Appendix I. Multiple National Surveys

National surveys use different sampling methods and income definitions, delivering considerably different income inequality estimates. For example, Japan's NSFIE excludes some households and some income items, while Japan's CSLC includes students' households and more of the elderly. OECD (2012) reports that, due to the differences between surveys, NSFIE's measures of income inequality are lower than those reported by national studies based on CSLC. OECD measures of income inequality are estimated with CSLC data and are in between those from CSLC and NSFIE. Similarly, poverty rates as measured by the OECD are similar to those from national estimates based on CSLC, while both OECD and CSLC report higher poverty rates than NSFIE.

Table 1. Databases and National Surveys

Database	Time Period	Sample Size	Notes	Source
National Family Income and Expenditure Survey (NSFIE)	Every 5 years. Statistical tables available for 1999, 2004, 2009, and 2014.	57,000 households. Household head is defined as main earner.	In 2009, there is only Gini data for two-or-more-person households, and workers households. No Gini data for one-person household or total household available in 2009. Executives are not included in workers' households. Period when most workers receive bonus is not included. Specific survey period (two-or-more person households: from September to November, one-person households: from October to November) can cause bias reflected by seasonality. 13 percent of surveyed households have annual income below 3 million yen (2009).	Japan's Statistics Bureau
Comprehensive Survey of Living Conditions (CSLC)	Large scale every 3 years, small scale surveyed in interim year of large scale year.	About 290,000 households surveyed. For income and savings portions, about 30,000 households surveyed. Household's head is defined as the reported household's head.	Proportion of single-person households was lower in CSLC than other statistics (suggesting one-person households are underrepresented in CSLC). Does not replenish when survey is refused. Average age of household's head is higher in CSLC than NSFIE. CSLC has larger share of three-or-more-person household and lower share of one-person household. 32 percent of surveyed household have annual income below 3 million yen (2010).	Ministry of Health, Labour and Welfare
OECD Income Distribution Database	Latest year with data available varies by country. Starting from December 2017, the OECD Income Distribution Database is updated 3 times per year.	Data available for total population, working age population (18-65 years old), and retirement age population (above 65 years old).	Japan Gini data available as of 2012 only.	OECD measures of income inequality are estimated with CSLC data and are in between those from CSLC and NSFIE. Poverty rates from OECD are similar to those from national estimates based on CSLC, while both OECD and CSLC report higher poverty rates than NSFIE.
OECD Wealth Distribution Database	Latest year with data available varies by country.	Data available for total population only.	Data begin in 2003 with few data points across all countries.	
Social Indicator by prefecture	Data are available annually.		Data on income decile by prefecture were discontinued in 2009.	Japan's Statistics Bureau

Source: IMF staff compilation.

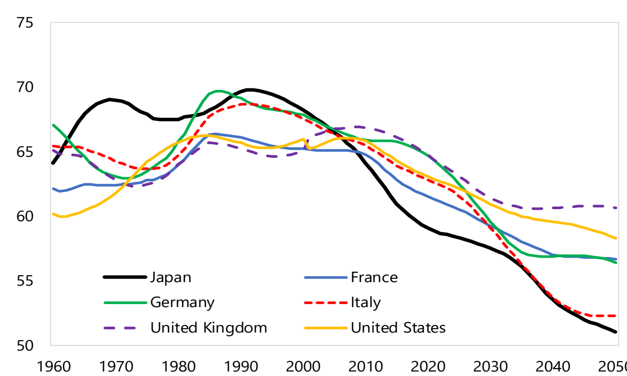
JAPAN—MACROECONOMIC IMPLICATIONS OF AUTOMATION[1]

The rapid decline of Japan's work force, together with the thus far limited influx of foreign labor, create a powerful incentive for automation to help address an already serious labor shortage. This chapter assesses the macroeconomic implications of automation in a Japan-specific context, taking particular account of its aging and declining population. We find that automation could help compensate for shrinkage of the labor force, and may increase overall output growth. As the country has successfully embraced automation in the manufacturing sector, a new wave of automation could potentially unlock productivity gains (especially in the services sector) and help circumvent labor shortages and their negative effect on growth. However, low-skilled and female workers with greater job substitutability may be adversely affected, and policy measures will be needed to address such distributional consequences.

A. Introduction

1. **Japan's rapidly shrinking labor force poses a direct threat to its future economic growth and productivity.** Japan's severe demographic challenges are well known—possessing the fastest decline of total and working age population among its economic peers. The Population Division of the U.N. Department of Economic and Social Affairs estimates that by the century's end, Japan could lose 34 percent of its current population and labor force. Concurrent with this nominal decline, the population is also aging rapidly. Nearly a third of all Japanese citizens were older than 65 in 2015, and this will rise to near 40 percent by 2050, according to the National Institute of Population and Social Securities Research.

Labor Force Participation in Selected Advanced Economies



Source: United Nations, *World Population Prospects: 2017 Revision*.

2. **The Japanese government has embraced automation and AI technology as a pillar of economic revitalization and help in addressing strong demographic headwinds.[2]** The government's 2014 Japan Revitalization Strategy, envisaged a "New Industrial Revolution Driven by Robots." A 'Robot Revolution Realization Council,' comprising field experts and government officials,

[1] Prepared by Gee Hee Hong and Todd Schneider (both APD).

[2] "Automation" in this paper refers to the use of technology—including robots, information and communications, and artificial intelligence (AI)—to substitute for or augment human labor.

subsequently introduced 'Japan's new robot technology' in 2015.[3] The strategy promotes the utilization and dissemination of robots across Japan and seeks to globally standardize Japan's robot technologies. This vision was codified in the government's 'Society 5.0' initiative.[4] The initiative highlights health care, mobility, infrastructure, and FinTech as sectors that are both sensitive to demographic trends and where there needs to be a focus on integration of robot and AI technology.

3. This chapter assesses the macroeconomic implications of automation in Japan. Against the backdrop of Japan's aging and shrinking work force, two questions are addressed: First, how much has automation in the industrial sector influenced productivity and labor market dynamics in Japan? Second, what could be the influence of a second wave of automation—i.e., expanding into non-manufacturing activities—with respect to labor market outcomes and growth? For both questions, the distributional consequences across skill type and gender are also considered.

4. This chapter is structured as follows: Section B provides an overview of automation technology and its relevance in the context of Japan. Section C describes the penetration of industrial robots in Japan and analyzes its impact on local productivity and the labor market. Section D discusses robots and automation in non-manufacturing (service sectors) in Japan. Section E presents a model-based results on the potential implication of automation in sectors with the demographic features. Section F discusses policy implications.

B. Overview of Automation and its Prospects in Japan

5. The global trend toward greater use of automation—by robots, artificial intelligence, or information and communications technology—is well recognized. Particularly in advanced economies, the specter of automation replacing human labor in some tasks and processes has raised concerns about the future of jobs and wages. There has been dramatic progress in recent years in AI and robotics and their application in a diverse set of areas. Some observers have raised concerns regarding how automation and AI technology will adversely affect the labor market—reducing wages and employment (Acemoglu and Restropo, 2017). Others have highlighted the likelihood of job creation, however, and that the current wave of technological change is not vastly different from other periods of innovation and adjustment (Borland and Coelli, 2017). In addition, automation is likely to have distributional consequences, as it will disproportionately affect workers in more automatable occupations while benefiting workers in non-automatable occupations (Autor, 2015; Berg, Buffie, Zanna, 2018).

6. However, the implications of automation may not be uniform across countries. Country-specific factors, such as demographics, the level of human capital, the advancement of automation technology, and its dissemination in the economy can influence how automation will affect labor markets, productivity and income. The distributional effect of automation will be influenced by various factors such as industry composition, level of human capital, the degree of

[3] New Robot Strategy by the Headquarters for Japan's Economic Revitalization available at (http://www.meti.go.jp/english/press/2015/pdf/0123_01b.pdf)

[4] Details of 'Society 5.0' available at the Cabinet Office: (http://www8.cao.go.jp/cstp/english/society5_0/index.html)

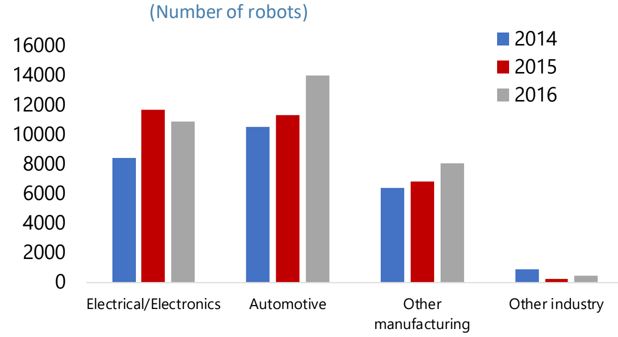
labor market duality across workers with different skill sets, and availability of education to train workers with skills to benefit from the new technology and its redistributive effects.

7. Japan's adverse demographic trends makes it a unique and important laboratory to understand the opportunities and challenges of future automation. With a limited influx of foreign workers (which might otherwise mitigate the effects of a declining labor force), automation may yield greater benefits in Japan than in other countries with different circumstances. Automation technology, even those that are labor-saving, could be a promising channel to offset a shrinking work force and prevent overwork. It will be particularly useful in sectors that are expected to have greater demand in an aging society such as health care, logistics/transportation, delivery and accommodation. On the other hand, Japan's significant degree of labor market duality and the state of investment in human capital investment suggest that the distributional cost entailed with automation technology may not be negligible.

C. Industrial Robots and Their Impacts on Productivity and Labor Market

8. Japan is the world's predominant robot manufacturer, with by far the highest level of global shipments/sales, and has high robot density. Robots have been used in industrial settings in Japan—particularly in the automotive, electrical, and electronics industries—since the early 1980s. For instance, about 700,000 industrial robots were used worldwide in 1995, 500,000 of them in Japan. Japan has been one of the most robot-integrated economies in the world. One metric often used to refer to the penetration of robots into manufacturing sector is 'robot density' – measured as the number of robots relative to humans (either number of hours worked or number of workers). Japan had the highest robot density until 2010, when Korea's use of industrial robots surged and Japan's industrial production increasingly moved abroad. Japan is also a leader in producing robots, responsible for about 52 percent of global robot production in 2016.

Japan: Industrial Robot Usage by Industry
(Number of robots)



Source: International Federation of Robotics

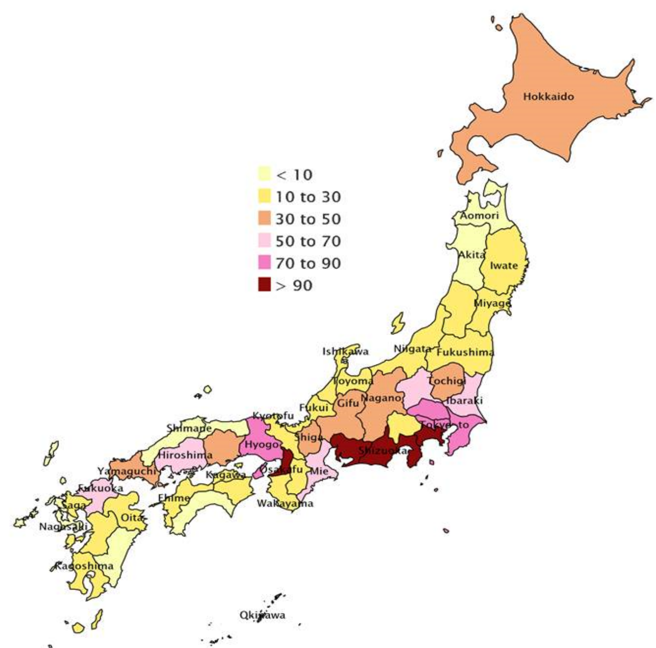
9. Empirical evidence on the impact of industrial/manufacturing automation and labor-saving technology on productivity and the labor market is mixed. Some studies suggest that industrial robots have adversely affected the local labor market. For instance, Acemoglu and Restrepo (2017) estimate that one additional robot results in a reduction of employment by 6.2 workers in certain regions in the United States. On the other hand, cross-country work conducted by Graetz and Michaels (2015) suggest the opposite, by showing that the increased use of robots raised countries' average growth rates by about 0.4 percent, and increases both wages and total factor productivity. Borland and Coelli (2017) provides evidence that in Australia, computer-based technologies have not necessarily reduced the total amount of human work, and that automation will not necessarily lead to the job loss. Despite the differences across studies in their assessment of the impact, studies tend to agree that industrial robots have contributed to an increase in inequality, as labor-saving technology has predominately replaced the jobs of middle-skilled or low-skilled workers whose occupations are, thus far, more automatable (Autor and Dorn, 2013; Goos and Manning, 2007).

10. Japan's experience with industrial robots—measured on the prefectural (regional) level—is instructive on the future impact of automation on productivity and labor. Following recent work by Acemoglu and Restrepo (2017) for the United States, the question is addressed here by estimating prefecture-specific robot density. Prefecture-level robot density is estimated as a weighted sum of the share of robots used in each sector out of the total number of robots used in the economy, weighted by the share of a prefecture's output contribution to a specific industry to the total output of the industry. That is, for each prefecture that has S_p number of industries, robot density of prefecture *p* at time *t*, $robot\ density_{p,t}$ is calculated as below:

$$robot\ density_{p,t} = \sum_{s=1}^{S_p} \frac{y_{st}^{p}}{y_{st}} \frac{robot\ stock_{st}}{Hours\ worked_{st}}$$

where y_{st}^{p} is the total output of industry *s* of prefecture *p* at time *t*, y_{st} is the total output of industry *s* at time *t*, $Hours\ worked_{st}$ is the total hours worked, and $robot\ stock_t$ is the number of operational stock of robots for industry *s* at time *t*. Based on this calculation, robot density varies across prefectures, depending on the industrial composition of the prefecture. Prefectures with the highest robot density are those that have large automotive and electronics manufacturing plants: Aichi prefecture with several automobile manufacturing plants including Toyota, and Kanagawa prefecture with Nissan's headquarters and some of Nissan's manufacturing plants. Some examples of prefectures with the lowest robot density are located in the Northwestern part of Honshu (such as Akita and Aomori prefectures)—known for its agriculture, fishing and forestry. Honshu (such as Akita and Aomori prefectures)—known for its agriculture, fishing and forestry.

Japan: Prefecture-Level Industrial Robot Density (2014)



Sources: International Federation of Robotics, Japan Statistical Bureau; IMF staff calculations

11. Panel regressions using estimated prefecture-level robot density shows that Japanese prefectures with greater exposure to robots had higher productivity and employment growth.

In a panel regression with prefecture and industry group fixed-effects, we find that prefectures more exposed to robots have sizeable positive effects on local labor market outcomes as well as productivity. Controlling for the Global Financial Crisis (GFC) where the adoption of robots collapsed due to weak global demand, we find that an increase of robot density by one percentage point corresponds to 15 percent increase in TFP growth for all samples and 6 percent growth for the manufacturing sample. In addition, employment growth is also positively correlated with an increase in robot density by 0.3 percentage points (Table 1).

Table 1. Robot Density and Manufacturing Sector at Prefecture Level

	All Sample			Manufacturing		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	TFP	Wage growth	Employee growth	TFP	Wage growth	Employee growth
Robot Density (prefecture)	15.31***	0.0454	0.201***	6.307**	0.0912	0.275***
	(0.367)	(0.159)	(0.067)	(2.657)	(0.171)	(0.078)
Crisis * Robot Density	-11.94***	-0.525***	-0.169***	-14.28***	-0.533***	-0.173***
	(0.139)	(0.060)	(0.025)	(0.996)	(0.064)	(0.029)
Constant	-1.342	-0.586	-0.644	-22.63	-2.551*	-3.681***
	(2.557)	(1.108)	(0.467)	(22.630)	(1.456)	(0.666)
Prefecture FE	N	N	N	Y	Y	Y
Prefecture*Industry Group FE	Y	Y	Y	N	N	N
Observations	4,700	4,700	4,700	940	940	490
R-squared	0.77	0.158	0.546	0.207	0.1	0.111

Source: IMF staff calculations. Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

12. **Our results are also indicative of potential spillover effects of automation in the manufacturing sector onto service sectors.** Using prefecture-level information, higher robot density per prefecture is significantly correlated with higher TFP growth. However, it also shows that higher automation in manufacturing is negatively correlated with some labor market outcomes in service sectors of that same prefecture (Table 2). Controlling for GFC and prefecture fixed effects, we find that an increase in robot density by one percentage point leads to a 1.2 percentage point decrease in employee growth in the service sector, while the impact on service-sector wage growth is negative, but insignificant.

Table 2. Japan: Robot Density and Service Sector at Prefecture Level

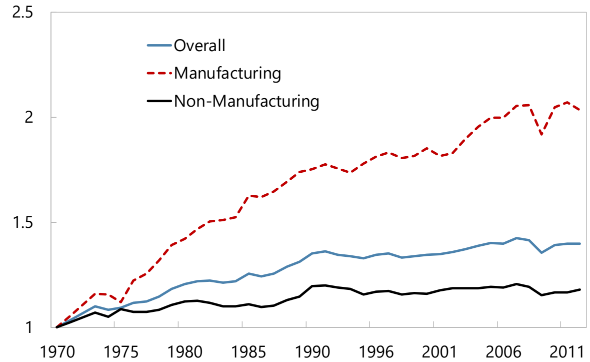
	(1)	(2)	(3)
VARIABLES	TFP	Wage Growth	Employee Growth
Robot Density (Prefecture)	3.235***	-2.132	-1.208***
	(0.911)	(1.905)	(0.433)
Crisis*Robot Density	-1.159***	-3.687***	-1.136***
	(0.353)	(0.737)	(0.167)
Constant	-1.789**	2.739	2.159***
	(0.826)	(1.726)	(0.392)
Prefecture FE	Y	Y	Y
Observations	940	940	940
R-squared	0.048	0.036	0.141

Source: IMF staff calculations. Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

D. Automation in the Services Sector of Japan

13. The productivity gap between manufacturing and the services sector is significant in Japan. Labor productivity has tripled since 1970 in manufacturing, but improved by only 25 percent in the non-manufacturing sector. While there are many causes, the largest gains in industrial productivity have been closely related to increased use of information and communication technology and to automation. The most productive manufacturing sectors in Japan—automotive and electronics—are those where production processes are heavily reliant on automation. By contrast, the services sector, which accounts for 75 percent of Japan's GDP, has seen little annual productivity growth—only about half that of the United States.

Japan: Labor Productivity by Sector (1970-2012)
(Unit: labor productivity, 1970=100)



Sources: RIETI Japan Industrial Productivity Database

14. Tight labor market conditions and severe labor shortages in certain service sectors have resulted in a deterioration in the quality of services in Japan. Surveys support the view that both the volume and quality of services in Japan are in decline. Recent work by the Research Institute of Economy, Trade and Industry (Morikawa, 2018) shows eroding quality of services due to labor shortages, with the sectors most critically affected being parcel delivery, hospitals, restaurants, elementary and high school education, convenience stores, and government services.

15. The advancement of technology to utilize automation technology in the non-manufacturing sector coincides with an increase in the need for automation in some age-related service sectors. The government's new industrial vision (Society 5.0) counts on the integration of automation to transition smoothly in the face of a shrinking population and an aging society. Also, with significant labor shortages, firms have begun to embrace new technology to compensate for scarce labor and stay competitive. For instance, Japan's *Regional Economic Report* and the annual survey on planned capital spending by the Development Bank of Japan suggest that retailers and service sector firms adopt labor-saving technology, i.e. self-checkout registers at retail convenience stores, touch-screen order terminals at restaurants and train terminals, robot chefs, and robot hotel staff in accommodation.

16. However, the introduction of automation in service sectors may negatively affect female and low-skilled workers disproportionately, as they tend to work in highly-automatable occupations. Hamaguchi and Kondo (2018) estimate the 'computerizability' of each occupation in Japan based on the sophistication of tasks involved in the occupation, such as; the use of creative intelligence; social intelligence; and cognitive perception and manipulation. Matching these estimates with rich employment data in Japan, the paper finds that female workers are exposed to higher risk of computerization than male workers, since female workers tend to be engaged in occupations with higher probability of computerization such as receptionists, clerical workers, and sales workers.

E. Macroeconomic Implications of Automation with a Declining Labor Force

17. **In this section, a simple theoretical model is used to project the potential impact of technology, whether labor-saving or labor-augmenting, on output and wages.** As in previous models which address similar questions (Berg, Buffie and Zanna, 2018; IMF 2018), the key parameter in this exercise is the substitutability of labor and capital. To address this, we take two scenarios for technology: *labor-saving technology* which substitutes existing human labor and *labor-augmenting technology* which complements human labor. As an extension of the previous models, the role of Japan's shrinking labor force (and thus rising dependency ratio) is a crucial factor that reflects its unique setting.

18. **An increase in the dependency ratio (number of non-workers as a ratio to workers) leads to over-saving, resulting in the over-accumulation of capital.** Our baseline scenario is a standard Blanchard-Yaari overlapping generation model (Blanchard (1985); Yaari (1965)) which introduces retirement. An increase in the number of retirees, *ceteris paribus,* captures an increase in the dependency ratio, as the relative size of the work force which enters at a constant rate declines with an increase in the share of retirees. Under this setting, a high retirement rate may lead to over-saving since a higher rate of retirements, which is equivalent to early retirement in the model, implies a longer span of the retired period and therefore a need for higher saving for retirement. In such a case, capital accumulation exceeds its optimal level and due to this misallocation, output growth is lower than optimal.

19. **Introduction of labor-augmenting robots to the baseline leads to higher output growth and real wage growth, compared to the case without the introduction of robots.** The first scenario introduces labor-augmenting robots in a production function, where robots are assumed to be complements to capital. That is, a unit of robot improves 'productivity' of labor. With an increase in the retirement rate, and therefore an increase in the dependency ratio, an increase in the use of labor-augmenting robots may offset the lower-than-optimal output in the baseline scenario. However, the wealth disparity between workers and retirees increases, as the wage for workers rises in proportion to the increase in the growth of technology of robots.

20. **In the scenario of labor-saving technology, the wealth of workers and retirees depend crucially on the degree of substitutability between human labor and technology.** Without separation of skills among workers, a high degree of substitutability between human labor and the technology of labor-saving automation will lead to higher output of the economy, where the share of income going to capital (robots and traditional capital) is much higher than the share of labor income going to retirees and workers altogether.

21. **Finally, automation leads to an increase in inequality between skilled and unskilled workers.** A simple modification to differentiate workers into two types—skilled workers who are

complements to robots and unskilled workers who are substitutes to robots—shows that overall growth could be higher when the productivity of robots exceeds certain level, even in the face of an increase in the dependency ratio. However, wages of skilled workers will rise in proportion to the productivity increase of robots, while that of unskilled workers will experience dislocation as robots replace them as workers. As a result, the inequality between the two groups of workers in terms of wage growth will increase, as well as the stock of wealth of each group after their retirement.

F. Policy Implications

22. Automation technology and artificial intelligence can be a partial solution for Japan to deal with its rapidly-declining labor force. Strong and effective social safety nets will be crucial, since disruption of some traditional labor and social contracts seems inevitable. While there is no one-size-fits-all policy, policies to accentuate the positive aspects of automation should be introduced to encourage automation technology in areas most affected by labor shortages due to demographic challenges.

23. Given the expected distributional consequences of automation technology, the quality and adaptability of education to provide adequate training for the new generation of workers will be crucial. While it is difficult to prognosticate how individual occupations and tasks will evolve with the introduction of automation and AI technology, most agree on the growing importance of technological as well as social and emotional skills, rather than manual and physical skills (McKinsey, 2018). The need for education and training of the next generation of workers to adapt to such changes, and to reflect the rising need for these skills, are essential to minimize the negative effects that disproportionately hurt highly substitutable workers. To equip future workers with skills to shift across occupations more easily, general education may need to re-focus on problem-solving and emphasize cognitive skills (IMF, 2018).

24. To offset demographic challenges, policies to encourage an untapped labor force, such as female workers, should be further promoted and consideration given to permitting more foreign workers. Beyond the adoption of automation to offset Japan's demographic headwinds, policies should first address issues that prevent the existing pool of potential workers from entering the labor force, i.e. female workers or older workers. While it is encouraging that Japan's female labor force participation has increased in recent years, greater efforts to help females better balance between domestic responsibilities and professional careers could be done, for instance, by providing greater access to child care, equal treatment of female workers at work. On foreign workers, while some progress has been under consideration to accept foreign workers who have a certain level of professional and technical skill, the government could make further efforts, particularly in sectors that are suffering from significant labor shortages. [5]

[5] The Japanese Cabinet decided to create new status of residence in June 2018, to allow foreign workers into the country to ease labor shortages and, if the relevant act is amended, starting April 2019, to accept foreign workers who have a certain level of professional and technical skill.