/news/scott-walker-signs-foxconn-deal/index.html; Kensaku Ihara, *Foxconn plots $4bn automation push as labor costs bite*, NIKKEI ASIAN REV. (Feb. 24, 2018), https://asia.nikkei.com/Asia300/Foxconn-plots-4bn-automation-push-as-labor-costs-bite; Yang Jie, Yoko Kubota & Newley Purnell, *Foxconn looks beyond China to India for iPhone assembly*, WALL ST. J., Jan. 22, 2019; Danielle Paquette, *Foxconn scraps plan to build factory in Wisconsin, will hire white-collared workers instead*, WASH. POST, Jan. 30, 2019; Anandita Singh Mankotia, *Wistron, Foxconn to invest Rs 7,500 cr over five years in India*", ECON. TIMES, Feb. 12, 2019; Gabriel Wildau, *Foxconn unit rises by maximum 44% in Shanghai trading debut*, FIN. TIMES, June 8, 2018.

B. Samsung Electronics[39]

Unlike many of its competitors, Samsung Electronics retains significant manufacturing capacity. The company owns and operates several factories and thus relies less on outsourcing than many other firms in the industry. Publicly available information on the firm's mobile phone production suggests it may not yet make economic sense to automate assembly. It is reported that the majority of production takes place in emerging countries—including Brazil, China, India, and Vietnam—with only about 8% of phones estimated to be manufactured in South Korea, in spite of very advanced technological capabilities in South Korean facilities. According to recent reports:

> "Manufacturing in Gumi [in the South Korea] is more robotic than assembly by hand: It takes just 13 minutes for 14 giant machines to join a circuit board and battery, slip it behind a display, and seal it all into a glass and metal housing. It takes 30 minutes total to make the phone, counting the time required to install the operating system. In that time, only two or three people actually handle any given phone." Jeremy Kaplan, of digitaltrends.com reporting on Samsung's Gumi factory.

Therefore, it appears that technological advancements could allow for a high degree of automation in mobile phone assembly, but low-cost labor-intensive assembly remains economically advantageous. A 2015 study calculated that the processing cost per Samsung Electronics mobile phone in Vietnam was equivalent to 30% of the cost in South Korea. It is estimated

39. Sources for Samsung: Why Samsung of South Korea is the biggest firm in Vietnam, ECONOMIST, Apr.12, 2018; Jeremy Kaplan, Samsung punches back: With Galaxy S8, comes back stronger and better than ever before, DIGITAL TRENDS (Mar. 29, 2017), https://www.digitaltrends.com/mobile/behind-scenes-samsung-designed-built-galaxy-s8-s8/; Keun Lee & Mosuup Jung, Overseas factories, domestic employment and technological hollowing out: a case study of Samsung's mobile phone business, 151 REV. WORLD ECON. 461 (2015); Cho Jin-young, 50% of Samsung mobile phones made in Vietnam, BUSINESS KOREA (Jan. 28, 2015), http://www.businesskorea.co.kr/news/articleView.html?idxno=8785; Dane O'Leary, Where are smartphones made?, ANDROID AUTHORITY (Aug. 5, 2016), https://www.androidauthority.com/where-smartphones-are-made-707989/; SAMSUNG, SUSTAINABILITY REPORT 2018 (2018); Samsung, Samsung inaugurates world's largest mobile factory in India; Honorable Prime Minister Shri Narendra Modi flags-off 'Make for the world,' SAMSUNG NEWSROOM INDIA (July 9, 2018), https://news.samsung.com/in/samsung-inaugurates-worlds-largest-mobile-factory-in-india; Samsung, Samsung shows dedication to IoT with $1.2 billion investment in R&D, SAMSUNG NEWSROOM U.S., (June 21, 2016), https://news.samsung.com/us/samsung-electronics-internet-of-things-planning-1-2-billion-for-u-s-research-and-development-of-iot/; Samsung, Samsung Austin semiconductor continues central Texas growth with more than $1 billion in investment, SAMSUNG NEWSROOM U.S. (Nov. 1, 2016), https://news.samsung.com/us/samsung-austin-semiconductor-sas-continues-central-texas-growth-with-more-than-1-billion-in-investment/.

that the firm's factories in Vietnam produced over 50% of Samsung Electronics smartphones, and employed over 100,000 people in 2017—almost 60% of all employees in Asia (excluding South Korea). And the company continues to invest in manufacturing capacity in emerging countries. In July 2018, Samsung Electronics opened the world's largest mobile phone factory in India. At the same time, in 2016, the company announced investments of over $2 billion in the United States on Internet of Things R&D and a semiconductor factory. This indicates a preservation of the traditional international division of labor, whereby high value-added, technology-intensive activities (requiring less labor) remain in higher-cost locations, while (more labor-intensive) assembly is done in low-cost areas.

VII. ELECTRONICS SUMMARY

New technologies and their potential impact on employment feature prominently in public debates. Concerns over job losses stem from estimates based on the idea that jobs characterized by high incidence of repetitive tasks are most susceptible to automation. In such a context, employment in labor-intensive electronics assembly in middle-income countries is deemed at high risk of technological unemployment. Assembly workers would be in competition with automation in their own countries, as well as in high-income economies, which could lead to reshoring. Fears are heightened by rising sales and stock of robots in the electronics industry, especially in high-income countries. The existence of Samsung Electronics' highly automated mobile assembly plant in Gumi suggests that new technologies are increasingly capable of performing many of the assembly tasks traditionally done by hand, further corroborating the negative outlook on job displacement and reshoring. But our research indicates that there are several caveats to a scenario in which robots replace workers in fully automated assembly lines.

The majority of robots in the electronics industry are for the manufacture of components, rather than assembly, which have distinct technical needs and challenges. Moreover, despite advanced technical capabilities in South Korea, Samsung Electronics assembles over 90% of mobile phones in labor-intensive low-cost locations. It thus appears that, currently, it does not make economic sense to adopt emerging automation technologies for electronics assembly and that the comparative advantage of low-cost labor persists. In addition, Foxconn's general manager for automation technology has stressed that for the foreseeable future, robots and workers will continue to collaborate on the shop floor. This indicates that technological bottlenecks related to requirements such as flexibility and tactile dexterity have not yet been fully remedied. It is also possible that electronics assembly automation takes the shape of labor augmentation rather than displacement. It has been found that in the heavily automated automotive manufacturing, teams of robots and workers perform better than teams of workers or robots alone, as highlighted above.

Technology availability is not the only factor favoring the permanence of electronics assembly in middle-income countries. Previous research indicates that a significant movement of electronics manufacturing back to Europe and the United States is unlikely.[40] Industry experts suggest that it would currently not be possible to achieve the same speed of production in Europe or the United States as is possible in China. Well-established Asian manufacturing hubs cluster suppliers, skills, and infrastructure that may be hard and costly to replicate. Distance from the Asian supply chain has been cited as one of the factors threatening the promised LCD display factory in Wisconsin.[41] The importance of clusters is also evident in the months-long delay in the assembly of Apple computers in Texas, due to the contractor's inability to procure sufficient U.S.-made screws.[42] In addition, a growing trend to keep production close to customers could eventually lead to some reshoring, but it could also support electronics production in emerging and developing countries with expanding markets. In Asia, rising labor costs in China provide opportunities to countries such as India and Vietnam, with relatively low labor cost and sizable domestic markets.

It is also important to note that the impact of greater automation on workers is not only restricted to job displacement, but also affects working conditions and compensation. It has been argued that robots may improve workers' welfare by performing dirty, dull, and dangerous tasks.[43] On the other hand, the presence of robots can increase pressure on the pace of workers, as has been observed in robot-worker collaboration in warehousing.[44] Greater use of automation technologies in assembly lines could also reduce the number of workers or their working hours, with potentially negative consequences on earnings. These are critical concerns in the assembly of electronics, where poor working conditions have made headlines on multiple occasions, including for issues related to under

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40. Chang & Huynh, *supra* note 2.

41. Valerie Bauerlein, *Foxconn tore up a small town to build a big factory—then retreated*, WALL ST. J., Apr. 29, 2019.

42. Jack Nicas, *A tiny screw shows why iPhones won't be 'assembled in U.S.A.'*, N.Y. TIMES, Jan. 28, 2019.

43. Charlotte Shea, *Robots tackling the three D's of industry*, ROBOTIQ (Aug. 17, 2016), https://blog.robotiq.com/robots-tackling-the-three-ds-of-industry.

44. Radhamadhavan Madhavan, Ludovic Righetti & William Smart, *The Impacts of Robotics and Automation on Working Conditions and Employment [Ethical, Legal, and Societal Issues]*, 25 IEEE ROBOTICS & AUTOMATION MAGAZINE 126 (2018).

compensation.[45] This is even more crucial given that many of the countries with large electronics assembly industries are not signatories to international conventions on freedom of association and collective bargaining.[46]

VIII. CONCLUDING REMARKS

Mindful of the alarmist concerns accompanying the current wave of automation, the ILO Director General's report on the future of work asks "whether the unfurling technological revolution . . . is so far-reaching in its labour-replacing potential that it is inherently different from what has been experienced in the past, and on balance is an inhibitor rather than a generator of decent work."[47] Much of concern about new automation technologies and jobs is based on a narrow emphasis on substitution effects at the task level, but technology affects jobs no less importantly through complementarity effects, market expansion effects, income effects, and input-output production linkage effects with associated income-induced effects. These effects can play out in different directions at different levels of aggregation—that is, at the task, enterprise, industry, and economy-wide levels—such that negative substitution effects at the task level can be offset, for example, by complementarity and market effects at the enterprise and industry levels.[48] The cases of MAICA semi-automated machinery in the apparel industry and collaborative robots in the electronics industry suggest potentially significant complementarities between machines and workers, and both industries are also experiencing rapid market expansion.

Yet, as noted above, even focusing on substitution effects at the task level can yield widely different results, as exemplified by the studies of Frey and Osborne versus Arntz et al.[49] We have also seen that robots—the archetype of computer-controlled automation—are overwhelmingly concentrated in richer, developed countries. Insofar as developing countries have a greater extent of more readily-automatable work, the geographical distribution of robots is the opposite of what one would expect if technological considerations were decisive in their deployment.

45. Jamie Condliffe, *Foxconn is Under Scrutiny for Working Conditions. It's Not the First Time,* N.Y. TIMES, June 11, 2018.

46. Such as International Labour Organization (ILO), Freedom of Association and Protection of the Right to Organise Convention, July 9, 1948, Convention No. 87; and No. 98, ILO, Right to Organise and Collective Bargaining Convention, July 1, 1949, Convention No. 98..

47. ILO DIRECTOR GENERAL, THE FUTURE OF WORK CENTENARY INITIATIVE (2015).

48. For valuable discussions on these issues, see David Autor, *Why Are There Still So Many Jobs? The History and Future of Workplace Automation*, 29 J. ECON. PERSPECTIVES 3 (2015); Flavio Calvino & Maria Enrica Virgillito, *The Innovation-Employment Nexus: A Critical Survey of Theory and Empirics*, 32 J. ECON. SURVEYS 83 (2017).

49. *Id*.

Our approach differs from these studies in taking a more shop floor perspective, focusing on companies that are makers and users of new automation technologies in the apparel and electronics industries. This leads us to conclude that the technological bottlenecks to the implementation of new automation technologies are often underestimated. In apparel sewing, a key challenge in using robots results from the pliability of fabric, pieces of which need to be accurately aligned before they are sewn—something workers can readily accommodate, but robots cannot. In the electronics industry, the use of robots is increasing rapidly, particularly for the production of components. Yet, substantial technological bottlenecks remain to the use of robots in electronics assembly, regarding such operations of picking up the correct part among an assortment of parts and inserting small flexible parts into tightly-packed consumer electronics, challenges that are exacerbated by the short product cycles of such electronics.

There is also an ambiguity in empirical studies of the effects of new automation technologies, depending on whether they estimate potential labor displacement at the level of jobs vs. working hours spent on readily automatable versus non-readily automatable tasks for a given job. The automation of these tasks could result in pressure for fewer working hours for any given worker, or, the consolidation of non-readily automatable tasks among fewer workers. Though one must exercise caution in taking the estimates of these various studies at face value, the point remains that translating the share of working hours that are potentially automatable into the share of jobs that are potentially automatable is ultimately a contestable social rather than narrow technological consideration. New automation technology can impact the quality as well as the quantity of jobs, as suggested by the examples of collaborative robots being associated with greater work intensity and the threat of automation being used to counter workers' demands for better working conditions and pay.

As for the reshoring or nearshoring of production back towards developing countries, the evidence does not at present suggest a decisive trend.[50] At the same time, it would be rash to be dismissive of concerns over future reshoring, for the costs and capabilities of new automation technologies are rapidly evolving, while labor costs in many developing countries are rising. Nor is this issue reducible to unit costs of production—for reshoring provides other potential benefits, including more just-in-time production that is particularly important for the marketing strategy of the fast fashion segment of the apparel industry. Should reshoring become a significant trend, developing countries will be faced with a new set of challenges, including the need to strengthen skills policies so that workers

50. Koen De Backer, Carlo Menon, Isabelle Desnoyers-James & Laurent Moussiegt, *Reshoring: Myth or Reality?* (OECD Science, Technology and Industry Policy Papers No. 27, 2016); UNCTAD, *Robots and Industrialization in Developing Countries* (Policy Brief No. 50, 2016).

are employable in other activities, and to increase aggregate demand to offset the decline in foreign direct investment. In terms of development strategies, substantial reshoring could also limit the scope for integrating into global supply chains and export-oriented growth more generally.