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The contribution of human capital to economic growth:

A cross-country comparison of Germany, Japan, and the United States

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ABSTRACT

Traditional growth accounting exercises, which adjust for variations in the age, gender, and educational attainment of the workforce, conclude that changes in human capital contribute only modestly to economic growth. Yet, recent studies have argued that improvements in human capital make a more substantial impact through differences in the quality of education and the importance of human capital in the innovation process. In this study, we explore differences in the generation of human capital in Germany, Japan, and the United States. We focus on the dissimilarities in their education systems and labor markets as sources of variations in economic outcomes and the contributions of innovation to economic growth. We conclude with a brief discussion of the implications for policy in the three countries.

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CONFLICT OF INTEREST DISCLOSURE

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Introduction

Modern empirical research on the sources of economic growth has long been reliant on the neoclassical growth model of Solow (1956, 1957), which accounts for the growth in per capita income as largely the product of exogenous factors such as the rates of physical investment and depreciation, the growth of the workforce, and technology. Efforts have been made to incorporate some elements of human capital, such as educational attainment and skill levels, but economic growth accounts have long shown that those improvements in human capital contribute a modest amount.[1] In fact, Lucas (2015) suggested that a near-consensus had emerged among leading growth theorists that human capital, as conventionally measured, could not come close to eliminating the gap between output and orthodox measures of its inputs—hence the need to assign a large role to exogenous technical progress.

However, most of those empirical studies adopt a narrow perspective on the role of human capital by adjusting the workforce for changes in age, gender, and levels of educational attainment (Jorgenson and Fraumeni, 1989). One of the most comprehensive examples of that research is illustrated in the EUKLEMS growth accounts which incorporate compositional changes in the labor input.[2] The average annual contribution to labor productivity growth in the advanced economies of the European Union, Japan, and the United States averaged only 0.2% after 2000—rather minimal amounts.[3]

Lucas (1988), Romer (1990) and others have argued in favor of a more endogenous process in which much of the contribution of human capital is the result of spillovers traceable to interactions among people of higher-skill levels in their post-education years. Hence, they reject the notion that a simple accumulation of educational attainment is an adequate measure. Their work has unleashed a flood of new research into the linkages between education and economic growth.

One major branch of that research has focused on alternative approaches to incorporate gains in education into the measure of human capital. In a series of studies beginning in 2000, Hanushek and Woessmann (2015) have contended that variations in the quality of education can lead to large differences between measures of years of schooling and actual learning. Thus, they suggest adjusting for the quality of education, as measured by standardized assessments of student performance and cognitive skills.[4] International examples of such assessments are provided by Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA). Conducted every three years, PISA was begun in 2000, and by 2018 it had expanded to cover 79 countries. TIMSS was started in 1995, is conducted every four years, and currently has about 64 participating countries. Both programs focus on primary education.[5] Additional work to create an internationally compatible data set of quality-adjusted measures of education for 164 countries has been done by the World Bank (Angrist et al. 2019).

A second area of the research has revolved around the heterogenous nature of the skill level of the workforce and emphasizes imperfect substitutability between workers with different skill levels. The implications of incorporating vintage or cohort effects in measuring the contribution of human capital are discussed more fully and illustrated in Bowlus and Robinson (2012) and Inklaar and Papakonstantinou (2020). The significance of imperfect substitution among workers of varying skill levels are also

[1] The origins of human capital theory can be traced back to the contributions of Mincer (1958), Schultz (1961), and Becker (1964).
[2] The 2019 version of the EU KLEMS accounts is available at https://euklems.eu/.
[3] Similar magnitudes for the traditional neoclassical model are reported in Jones (2014, 2019). Jorgenson (1984) and Denison (1979) report somewhat higher estimates of the contribution of education but estimates of the contribution of labor composition from the Bureau of Labor Statistics for the period 1948-2015 are also 0.2 percent a year. See Baily and Montalbano (2016) Figure 1.
[4] An overview of their research is provided in Hanushek and Woessmann (2020).
[5] The United States has conducted its own National Assessment of Educational Progress (NAEP) on an annual basis since 1970 and it covers both primary and secondary schooling. A discussion of the results can be found at https://www.nationsreportcard.gov/

highlighted in Jones (2014, 2019). Most of these departures from the neoclassical perspective argue for an increased contribution of education gains to economic growth.

Third, others have examined the role of education in the promotion of entrepreneurship and innovation. Baumol (2004, 2010) identifies two channels of innovation: (1) independent inventors and entrepreneurs who contribute original breakthrough ideas, and (2) large industrial laboratories that are more likely to focus on successive incremental improvements in products and processes. The two types are referred to as inventive entrepreneurs and incremental innovators. He also argues that the two types of innovation require different types of education. The first benefits from an education that stimulates creativity and imagination. The second benefits from a high degree of technical competence and mastery of the available analytical tools.

A somewhat different perspective is provided by Bell et al. (2019) who stress the importance of socioeconomic factors and exposure to innovation activities in childhood as primary predictors of individuals who will become inventors in adulthood.[6] For example, they find that children whose parents are in the top one percent of the income distribution are found to be 10 times more likely to hold a patent relative to those whose parents' income is below the median. The authors suggest the environment in which children grow up has a major influence on career paths either via transmission of specific human capital or through changes in aspirations. Developing methods to increase exposure to innovation among disadvantaged subgroups is therefore a particularly promising direction for research and policy.

A similar view is provided by Aghion et al. (2017), who utilize a large sample of persons in Finland. Like Bell et al. (2019), they initially show an equally strong association between parents' income and the probability of becoming an inventor (patent holder), but they also report a large role for the individual's own IQ. Furthermore, they show that the effect of having a STEM Master's or PhD degree is 25 times larger than that of having a father in the top 95th income percentile and six times larger than that of belonging to the top 95th IQ percentile. Overall, they find a large association of parental education and own IQ as major determinants of the individual's probability of being an inventor.

In summary, the current evaluation of the impact on economic growth of improvements in human capital, as defined by education and job skills, is in the midst of a major transformation. The most recent research suggested that improvements in human capital can have a much larger impact on economic growth than implied by the traditional neoclassical growth accounting model.

In this study we will explore differences in the role of human capital in the economies of Germany, Japan, and the United States. We chose the three because they represent the most advanced economies of their respective regions, but they have significant differences in the structure of their education systems and the ways in which they organize their labor markets to promote the development of a skilled workforce. After examining differences in the structure of the three countries' education and labor market institutions, we review the evidence on how those differences have affected the distribution of income in each of the three countries. We then explore the impact of these differences on innovation and growth in each of our three countries. Growth has been slow in all three of these economies. We conclude by recommending policies that could improve the quality of education and enhance economic growth.

Education in the three countries

All three countries have highly ranked educational systems, but they differ significantly in their objectives and approaches. The United States and Japan have similar structures with 6 years of elementary school, 2-3 years of junior high school, 3-4 years of senior high and 4 years of college or university. The German system is more complex with multiple learning tracks and a large vocational training program.

[6] This research was based on a huge dataset that linked 1.2 million inventors (patent recipients) to their income tax records, allowing the tracking of individuals from birth to adulthood.

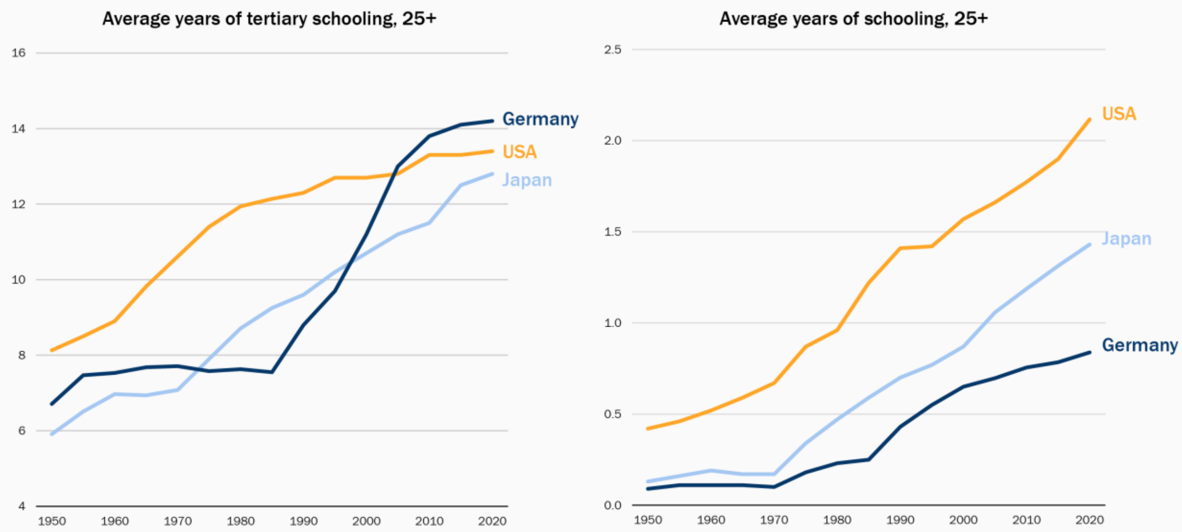
Japan has one of the world's best performing education systems. It emphasizes a standardization of a broad general education curriculum in the elementary and secondary years. Education is compulsory only for the nine years of elementary and middle school, but nearly all students go on to 3 years of high school. At age 15, students can choose among general education, vocational training, and colleges of technology. Vocational programs are smaller and less developed than in Germany, but their expansion has been a major goal of recent reforms. Admission to all post-compulsory education institutions is based on rigorous entrance examinations. The combination of the examination system with lifetime employment after graduation makes school performance a very serious affair for students. Hence, Japanese students work exceptionally hard in the elementary and secondary years but are likely to take a more relaxed approach to university life. Japanese students perform exceptionally well on international tests that measure basic skills. However, some critics argue that the importance of the university entrance exam creates excessive pressures on students and the system unduly emphasizes conformity. The public education system is largely free through the secondary level, but over 20 percent of secondary school students opt to attend private schools.[7] The costs of a university education are substantial, and about 75 percent of students attend private institutions.

The United States has lower standards in its elementary and secondary school programs with substantial variation in performance across states and communities. However, there is a greater emphasis on performance at the university and college level. There also has been an effort to develop a standardized core curriculum across states for elementary and secondary schools, but it has encountered significant opposition, mainly due to the emphasis on tests to measure student and teacher performance. Approximately 90 percent of elementary and secondary school students attend public schools. Higher education is largely financed privately, but the costs vary widely because of differences in the availability of need- and merit-based scholarships. The United States lags Germany and Japan with respect to student performance in elementary and secondary schooling, but students perform well in their university years.

In Germany, children participate in early childhood education programs prior to beginning their primary school education which typically starts at age 6 and spans 4 years. The secondary school system is very diverse with students divided at age 10 into three basic tracks extending through grades 5 to 12. The German system concentrates on formal classroom instruction in the morning hours; students leave at mid-day for lunch, and afternoons are devoted to extensive homework assignments. Starting in 6th grade, students are divided into those who go to Gymnasium, Realschule, or Hauptschule. Each of these has its own focus and curriculum. The Gymnasium has become the primary track for university attendance, the Hauptschule is a major route into the apprenticeship programs, and Realschule is a more intermediate program. Education is largely free through the university level, but there are significant entrance barriers at the university level, largely based on examinations. In the 1980s, enrollment in German universities was only about 10 percent of the student-age population, but it has risen to 30 percent in recent years.

[7]There can be substantial additional costs for extracurricular activities and after-hours tutoring programs.

Figure 1. Gains in Educational Attainment
Germany, Japan, and the United States



Source: Barro, Robert and Jong-Wha Lee, 2013, "A New Data Set of Educational Attainment in the World, 1950-2010." Journal of Development Economics, vol 104, pp.184-98; and updated data from the World Development Report, 2020, and UNESCO.

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Vocational training is also a key component of the German education system. The dual system of training is based on cooperation between mainly small- and medium-sized companies, on the one hand, and publicly funded vocational schools, on the other. Trainees in the dual system typically spend part of each week at a vocational school and the other part at a company, or they may spend longer periods at each place before alternating. Dual training programs usually lasts two to three-and-a-half years.

All three countries have seen a large rise in educational attainment over the past half-century, as shown in the top panel of Figure 1. For most of the post-WWII period, the average years of schooling was highest in the United States, but Germany and Japan achieved larger gains and the gaps have narrowed substantially. The rise in years of schooling has been particularly notable in Germany, and updated data from UNESCO now ranks Germany ahead of the United States.[8]

[8] The most cited set of data on school attainment is available in the Barro and Lee (2013) dataset, which reports mean years of school (MYS) at five-year interval and by age groups; but the latest year that they report is 2010. UNESCO has updated some of that data for more recent years, but the sharp rise in MYS for Germany after 1995 is puzzling and not reflected in an alternative data set from the OECD on the distribution of the population by levels of schooling attainment. The Wittgenstein Centre publishes a third dataset developed by Goujon et al (2016).

Table 1: Educational attainment of the population, ages 25-65 in 2019

Level of Education	Germany	Japan	United States
Primary	4		3
Lower Secondary	10		6
Upper Secondary	3	47	42
Vocational [a]	53	(1)	(1)
Short-cycle Tertiary	1	21	11
Bachelor's Degree	16	31	24
Master's Degree	12	2	12
PhD [b]	1	(2)	2
Total	100	101	100

Source: OECD. *Education at a Glance 2020*. Table a1.1, Educational Attainment, ages 25-64. [a] Vocational is included in upper secondary for Japan and the United States. [b] Data for Japan are drawn from national sources, and those with a Ph.D. are included with master's degrees.

The one area where the United States remains preeminent is in tertiary education (lower panel of Figure 1). Average years of tertiary education remain higher than in Germany and Japan with little evidence that the gaps are closing. Current data from the OECD indicate that the about half of the U.S. population has a tertiary education; while the percentage is equally high in Japan, it is dominated by short-cycle programs as shown in Table 1. Japan has a surprisingly low proportion of the population with master's and doctoral degrees, but that may be misleading if workers receive on-the-job training. With lifetime employment after graduation from college, there is less incentive to seek a formal postgraduate degree. Germany has the lowest proportion of the population with a tertiary education, but that is partly a reflection of its greater emphasis on vocational training programs. It is comparable to the United States in the proportion of the population with postgraduate degrees.

In terms of quality, Germany, Japan, and the United States all have highly rated educational systems, although results vary in terms of the precise criteria for comparison. Japan consistently ranks at or near the top of performance on international student achievement tests for elementary and secondary schooling. In the 2018 PISA assessment, Japan had a combined score (mathematics, science and reading) of 520, which placed it 6th among the 79 participating countries. Germany was 19th with a score of 500, and the United States was 25th with a score of 495. Hanushek and Woessmann (2011) computed an average of scores on various achievement tests stretching back to 1995 with similar results for the three countries.

In recent years, a considerable amount of work has been undertaken to develop more refined measures of educational attainment that incorporate systematic adjustments for quality. Hanushek and Woessman (2012, 2015) demonstrated a strong correlation between test scores and economic growth, and Filmer et al. (2018) expanded on that work to develop a Learning-Adjusted Years of Schooling (LAYS) index that incorporate both the quantity and quality of schooling.[9] Those data are regularly updated and reported in the World Bank's Human Capital Index, which includes further adjustments for health and expected survival. The latest available data are for 2020. On that basis, Japan still ranks very high at 3rd in the world (below Singapore and Hong Kong), Germany is 25th, and the United States is 35th.

Importantly, most international achievement rankings focus on primary and secondary level education programs. Yet, university education has become increasingly important within most advanced economies.

[9] The LAYS measure is the product of average years of schooling from Barro and Lee (2013) and an index of learning achievement as developed in Filmer and others (2018).

While there is no consensus on a methodology for ranking the world's universities, most schemes place a heavy emphasis on faculty awards, academic research publications, and frequency of patent applications. Within those publications, the United States is consistently home to more than half of the world's top-rated institutions. The QS World University Rankings, using a broad criterion, ranks the U.S. higher education system as the world's best performing with Germany 4th and Japan 10th.

Labor markets in the three countries

There are considerable differences in the structure of labor markets in the three countries and their links to the education system. At the one extreme, the United States' labor markets are frequently cited for their open and competitive structure. The workforce is very mobile with frequent job changes, and there is notable lack of regulation of employment relations. Alternatively, Japan places more emphasis on a heavily regulated system of lifetime employment where large firms employ school graduates and promise employment until retirement. There is only infrequent job turnover in the years between school graduation and retirement. Germany represents an intermediate case of labor market regulations that limit firms' ability to dismiss workers without cause as in Japan, but it has promoted alternate means of introducing some flexibility into employment relations. In recent years, both Japan and Germany have tolerated the emergence of a dual labor market structure: a core market with strong employee protections, and a more open, less regulated periphery or secondary labor market.

United States

The U.S. labor market is very effective in reallocating workers in response to changes in demand—monthly job turnover rates average about 4 percent. Notably, about two-thirds of labor turnover is the result of the voluntary action of workers. The social and economic costs of changing jobs are low. Young workers often view job changes as a normal part of their search for a rewarding career. On the other side, the counterpart of firms' freedom to fire workers is a willingness to hire as it implies no commitment to retain them.

Workers face incentives to invest in their own skill development since they face little employment protection and low unemployment benefits. The accumulation of skills is concentrated in secondary and post-secondary institutions of learning, with a limited role for vocational training programs. Incentives for employers to provide extensive on-the-job training are often constrained by the pattern of very frequent job changes. While wage rates rise with experience, the age profile is flatter than that of other countries.

Unionization is very low in the U.S. and there is no counterpart to the European notion of a social partnership; labor-management cooperation is a largely foreign concept.[10] The American labor market is characterized by an adversarial labor-management relationship, where labor and management are in effect opposing parties who often antagonize each other. Given the confrontational nature of U.S. labor management relations, foreign firms in the U.S. also try to avoid unionization even if they support it in their home market.

Japan

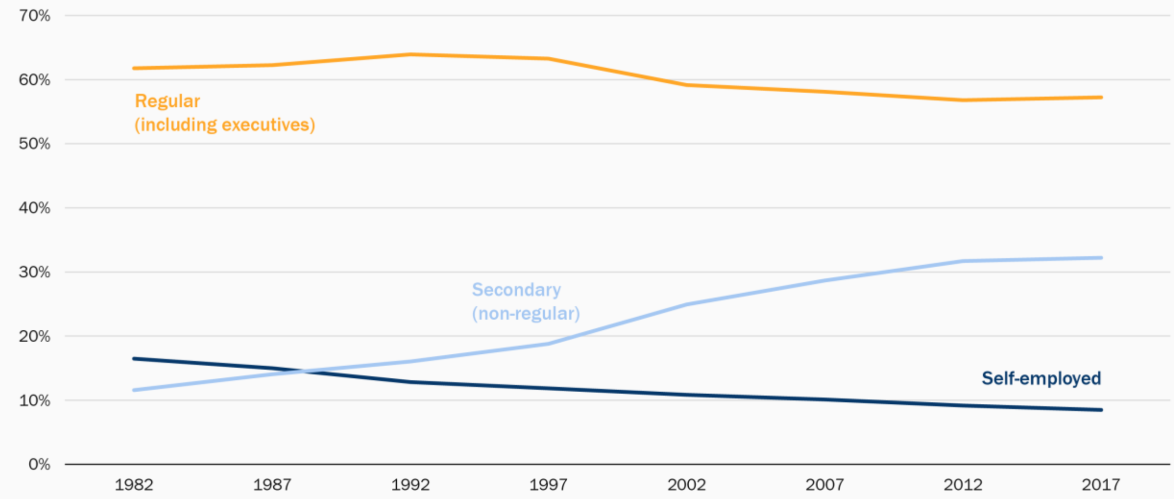
The Japanese employment system is often characterized in terms of its emphasis on long job tenure (lifetime employment), seniority-based wage increases, on-the-job training with frequent job rotation, weak enterprise unions, and semi-annual bonuses (Powell, 2016). The standard retirement age had been a

[10] According to Census Bureau tabulations, 6% of U.S. private sector workers were members of a union compared to 24 percent in the early 1970s. Public sector unionization has been stable at about 35% of the workforce. Rates of unionization in Germany (20%) and Japan (18%) are substantially higher.

young 55-60, but the national retirement age is now 65, and older workers often continue to work well beyond age 65, usually with a different employer or at reduced wages. Within this framework, entry-level wages are low and wage rates rise steeply with increased tenure up to the formal retirement age.

With the sustained slowing of economic growth since 1990, questions have arisen about the sustainability of the Japanese system. Hamaaki et al. (2012) argued that there had been a downward trend in the share of young workers in regular jobs and that the age profile of earnings flattened in the 1990s and 2000s, both which they interpreted as signs of deterioration in the overall quality of jobs[11]. However, in more recent work, Kambayashi and Kato (2017) emphasized the limited nature of the decline in job quality for prime-age male workers, though they agreed that job stability has lessened for younger workers and mid-career hires.[12] Kambayashi and Kato also highlighted the larger shift out of self-employment into secondary jobs (part-time, temporary, and contract work). Furthermore, while college-educated female workers gained some access to more stable jobs in the high-growth era, many of those gains were lost in the years after the financial crisis.

Figure 2. Distribution of Workers in Japan by Employment Status, 1982–2017



Source: Employment Status Survey, 2017, Table 4. Persons Engaged in Work by Sex, Status in Employment, Type of Employment and Industry.
Note: Regular workers have open-ended tenure arrangements, work fulltime, and are directly employed by the employer. Secondary employment includes part-time, contract, and temporary workers.

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As shown in Figure 2, regular workers (for whom the lifetime employment system largely applies) have declined as a share of total employment from an average of 62 percent in the 1980s to 57 percent in 2017, but the larger change was the fall in self-employment (from 25 to 10%) and the offsetting rise in secondary workers (14 to 32%). In addition, the length of the work week declined by 20%, from the highest among OECD countries to below the OECD average. There has been a huge rise in the female labor force participation rate since 2000 to the point that it now surpasses the United States. However, gender discrimination remains a major problem with a disproportionate number of women relegated to the secondary workforce with sharply lower wages and limited job security (Kawaguchi and Mori, 2019).

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[11] Regular employees are full-time workers whose *employment* is not limited in duration except for the mandatory retirement age.

[12] Esteban-Pretel and Fujimoto (2020) compute a larger decline in the share of regular employees by excluding the self-employed from the denominator. They also report a strong influence of marriage on increasing the probability that men will have stable regular jobs, while decreasing the probability for women.

Germany

The German labor market has undergone a major transformation in the aftermath of the country's reunification. Its competitive position changed with the emergence of the East European countries, and its labor market institutions responded with innovative changes that greatly increased their flexibility. Under the pressure of a deep recession, the "Hartz Reforms" scaled back the magnitude and duration of unemployment benefits and strengthened incentives to find employment (Jacobi and Kluve, 2007). The regulation of temporary work and contract labor was softened, and it contributed to the emergence of a two-part labor market: a regular or core that is characterized by high job security and high wages, and a secondary labor market of temporary and part-time workers. There has also been a major decentralization of labor-management negotiations with more decisions being agreed to at the firm level (Eichhorst and Tobsch, 2014). The structure of German labor-management relations is unusual in its emphasis on work councils, which represent workers in medium and large enterprises on a wide range of local issues, and a system of codetermination with worker representatives on supervisory boards of large corporations.

The employment-population rate has surged since the early 2000s, mainly due to the increased participation of women, to be now among the highest in Europe and the unemployment rate is now among the lowest. At the same time, Germany has experienced a major widening of the wage distribution (Dustmann et al., 2014), and gender inequality in wages remains substantial (15.5% in 2019).

However, the reforms did not significantly alter the long-standing emphasis on job training programs, which remains a major feature of the German labor market. The main characteristic of the dual system of vocational training and employment is cooperation between small- and medium-sized companies as employers, on the one hand, and publicly funded vocational schools, on the other. This cooperation is regulated by law. Trainees typically spend part of each week at a vocational school and the other part at a company. The training extends over two to three-and-a-half years. Training, testing, and certification are standardized in industries throughout the country. About 50 percent of all school-leavers participate in the vocational training system (Haasler, 2020). While the popularity of the vocational training programs has declined in recent years as more students opt for attending university, they are a major reason for the low rate of unemployment among German youth.

Finally, the three countries differ greatly in employee tenure. In a 2015 analysis, the Japan Institute for Labor Policy and Training reported that the percentage of workers with job tenure of more than 10 years was 45% in Japan, 43% in Germany and 29% in the United States. The proportion of Japanese workers with tenure beyond 20 years (22%) was twice that of the United States (11%).[13] In a comparison of job retention rates in Japan and the United States stretching back to the early 1980s, Kambayashi and Kato (2017) found a pattern of substantially greater job stability for prime-age male workers in Japan, a practice which remained strong during and after the 1990 financial crisis.

There are also substantial differences among the three economies in the number of hours worked per year. U.S. workers on average worked 1,779 hours per year in 2019, one of the highest rates among OECD economies. Japanese workers used to work very long hours, but by 2019 average hours had declined to 1,644 hours per year, a few percentage points below the U.S. level. German workers worked among the fewest hours per year among the OECD economies in 2019: only 1,386 hours on average, 77.9 percent of the U.S. level.[14] It is not certain why these differences and changes have occurred. Strong unions and high taxes in Europe are possible reasons for reducing hours of work. Persistent high unemployment in Europe in the 1970s and 1980s led to the view that reducing hours of work might increase employment, and a similar issue may have been important in Japan during the period after the growth bubble burst. Weaknesses in the social safety net and the lack of universal health insurance may have encouraged continued long workhours in the United States since full-time work is a common requirement for access to employer-provided health care. Low birth rates in both Europe and Japan might have been expected to lead to increases in hours of work, but that has not been the case so far.

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13 There was no corresponding figure available for the Germany.

14 Data from the Organisation for Economic Cooperation and Development, https://data.oecd.org/emp/hours-worked.htm

Income inequality and the role of education

Many advanced economies have experienced a significant widening of their income distribution in recent decades. For the three countries in this analysis, this is particularly evident for Germany and the United States, but it is less true for Japan. The search for an explanation for the growing inequality has stimulated many empirical studies, and that research has documented the extent to which the change is dominated by changes in labor income, as opposed to capital, as well as the large role played by differences in educational attainment and gender.[15]

The research has focused on two models to examine the role of education as a determinant of the wage structure. The first is the estimation of Mincer equations that relate the *level* of wage rates to education in cross-sectional data sets. The basic Mincer (1974) earnings function relates labor earnings to schooling and labor market experience, providing a straight-forward measure of the monetary return to one additional year of schooling:

$$\ln Y = \alpha + \beta \cdot S + g(A),$$

where Y is a measure of labor earnings, S is years of schooling, A is age (or preferably years of work experience), and g is a third or higher order polynomial that can capture the concave nature of the age-earnings profile. The Mincerian function has become ubiquitous in empirical studies and the coefficient β is often interpreted as a measure of the return to another year of schooling. It has been applied to samples of people in many different demographic groups and countries and can be easily modified to include other determinants.[16] Work experience (or job tenure) is another important determinant of wages, but it is often difficult to accurately identify independently of age in empirical data. Survey respondents often cannot accurately recall their age when they entered the labor force and experience is often proxied by adjusting age for years of schooling.[17]

With the large increase in the number and size of datasets that provide measures of income, education, and age at the individual level, there is less need to adhere to the parsimonious form of the Mincer earnings function. Recent studies often introduce categorical measures of the various levels of educational attainment and years of experience/age, allowing for various discontinuities in the relationship between earnings and education. Yet, the Mincer equation is still a surprisingly useful representation of the earnings function a half-century after its introduction.

The second research model is more focused on the *evolution* of the wage structure over time within a supply-demand framework and its growing inequality in recent decades. That research places a strong emphasis on the complementarity between technological advances and increases in the demand for skilled labor (Katz and Murphy, 1992; Goldin and Katz, 2008):

$$\ln\left({}^{w_{St}}/_{w_{Ut}}\right) = \frac{1}{\sigma_{SU}}\left[D_t - ln\left(\frac{L_{St}}{L_{Ut}}\right)\right],$$

where w_{St} and w_{Ut} represent the wage rates of skilled and unskilled workers, respectively. D_t is a measure of demand shifts, L_{St} and L_{Ut} are the quantities of skilled and unskilled labor, and σ is the elasticity of

[15] A very recent overview with an international dimension is available in Hoffman, Lee, and Lemieux (2020). Aizawa, Deckle, and Helble (2017) provide a detailed comparison of the United States and Japan.
[16] Card (1999) provides a detailed discussion of the modeling of the relationship between educational attainment and incomes and the issues of causality. A critique of the Mincer earnings function is provided in Heckman, Lochner, and Todd (2003).
[17] Researchers have defined potential work experience as the respondent's age minus years of schooling. Some surveys have asked respondents for actual work experience, defined as years since a specific age minus years devoted to schooling, child-raising, unemployment, or other episode of out-of-labor force. Job tenure is a measure of years with current employer.

substitution between skilled and unskilled labor. In this dynamic version of the link between education and earnings, the outcome is often modeled as a race between education and skill-biased technical change (SBTC). Technological advances raise the demand for educated workers and if the supply does not respond equivalently, their relative wage will increase. In the United States, this is reflected in a dramatic widening since the 1970s in wage differentials between college-educated workers and those with less education (Card, 1999; Goldin and Katz, 2008). Broadly similar increases in wage differentials have emerged in Germany (Biewen, Fitzenberger, and Lazzer, 2017; Antonczyk, Deleire, and Fitzenberger, 2018). However, there is far less evidence of increased wage inequality in Japan (Kawaguchi and Mori, 2016). Furthermore, while it is relatively easy to identify changes in the supply of skilled workers using information on educational attainment, measures of changing demand are more ambiguous, and some studies are forced to represent the demand side as a simple trend.

United States

There has been an extraordinary number of empirical studies focused on the increased inequality in the United States labor market. Most studies date the phenomenon as beginning around 1980, and its growth throughout the 1980s and 1990s was strongly associated with an increased educational wage premium, particularly that of college relative to high school. The college wage premium was rising even though the supply of college graduates was increasing, indicating the demand for skilled (college-educated) labor was increasing faster than the entry of skilled workers into the labor force. This was interpreted as a product of skill-biased technical change. However, growth in the higher education wage premium did moderate in the 2000s, while standard measures of wage inequality continued to expand, particularly at the top. Recent explanations have relied on the notion of polarization, or the erosion of the middle of the labor market (Acemoglu and Autor, 2011). Polarization suggests that workplace technologies that are computer-intensive have reduced the need for the "routine" jobs, such as clerical and production monitoring positions, that were previously concentrated in the middle of the wage distribution.[18]

Germany

The analysis of wage trends in the United States has been matched by similar studies in Germany that examined the link between education and wage structure. Ammermüller and Weber (2005) provide a detailed assessment of the returns to education in Germany based on their estimate of the Mincer earning function over the period of 1985-2002. They also provided a useful summary of the prior research. They found that men obtained a higher qualification level than women in West Germany, but the gender differences were smaller in East Germany. There was also a steady expansion of people with tertiary degrees in West Germany. Qualification levels in the East were more stable over time but at a higher level than in the West. They report a return to education of 8-10 percent in West Germany and 7-8 percent in the East.

An interesting comparison to the United States is provided by Antonczyk, DeLeire, and Fitzenberger (2018).[19] They found growing wage inequality in both countries, apart from low-wage workers in Germany. They also found evidence of wage polarization (a hollowing out of the middle) in the United States but not for Germany. Furthermore, the importance of educational differences was smaller in Germany than in the United States. The wage premium for highly educated workers grew far less in Germany, and there has been only a modest increase in the premium for median versus low education workers.

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[18] Valletta (2019) provides a overview of the competing explanations for the recent changes in the wage distribution and the slowing growth in the education premium.

[19] Other important contributions are those of Dustmann, Ludsteck, and Shönberg (2009), Card, Heining, and Kline (2013), Biewen, Fitzenberger, and Lazzer (2017), and Hoffmann, Lee, and Lemieux (2020).

Japan

The experience with changes in the wage distribution in Japan has been much different. In a comparison of comparable wage data for Japan and the United States, Kawaguchi and Mori (2016) found that the wage premium for male college versus high school graduates was much smaller in Japan, and there was no significant widening of the premium between 1986 and 2008. They trace a major portion of the difference to a faster growth in the supply of college-trained workers in Japan, and they reported that differences in relative supply growth could account for about two-thirds of the divergent trend in the male college wage premium. In a 2019 update, Kawaguchi and Mori reported a continuation of the stable structure of relative wages through 2018, and they extended their analysis to include female workers. Recent studies (Kimura et al., 2019; Nakamura, 2020) have gone further to report a modest decline in the returns to education.

Surprisingly, the same pattern does not hold for those with a master's degree or higher. Prior to the mid-2000s, official Japanese labor statistics did not distinguish between undergraduates and postgraduates. Using data from the 2007 Employment Status Survey, Morikawa (2015) found a substantial wage premium for both male and female workers with a postgraduate degree (30-40 percent relative to those with an undergraduate degree). He also found that the wages of postgraduates continued to rise into their late 50s with only a modest drop for those past the mandatory retirement age, a further break with standard patterns in the Japanese labor market. After correcting for potential self-selection bias, Suga (2020) reports a significant, though smaller wage premium (16-24% for men, and 14-26% for women).

Given the absence of changes in the distribution of earnings by level of education, several Japanese studies have focused on the role of on-the-job training and changes in job tenure as determinants of the wage structure. Kimura et al. (2019) estimate the relationship between labor income and job tenure for regular employees over the period of 2005-2017 and argue that a flattening of the tenure-wage profile in recent years implies a decline in the return to human capital obtained on the job.[20] They find that the returns to both general and firm-specific human capital have fallen over the years. A similar analysis by Nakamura (2019) adjusted for statistical biases and argued that the role of firm-specific (tenure) human capital was overstated in the previous literature, but also found a significant role of general job experience.

Comparing returns to education in the three countries

While each of the three countries has an extensive research base examining the effects of education on labor market outcomes, we would like to compare their performance using a common specification of the relationship between education and labor earnings over a common time frame. That is possible using cross-national household data sets provided by the Luxembourg Income Study (LIS).

The LIS is a cross-national data center located in Luxembourg. It provides on-line access to micro-data drawn from household surveys in many advanced and emerging economies. Importantly, the data sets have been standardized to provide consistent transnational definitions of variables in the surveys. The LIS provided us with access to annual surveys for Germany (the German Socio-Economic Panel), Japan (the Japan Household Panel Survey) and the United States (Current Population Survey).[21] For Japan, we

[20] The methodology used to distinguish job tenure (continuous time with current employer) and job experience (total number of working years) restricts their analysis to regular workers, excluding the self-employed, part-time, contract workers, and workers beyond the formal retirement age.

[21] The German Socio-Economic Panel (GSOEP) is administered by the German Institute for Economic Research (DIW). The Japan Household Panel Survey is conducted by the Panel Survey Research Center at Keio University. The center has combined panel two surveys (JHPS/KHPS) that provide a larger sample extended from 2004 to the present, but with the same survey variables supplied to the LIS. We obtained that data directly from the Panel Survey Research Center. The United States' Current Population Survey (CPS) is conducted by the U.S. Census Bureau. Both the GSOEP and the JHPS/KHPS are structured as panel datasets, but they are used in a cross-sectional form in the LIS. The annual U.S. CPS has a cross-sectional structure.

obtained the data directly from the Panel Survey Research Center at Keio University where data were available for the survey for an expanded period of 2004 to 2018.[22]

In the first set of regressions, we use a standard specification of the Mincer equation in which the wage is related to the level of educational attainment, the worker's age, and a set of control variables that differ across the three countries:

$$\ln(Y)_i = \alpha_i + \beta_i \cdot S_i + \delta_i \cdot Age_i + \gamma \cdot Age_i^2 + \lambda \cdot X_i \ ,$$

where Y_i is annual labor income (including self-employment), S_i is a set of categorical variables measuring educational attainment, and Age_i is the worker's age at the time of the survey. X_i represents a set of control variables (such as weekly hours worked, marital status, temporary and part-time work, and standard retirement age). Alpha subscript i is the constant (cons in Table 2). The categorical variables for schooling are based on years of education: less than secondary (<12), secondary (12-13), some post-secondary (14-15), university degree (16-17), and postgraduate (18+). Secondary is the omitted category, so all the education measures are relative to that level of attainment—workers that had completed secondary education but not more than that. Vocational training in Germany and less than 4-year college in Japan and the United States are effectively coded as equivalent. We also estimated a constrained version of the earnings relationship in which annual income was divided by weekly hours to construct a measure of the wage rate, the results of which are shown in Appendix 1. Separate relationships are reported for male and female workers. Spouses of survey respondents are included. We also experimented with dividing the estimation period into three subperiods.

The basic results are reported in Table 2. Because the results for the subperiods were remarkably similar, we focus on a regression that included all the available years. The more detailed results for three subperiods are reported in Appendix 2. However, we found no significant support for the hypothesis that the marginal returns to education have varied over the full estimation period—a surprising and perhaps important result. As we have said, there is much interest in whether the returns to education have changed over time. They may have increased because of increases in the demand for educated labor (skill-biased technical change). Alternatively, the returns to education might have fallen because of an oversupply of educated labor. The results we obtained indicate that neither effect has predominated in the three countries—the increase in demand for educated labor has offset the increased supply of educated labor.

[22] Working through problems with the data has been time-consuming. Once the data was in shape, getting the results was comparatively easy, but ensuring that it was comparable with that of the United States and Germany was complex.

Table 3. Regression results, common specification, labor return by level of educational attainment

	Germany		US		Japan	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
edyrs1	-0.320***	-0.311***	-0.349***	-0.340***	-0.201***	-0.119***
edyrs3	0.202***	0.199***	0.161***	0.197***	0.142***	0.080***
edyrs4	0.365***	0.235***	0.440***	0.450***	0.204***	0.195***
edyrs5	0.588***	0.497***	0.723***	0.734***	0.471***	0.442***
age	0.096***	0.088***	0.062***	0.048***	0.098***	0.040***
age_sq	-0.093***	-0.084***	-0.061***	-0.046***	-0.097***	-0.037***
age65+	0.101***	-0.002	0.066***	0.044***	-0.307***	-0.042
married	0.157***	0.013**	0.197***	0.037***	0.319***	-0.108***
ptime	-0.765***	-0.237***	-0.462***	-0.394***	-0.969***	-0.847***
loghours	0.594***	0.934***	0.508***	0.579***	0.167***	0.423***
Constant	5.703***	4.435***	7.074***	6.924***	12.077***	12.228***
R2	0.469	0.513	0.321	0.357	0.488	0.510
N	103,134	100,815	584,660	537,946	20,448	15,508
RMSE	0.657	0.701	0.731	0.701	0.508	0.620

Source: Authors' calculations using data supplied by Luxembourg Income Study and the Panel Data Research Center at Keio University. p values less than .001 are identified by ***, and a p value of less .01 by **.

The regression results were based on a logarithmic specification where, for example, the coefficient of 0.44 associated with a university education for males in the United States would indicate that men with a college degree earn a wage premium of this magnitude compared to high school graduates.[23] A key result for understanding productivity impacts of education in the three economies is that the college wage premium is notably smaller for Japan (0.20 log points for male workers) than in the United States (0.44) and Germany (0.36). Under the assumption that wages reflect the marginal productivities of workers, a larger premium for workers with college educations means they are able to contribute more to the performance of their companies based on their skills. If a student studies subjects like science or engineering (or other STEM subjects), one can see immediately how that would contribute to a firm's productivity. In addition, training in history or other liberal arts subjects can help students think clearly and be better able to conceptualize problems. The evidence here only identifies the differences among the countries in the returns to education, but these differences do suggest further research would be helpful to examine why the returns to college are lower in Japan and to look for ways to boost the wage and productivity returns from college education.

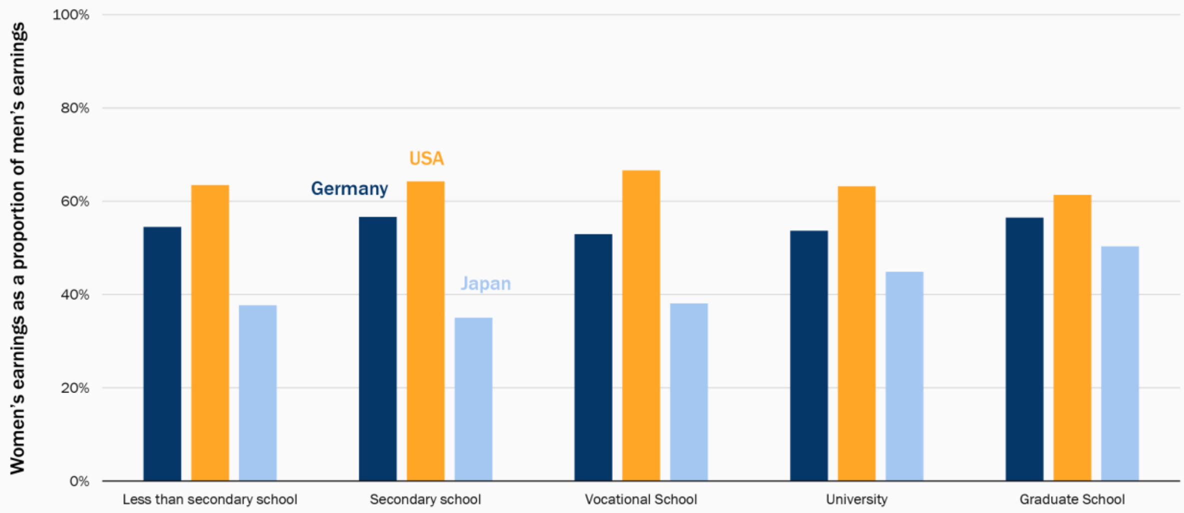
An alternative reason for the greater college wage premium in the United States is that the wages of workers with a high school education have been stagnant or falling. Workers in Japan that enter employment after high school are more likely to have stable career paths and have on-the-job training. A challenge for the United States is to improve the education and training opportunities of workers that do not go to college to help them avoid dead-end jobs with low pay.

The relative marginal returns to education are nearly equal for men and women in Japan and the United States, but slightly smaller for women in Germany. The post-graduate wage premium relative to a

[23] Logarithmic formulations do not match with percentage differences exactly, but it may be helpful to think of the college wage premium in the United States as being roughly 44%.

university degree is large in all three countries. The results for men and women indicate that the incremental or marginal benefit from college is similar between the sexes. This does not mean that the two sexes earn the same wages. There is a substantial gap in earnings between men and women in our data, across all three countries in our sample. As Figure 3 demonstrates, the average woman earns less than 70% of the average man at all education levels. In Japan, this figure drops to as low as 35% for women with a secondary school education.

Figure 3. Raw Gender Wage Gap by Educational Attainment

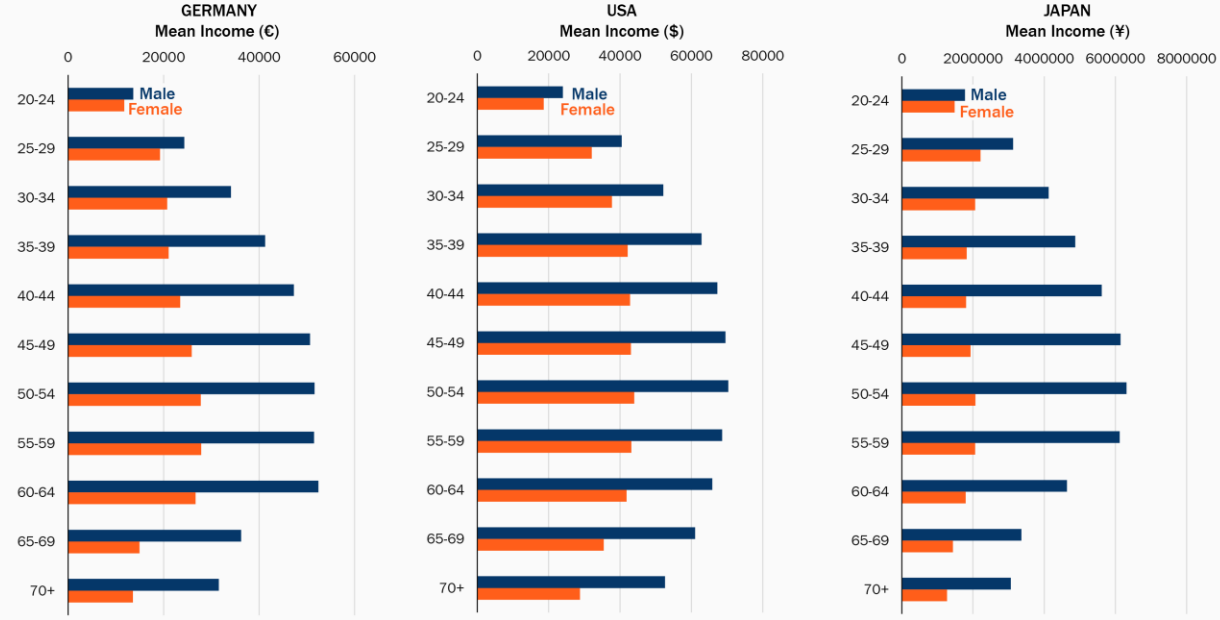


Source: Authors' calculations using data supplied by Luxembourg Income Study and the Panel Data Research Center at Keio University.

Some of this gender gap also comes from the relatively flat earnings profile over time that women face. Figures 4A-4C show the age profiles by gender for each country in our dataset. While men's earnings increase as they grow older until their 50s (and even their 60s in Germany), women's earnings peak earlier and increase less. They do not move up the job ladder in the same way that men do. This is especially a problem in Japan, where women's earnings appear to remain flat throughout their lifetime, even as men's earnings rise dramatically until their mid-50's. *That suggests another mechanism by which productivity can be enhanced in all three economies, and notably in Japan*. There are talented women that are not in jobs that allow them to be as productive as they could be. That is a cost to them, as they are trapped in unrewarding positions, and it deprives the economy of the full talents of women workers.

More insight into the male-female earnings differential comes from the control variable for marital status. This has a highly positive association with male earnings in Japan and a negative association with the earnings of women. In traditional family relationships, men were expected to be the family breadwinner while women were expected to stay at home and look after the household. Historically, female labor force participation has been low. If a woman worked, it was often in a low-paying, undemanding job that did not interfere with her duties in the family. That model of the family is changing in all societies as women are demanding more opportunities to choose whether to work and to aspire to more rewarding and better-paid careers. Labor force participation among women in Japan has risen substantially, but unfortunately the rewards from work have not grown commensurately. Our results indicate that men tend to increase their earnings when they marry, but women's earnings decline.

Figure 4. Earnings by age and gender



Source: Authors' calculations using data supplied by Luxembourg Income Study and the Panel Data Research Center at Keio University.

The coefficient on the control variable for marital status is smaller but still statistically significant in Germany and the United States, and the coefficient is positive for women in the United States. The role of marital status in the regressions is tricky to interpret even though it has very strong statistical effect. It is likely that marriage changes labor market behavior, but it is also likely that those who marry differ in preferences and abilities from those that do not marry. The findings on the impact of marriage should be viewed with caution.

As we would anticipate, earnings are substantially lower for part-time workers, and the effect is particularly large in Japan.

The measure of labor earnings applies to income in the prior calendar year, whereas our only measure of work hours is for a typical week in the survey year. Thus, the dependent variable in our basic equations is the prior year's earnings (wages and self-employment income), and we included the logarithm of weekly hours as a right-hand-side determinant. The coefficient on hours is very significant, and it accounts for major portion of the explained variation but less than the unity value that might be expected if its time dimension were the same as for earnings.

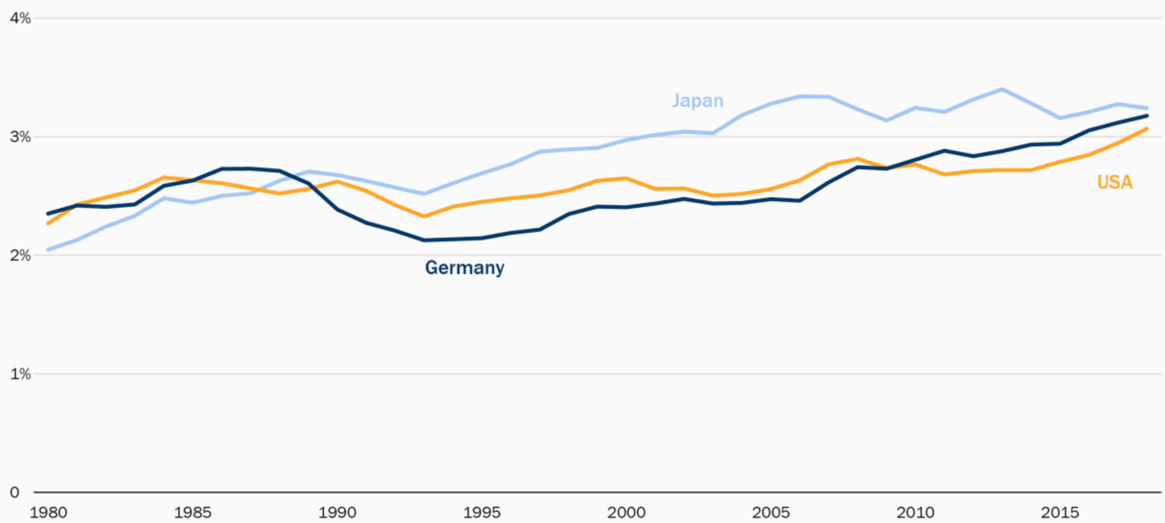
In Appendix 3, we report versions of the earnings regression with a constrained unity value for the coefficient on log hours to form an estimated wage rate. Interestingly, the constraint has little or no effect on the return to education, but it does change the role of part-time labor. We also show the results of estimating the regression separately for the three subperiods in Appendix 2. Again, there is only a trivial impact on the coefficients for the levels of educational attainment, with the exception of postgraduate education in Germany in the 2004-2008 time period for which we found no available data.

Innovation and the role of the educational system

Once a country has advanced to the point where most of its industries are operating at the technological frontier, the opportunity to raise productivity and living standards by replicating the production processes of other countries is greatly diminished, and future gains are reliant on its own ability to innovate new products and production processes. As a result, innovation has become the central driver of economic growth in many high-income advanced economies, and policies to promote innovation have become critical elements of countries' economic development strategies. The advance of technology is a world-wide phenomenon, of course, so innovation strategy must involve adopting new ideas wherever they are generated and adapting new technologies from abroad to work well in the home country.

Until the rise of China in the 2000s, the three countries in our analysis dominated R&D spending and the issuance of patents at the global level. As shown in Figure 5, Japan moved ahead of the United States in the proportion of its GDP that it devoted to R&D in the late 1980s. The percentage dropped in the immediate aftermath of Japan's 1990 financial crisis, but then rose strongly until the global financial crisis of 2008. U.S. R&D spending has fluctuated about an average of 2.6 percent of GDP, with little evidence of a discernable trend. Spending was equally strong in Germany but dropped sharply under the financial pressures of East-West integration in the 1990s. It recovered in subsequent decades and moved back ahead of the United States in 2010. In the latest available year (2019) the three countries devoted nearly identical shares of their GDP (3.2%) to R&D expenditures. According to the OECD, the proportion of the workforce devoted to research is equally similar: Germany (10.3%), Japan (9.9%) and the United States (9.5%).

Figure 5. R&D Expenditures as a Percent of GDP, 1980–2019



Source: OECD, Main Science and Technology Indicators, 2021 edition.

The three countries also have similar distributions of R&D funds, as the business sector provides most funding and conducts the largest share of the performance (Table 4) in all three. But the role of the business sector is more dominant in Japan relative to Germany and the United States, and the function of the government sector is correspondingly reduced. The contribution of the government is amplified in Germany because it includes the activities of non-university research institutions.[24] The proportion of R&D undertaken within universities is also high in Germany and low in Japan.

[24] They are coordinated within four umbrella organizations: the Fraunhofer Society (FhG), Max Planck Society (MPG), Helmholtz Association of German Research Centres (HGF) and the Leibniz Association (WGL).

Table 4: R&D performance and funding by country

	R&D performance (% of total)			
	Business	Government	Higher education	Private nonprofits
Germany	68.89	13.54	17.58	N/A
Japan	79.42	7.74	11.56	1.27
United States	73.36	9.91	12.33	4.4
	R&D source of funds (% of total)			
	Business	Government	Other domestic	Rest of world
Germany	66.01	27.85	0.35	5.8
Japan	79.06	14.56	5.77	0.61
United States	63.12	22.35	7.3	7.23

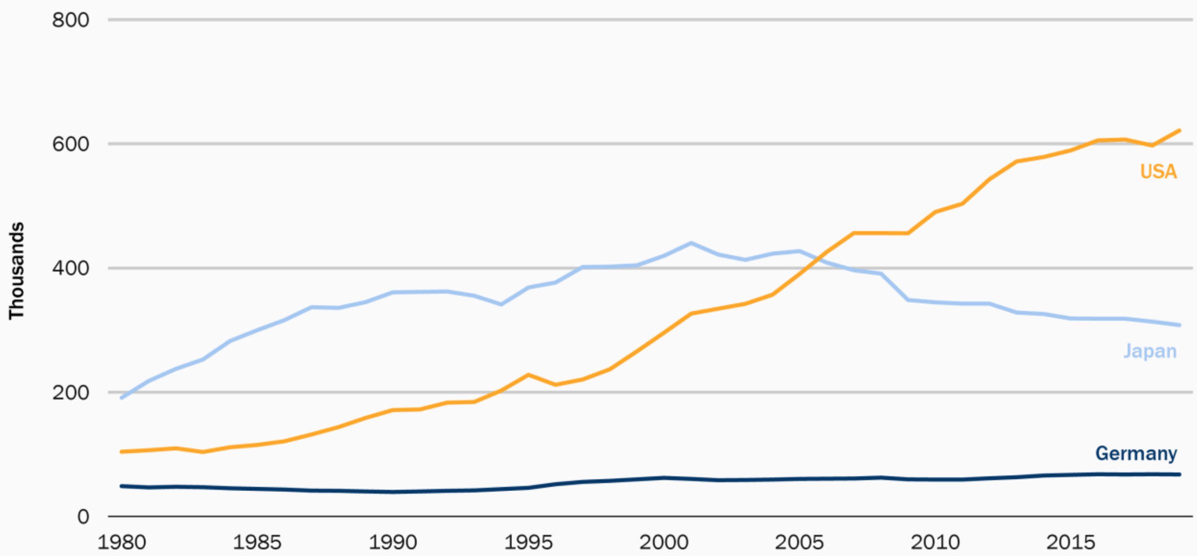
Source: OECD, *Main Science and Technology Indicators, 2020.*

Patenting

While expenditures on R&D represent comparable shares of GDP, it is very difficult to devise a means of evaluating their effectiveness. A simple measure of the output of R&D activities is provided by the count of patent allocations as shown in Figure 6 for the 1980-2020 period. That criterion shows a strong upward trend for the United States, a declining pattern for Japan since 2000, and a constant level for Germany. However, it is important to remember that the United States is a much larger country, and adjusted for the size of its labor force, the level of patent activity is higher in Japan than in the United States but still with a declining trend.

In addition, the quality and value of patents may vary across countries and over time. The valuation of physical assets can rely on their market prices, but an active market for patents is a rare occurrence. In a few situations, it may be possible to focus on the market value of the companies that hold the patents, but its application is also limited. This lack of a market valuation for most patents is a major limitation on efforts to use information on patents activity as a measure of the output of R&D activities. Furthermore, the current efforts to develop COVID-19 vaccines highlight the additional complication that the private valuation of R&D may be a very inadequate measure of its social value.

Figure 6. Total Patent Applications, 1980–2019



Source: World Intellectual Property Organization.

B Economic Studies at BROOKINGS

Most recent work on the construction of measures of patent quality or value rely on composite indexes that combine several elements (Lanjouw and Schankerman, 2004). For example, researchers at the OECD proposed a composite index of four to six dimensions (Squicciarini, Dernis, and Criscuolo, 2013). By their measure, the quality of patents in the United States ranked above those of Japan and Germany, but the differences were small. They also conclude that there had been a general decline in overall patent quality between 1994 and 2004.[25]

A similar approach used by the World Intellectual Property Organization (WIPO) relies on the construction of a broader composite Global Innovation Index that divided into an innovation input sub-index with five groupings and an innovation output sub-index with two groupings.[26] The overall innovation index is an average of the input and output sub-indexes.[27] In the 2020 report the United States is ranked 3rd in the world, Germany is 9th, and Japan is 16th.

Innovation

Germany

Germany has a very diverse R&D system. The business sector plays a somewhat reduced role, and the government is the principal funder of over 400 independent research institutes. At the same time, there are 142 universities with active research programs. The research institutes have been perceived as playing the leading role in research and receive a disproportionate share of the government's research budget. In many cases, the individual institutes have been built around the notion of maximizing the contributions of

[25] Their index incorporated the number of forward citations (up to 5 years after publication), patent family size, the number of claims, an index of patent generality, plus the number of backward citations and the length of the examination process. An additional application of their work is provided in Bahar and Strauss (2020).
[26] The index is closely related to earlier work by Furman, Porter, and Stern (2010) who constructed an index of national innovative capacity.
[27] Further details are available in appendix 1 of the 2020 edition.

a prominent senior researcher as head of the institute with full control of hiring, budget allocation, and determination of the research priorities. Universities are charged with the primary function of educating and training the nation's future scientists, and while they are expected to undertake research, it has been regarded as secondary to their teaching role. This combination of government-financed research institutes and research universities is known as the dual-pillars policy. This structure has been questioned in recent years as the universities came under increased financial pressure to meet the needs of a greatly expanded demand for tertiary education.

An evaluation of the dual-pillar system was undertaken by a recent study that focused on authorship of STEM+ journal publications (Dusdal et al., 2020). They find that the research institutes have been successful in generating a large amount of top-tier research, but the universities have generated a larger proportion of the nation's science publications despite their lower level of funding. They express concern about the sustainability of a dual-pillar system that underfunds university-based research efforts.
A broader critique of the German innovation system is provided by a recent discussion of its historical performance (Naudé and Nagler, 2021). The authors argue a decline in innovation within Germany follow a more general pattern of deteriorating performance across a broad number of advanced economies (Bloom et al., 2020; Gordon, 2015; Jones, 2009). They point to a fall in research productivity, a reduced rate of return on R&D spending, and lower patent citations as primary indicators. They blame the decline in Germany on (1) an excessive focus on incremental improvements in existing industries as opposed to efforts to achieve more radical innovations that would lead to new industries, (2) a slower diffusion of technology, (3) a lower capacity to learn and adopt new technologies, and (4) a weak entrepreneurial system. These criticisms are very similar to the efforts to explain the slower pace of innovation and other advanced economies.

United States

The United States' education system does not perform well in inducing its own students to participate in STEM (Science, Technology, Engineering, and Mathematics) programs at the level of primary and secondary education, and as discussed previously, American students perform poorly in international achievement tests aimed at measuring the quality of their education. Yet the U.S has offset much of that weakness by attracting large numbers of foreign students with STEM training to pursue their education at U.S. universities.

Foreign students comprise 22 percent of graduates from U.S. post-secondary STEM programs, and the percentages rise to 54% for master's degree and 44% for doctorate degree programs (Granovskiy and Wilson, 2019). International students can remain in the U.S. for one year after graduation, and those with a STEM degree can stay for an additional two years to obtain practical training. Furthermore, many will apply for H-1 employment visas to remain even longer.

In addition, American technology firms rely on visa programs to bring in large numbers of foreign trained workers. Foreign-born workers comprise 17 percent of the overall U.S. workforce, but they accounted for 23 percent of the STEM workforce in 2016.[28] Furthermore, 26% of U.S.-based Nobel Prize winners from 1990 through 2000 were foreign-born. Based on a 2003 survey, U.S. immigrants with a 4-year college degree were twice as likely to have a patent than U.S.-born college grads (Hunt and Gauthier-Loiselle, 2010).[29]

There has also been a rapid development of R&D centers in emerging market economies like India and China. This development has been driven in part by increased restrictions on immigration into the United States. Multinational corporations (MNCs) faced with visa constraints have an offshoring option: namely, hiring the labor they need at their foreign affiliates. The effect is strongest among MNCs that are more

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[28] STEM occupations are defined as engineers, mathematical and computer scientists, natural scientists, and sometimes include physicians (STEM+).
[29] See additional recent articles on immigration by Azoulay et al. (2020), Brown et al. (2020), and Kerr and Kerr (2020).

R&D-intensive, that operate in industries in which services can be more easily offshored, and that were more reliant on H-1B visas prior to the cap restrictions.

Three countries account for much of this increase in MNCs' activity overseas: India, China, and Canada. India and China are prominent because they were the source of a high percentage of the skilled labor that firms hired before visas became scarce. Canadian workers are hired at a high rate because of their country's proximity to the United States and its more relaxed rules on high-skilled immigration. However, the United States enjoys other advantages for the location of R&D beyond its ability to attract high-skilled immigrants. Its academic research institutions dominate world rankings, and it operates a strong system of intellectual property protection, a generous scheme of tax credits and subsidies to various forms of research, and a financial system that provides substantial venture capital financing.

Japan

The immediate post-war years presented Japan with an extraordinary opportunity for rapid economic growth based on recovery from wartime destruction, the potential for technology transfer from the West, and a workforce that had acquired the basic levels of knowledge and skills needed to operate a large factory system. Those conditions elevated the return to physical capital and Japanese industry responded with an extraordinarily rapid rate of capital accumulation.

Over the four decades from 1950 to 1990, increases in physical capital per worker were the driving force behind the so-called "Japanese Growth Miracle," but Japan also continued to catch up to the West with rapid gains in mid-level education and extensive on-the-job training programs. In the 1980s, it became a global leader in the production of high-quality, mass-produced industrial products, contributing important innovations in industries such as steel, automobiles, machine tools, high-speed trains, and consumer electronics. The result was extraordinary success in developing new and improved products and production processes. Innovations such as the Toyota production system and the development of computer-controlled machine tools, gave Japanese companies and industries a leading role in productivity and performance worldwide. The innovative capacity of Japanese firms was widely admired, and some argued that Japan had moved ahead of the United States in many critical technologies (Mansfield, 1988; National Research Council, 1992).

However, the extraordinary success of the 1980s also touched off an asset-price boom of unprecedented magnitude. The prices of corporate equity and real estate soared to unsustainable levels and ultimately collapsed in the early 1990s. The crash of asset prices led in turn to severe financial dislocations to which the government was slow to respond, and the resulting economic crisis forced Japanese firms to reduce their spending on R&D and distracted attention from the need to broaden the structure of the underlying growth process.

As shown in Figure 5, Japan's spending on R&D turned down as a share of GDP in the early 1990s before recovering and moving ahead of the United States and Germany. It peaked in 2007 and then declined again and remained constant as a share of GDP in subsequent years. There has also been a heightened concern about the productivity of R&D as patent applications have steadily declined after 2000.

After the slow growth of Japan's "lost decade," the evaluation of the Japanese innovation system also has turned much more negative (Goto, 2000; Branstetter and Nakamura, 2003; Yamashita, 2021). Japan continues to benefit from the presence of a large pool of scientists and engineers. However, it has a small number of researchers with advanced degrees, and it suffers from a relative lack of world-class research institutions and collaboration between those institutions and the private sector.

Bahar and Strauss (2020) argued that while Japan allocates more resources to R&D per capita than Germany and the United States and develops more patents per capita, the quality of Japanese innovation lags these countries. In follow-up research, Bahar and Ozdogan (2021) suggest that a reason for this quality deficiency is that Japan engages in fewer international collaborative research efforts.

Yamashita (2021) evaluated the relative performance of Japan's research programs by using patent citations as a measure of the quality of the patents. He used patent data from the United States Patent and Trademark Office (USPTO) for the period of 1980-2011, sorted by country of origin. The analysis was based on a differences-in-differences regression model with a control group of 11 other countries (including the United States).[30] The use of a single patent office ensures a common standard, and the analysis was performed annually to control for changes in the methodology of the USPTO. The study found a 14 percent decline in patent citations after the 1991 crisis, and the annual effects estimates were negative—but with declining magnitude—throughout the 1991-2006 period. He interpreted the results as being very suggestive of a decline in the productivity of Japanese R&D in the years after the 1991 crisis.

Venture capital funds

According to data from the OECD, the overwhelming proportion of R&D is conducted in large business enterprises with more than 1000 employees. The proportion ranges from 55 percent in Germany and the United States to over 65 percent in Japan. Large corporations are in turn likely to have the internal capability to bring sophisticated technological products to market. Much of their R&D is directed at incremental improvements in their existing product line, and the ability to introduce new models and enhancements on a regular basis is a critical component of their competitive strategy.

However, commercialization is likely to represent a bigger challenge to new small firms that do not have the same accumulated knowledge and background. Small firms and startups also lack the regular flow of revenues from existing products to support their development efforts, and they face significant barriers accessing traditional financial sources. Yet, it is often argued that small firms and startups are more likely to be the source of breakthrough innovations (Baumol, 2004). With their lack of bureaucracy, small entrepreneurial firms can react quickly to take advantage of new opportunities. It is for these startups that venture capital markets have emerged as a critical source of support.

Over the past half century, venture capital (VC) has emerged as an important alternative source of financing for high-potential startups that are focused on the commercialization of risky new ideas and technologies. Venture capital has been particularly significant in the United States where venture-capital-backed firms accounted for about half of the initial public offerings (IPOs) between 1995 and 2019 (Lerner and Nanda, 2020). Several of the country's largest corporations relied on venture capital financing in their formative years. VC-backed firms also have represented about 90 percent of the R&D spending reported by all IPOs.[31] According to the OECD, venture capital investments amounted to $152 billion in 2019, and 90 percent of these investments were in the United States. However, at the scale of the total economy venture capital investments remain small, representing about six tenths of a percent of GDP in the United States, and less than a tenth in Germany and Japan.[32]

The liberalization of regulatory restrictions on pension fund investments played an important role in the initial growth of the VC market in the United States, but in recent year years VC funds have attracted very diverse funding—including public and private pension funds, insurance companies, individuals, university endowments, and foundations. Typically, a venture capital firm will create a limited partnership with the investors as limited partners and the firm itself as the general partner. Each fund is a separate partnership with a lifespan of 7 to 10 years. The payoff comes after the company is acquired or goes public. About 15-20 percent of fund exits are the result of an IPO and half are through a merger or acquisition (M&As). In addition, the U.S. has experienced significant growth in corporate venture capital funds (CVC), which accounted for about 20 percent of overall VC activity in 2018.[33] CVCs are established with the objective of

[30] The three countries on which we have focused-the United States (53%), Japan (20%), and Germany (7%)-dominate the sample.

[31] Mergers and acquisitions (M&As) are an increasingly popular alternative to IPOs by which investors can exit their positions in venture-backed companies.

[32] From OECDstat, OECD Entrepreneurship Financing Database: Venture Capital Investments.

[33] **National Venture Capital Association, 2021 Yearbook**

investing a firm's funds directly in new external startups as opposed to being a limited partner in venture capital funds managed by others.

While the level of investments in startups remains small in Japan, they have expanded rapidly in recent years, quadrupling between 2013 and 2018 (Takeshita, 2020). The expansion has been encouraged by the liberalization of regulations that previously limited such activity. In contrast to the diversity of funders in the United States, banks and nonfinancial corporations account for about 60 percent of venture capital funding in Japan.[34] Again, unlike the United States, the IPO remains the dominant form of exit because acquisitions of outside firms and their culture continues to have a negative connotation in Japan. Cultural factors, broadly defined, appear to be the major barrier to the growth of innovative small firms. While the government has sought to increase the supply of funds, there is a shortage of young entrepreneurs willing to undertake the risks of forming a new company.

While venture capital investments have also grown in Germany and it is the leading source of VC financing within the EU, the volume of investments as a share of GDP is only slightly larger than in Japan and less than a tenth that of the United States. There is a much higher incidence of startups with a valuation of $1 billion than in Japan. In addition, the German economy has many small and medium-sized manufacturing companies (the Mittelstand companies). These companies are successful innovators despite their modest size. They find the resources to innovate by a focus on niche products, they mostly make incremental innovations, and they have constant interaction with customers to determine where innovations will be successful (De Massis al. 2017). They are export oriented.

Lessons on the education system, productivity, and innovation

There is a widespread view that slow productivity growth among all the advanced economies is the result of a lack of major advances or innovations pushing out the productivity frontier.[35] This is the broad context within which the advanced economies are operating. There are, however, important differences among the three economies that suggest policy or institutional changes could provide a stimulus to faster growth in each of them. That is particularly the case for Japan where productivity remains lower than in the United States and Germany, as we noted in our earlier work (Baily, Bosworth, and Doshi, 2020). Why does Japan lag? And what could be done to close the gap?

Our answer is threefold. First, the education system beyond high school does not provide the same boost to the productivity and wages of graduates that is achieved in Germany and the United States. That makes a clear case for reform of the higher educational system in Japan and perhaps of the way in which companies select and hire college graduates. Faculty should be judged on some combination of their teaching and research skills; there should be competition for academic positions; and tenure and salaries should be geared to performance even after a permanent academic position has been obtained. Students should be encouraged to complete academic courses with strong intellectual content that require independent thinking and originality. Employers should hire new graduates based on their demonstrated performance in their university training, and ability to conceptualize, think clearly and be original should be prized by employers as they select graduates to hire into their companies. There can positive benefits from a labor market that provides lifetime employment and seniority-based promotion, but firms must look for ways to maintain motivation and encourage risk taking.

The second concern about Japan and its ability to match other countries in terms of innovation and productivity comes from the lack of international engagement in the labor market and in R&D. We noted earlier the work of Bahar and Ozdogan (2021) that suggested international collaboration in R&D was important to improving the productivity of this activity. Perhaps even more important to overall economic growth is the fact that few highly talented immigrants are allowed or encouraged to come to Japan. High-skill immigration is seen as one of the success factors for innovation in the United States. A paper by Baily (2020) pointed to the importance of immigrants: "Foreign-born individuals have made major

[34] Takeshita (2020).
[35] See, for example, Gordon (2015).

contributions both to U.S. entrepreneurship and to science and technology. A 2016 study looked at U.S. startups that were, at the time, valued at $1 billion or higher and found that more than half, 44 out of 87, were started by immigrants, and immigrants were key members of management or development teams in over 70 percent of these companies. The New York Times in 2017 argued that Silicon Valley simply would not work without immigrants."

The importance of immigrants goes back many years. We noted the strength of American universities, which benefitted from the flow of high ability academics that fled from Europe. This contrasts with Japan where immigration is difficult and there has not been the same potential for foreign entrepreneurs to come and establish new innovative businesses. Given its current very low birthrate, Japan should consider encouraging more immigrants into its economy and society.

The third lesson for Japan is that it should use more effectively the talents and capabilities of its female workforce. Women are no longer choosing to stay home and instead are looking for careers that give them inspiration and meaning. America and Germany are far from perfect in this regard, but they do seem to be ahead of Japan. Women can win Nobel prizes, earn patents, serve on corporate boards, and manage offices, and they should have the opportunity to choose these careers. Japanese society should welcome the changing status of women as providing a huge pool of talent that can jump start faster growth.

The United States also has lessons to learn. The most important lesson is that the education and training system is failing young people that do not go on to become college graduates. While the great majority of young people graduate from high school, their diplomas do not guarantee that they have acquired the skills needed to find productive jobs. As we have said, young Americans perform poorly on standardized tests compared to other countries. After high school, most students enter some form of further education, seeking a diploma from a training academy or entering a community college. The dropout rates from these programs are very high, however, especially among young men. Companies provide the minimum of training, choosing instead to devise business models that allow them to hire cheap labor. The U.S. labor market is more flexible than that in Japan, but a downside is that companies do not see the benefit of providing much training when an employee is likely to leave for another job after a short time. These labor market failures also extend to older workers that lack the opportunity to receive retraining or find good jobs if they are laid off.

A related concern in the U.S. economy is that its strength in innovation, particularly in high-tech fields, does not spillover into good jobs for enough high school graduates. For instance, Apple is one of the most successful companies in the world, with a huge market value and a worldwide presence. It employs a lot of people, but it manufactures almost nothing, choosing to outsource to suppliers in China and elsewhere. Amazon is also a global leader, has created huge market value and creates many jobs. However, most of these are warehouse employees earning modest incomes. The American manufacturing sector remains a very large one, second only to China's, but it concentrates on activities that do not require large numbers of production workers and it is highly automated, so that its share of total employment has been declining for 50 years (Baily and Bosworth, 2014). Thus, while the United States is a strong innovator, the benefits from this are not being spread widely through the economy.

Germany's economic strength is concentrated in manufacturing, and it has been a strong innovator, particularly in areas such as machine tools where it may often be the sole global supplier for important products. VW is the largest producer of autos worldwide. Policymakers have provided subsidies to companies to preserve jobs in Germany, both in manufacturing and non-manufacturing, and the government also supports a very large apprenticeship program. Apprentices learn practical skills that allow them to move into employment, but they also learn academic skills that feed into their future jobs or allow them to shift jobs as technology changes.

In recent years, as we have said, Germany has expanded the share of youth entering universities, and the country has strong universities and research organizations. Still, it largely missed out on the digital revolution and lacks a high-tech sector that rivals Silicon Valley. Germany has the dominant economy in Europe and is a massive net exporter, but a concern is that it has achieved its economic success in part at the expense of its neighbors, notably southern Europe.

German productivity growth has been weak in the past twenty years and one reason cited is that it has absorbed a very large number of immigrants that, on average, lack skills or higher education. Unlike the United States, however, Germany has made substantial efforts to absorb these immigrants, teach them German, and help them acquire the skills needed for good jobs.

In short, Germany's education system is ahead of the American system in providing a skilled workforce. It is behind the United States in terms of top-ranked universities, like Stanford and MIT, where there is a ferment of innovative ideas and where professors and students move back and forth between the classrooms and company labs and boardrooms.

In seeking to improve their long-term growth, all three of the countries that we examine must pay attention to the role that their educational systems play in preparing students for productive, impactful careers, and in spurring the innovation necessary for sustained economic growth.

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Appendix 1: Regression results with wage rate approximation as dependent variable

Table A1: Regression results, Dependent variable annual income scaled by annual hours worked

	Germany		US		Japan	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
edyrs1	-0.281***	-0.298***	-0.339***	-0.337***	-0.260***	-0.167***
edyrs3	0.175***	0.192***	0.157***	0.196***	0.167***	0.131***
edyrs4	0.364***	0.230***	0.432***	0.447***	0.222***	0.218***
edyrs5	0.559***	0.489***	0.704***	0.720***	0.468***	0.359***
age	0.088***	0.090***	0.058***	0.044***	0.071***	0.033***
age_sq	-0.086***	-0.087***	-0.057***	-0.042***	-0.066***	-0.030***
age65+	0.218***	0.051	0.080***	0.069***	-0.263***	0.021
married	0.165***	0.020***	0.187***	0.045***	0.294***	-0.013
ptime	-0.416***	-0.194***	-0.099***	-0.095***	-0.603***	-0.544***
_cons	4.318***	4.139***	5.300***	5.429***	9.461***	10.259***
r2	0.277	0.183	0.213	0.182	0.232	0.154
N	88965	86361	584660	537946	20448	15508
rmse	0.656	0.704	0.739	0.710	0.652	0.716

Source: Authors' calculations using data supplied by Luxembourg Income Study and the Panel Data Research Center at Keio University.

Appendix 2: Regression results by time period

Table A2: Regression results, labor return by level of educational attainment over time, Japan

Japan	**Male**			**Female**		
	2004-08	*2009-13*	*2014-18*	*2004-08*	*2009-13*	*2014-18*
edyrs1	-0.187***	-0.206***	-0.191***	-0.104	-0.04	-0.141**
edyrs3	0.138***	0.176***	0.128***	0.072	0.092***	0.067***
edyrs4	0.216***	0.231***	0.176***	0.184***	0.213***	0.175***
edyrs5	0.376***	0.483***	0.492***	0.04	0.420***	0.483***
age	0.125***	0.107***	0.087***	0.031*	0.047***	0.030***
age_sq	-0.132***	-0.107***	-0.084***	-0.022	-0.045***	-0.027***
age65+	-0.150*	-0.255***	-0.365***	-0.259**	0.012	-0.064
married	0.376***	0.298***	0.308***	-0.142***	-0.130***	-0.096***
ptime	-1.029***	-0.956***	-0.948***	-0.910***	-0.874***	-0.818***
loghours	0.146***	0.184***	0.171***	0.364***	0.396***	0.445***
_cons	11.636***	11.825***	12.308***	12.526***	12.204***	12.399***
r2	0.491	0.486	0.483	0.456	0.514	0.529
N	2846	7483	7725	1922	5632	6004
rmse	0.542	0.513	0.493	0.699	0.609	0.600

Source: Authors' calculations using data supplied by the Panel Data Research Center at Keio University.

Table A3: Regression results, labor return by level of educational attainment over time, United States

US	**Male**			**Female**		
	2004-08	*2009-13*	*2014-18*	*2004-08*	*2009-13*	*2014-18*
edyrs1	-0.348***	-0.357***	-0.324***	-0.349***	-0.341***	-0.320***
edyrs3	0.159***	0.167***	0.143***	0.200***	0.199***	0.168***
edyrs4	0.420***	0.436***	0.447***	0.427***	0.437***	0.451***
edyrs5	0.700***	0.724***	0.727***	0.697***	0.721***	0.728***
age	0.069***	0.064***	0.055***	0.052***	0.051***	0.046***
age_sq	-0.071***	-0.063***	-0.054***	-0.053***	-0.050***	-0.044***
age65+	0.075***	0.065***	0.037**	0.050**	0.041**	0.035**
married	0.212***	0.201***	0.199***	0.025***	0.040***	0.060***
ptime1	-0.427***	-0.457***	-0.489***	-0.370***	-0.392***	-0.416***
loghours	0.535***	0.533***	0.470***	0.598***	0.589***	0.546***
_cons	6.762***	6.926***	7.438***	6.716***	6.822***	7.163***
r2	0.294	0.362	0.320	0.323	0.393	0.360
N	208804	185583	190273	191022	173119	173805
rmse	0.767	0.691	0.717	0.729	0.661	0.696

Source: Authors' calculations using data supplied by Luxembourg Income Study.

Table A4: Regression Results, Labor Return By Level of Educational Attainment Over Time, Germany

Germany	**Male**			**Female**		
	2004-08	*2009-13*	*2014-18*	*2004-08*	*2009-13*	*2014-18*
edyrs1	-0.241***	-0.298***	-0.312***	-0.290***	-0.318***	-0.305***
edyrs3	0.151***	0.206***	0.232***	0.178***	0.199***	0.196***
edyrs4	0.363***	0.387***	0.374***	0.224***	0.257***	0.202***
edyrs5	0.557***	0.619***	0.584***	0.454***	0.535***	0.477***
age	0.098***	0.095***	0.092***	0.104***	0.095***	0.082***
age_sq	-0.097***	-0.095***	-0.090***	-0.106***	-0.092***	-0.075***
age65+	0.122*	0.158***	0.112*	0.067	0.056	-0.073
married	0.166***	0.168***	0.160***	0.029**	0.005	0.023*
ptime1	-0.821***	-0.825***	-0.704***	-0.284***	-0.266***	-0.215***
loghours	0.554***	0.568***	0.657***	0.898***	0.912***	0.948***
_cons	5.784***	5.814***	5.576***	4.293***	4.326***	4.545***
r2	0.443	0.470	0.497	0.510	0.519	0.516
N	27592	39199	22174	24988	38535	22838
rmse	0.636	0.648	0.649	0.690	0.718	0.687

Source: Authors' calculations using data supplied by Luxembourg Income Study.

Appendix 3: Regression results with coefficient on hours constrained to unity

Table A5: Regression Results, Labor Return by Level of Educational Attainment, Constrained Coefficient on *loghours*

	Germany		**US**		**Japan**	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
edyrs1	-0.281***	-0.298***	-0.339***	-0.337***	-0.260***	-0.167***
edyrs3	0.175***	0.192***	0.157***	0.196***	0.167***	0.131***
edyrs4	0.364***	0.230***	0.432***	0.447***	0.222***	0.218***
edyrs5	0.559***	0.489***	0.704***	0.720***	0.468***	0.359***
age	0.088***	0.090***	0.058***	0.044***	0.071***	0.033***
age_sq	-0.086***	-0.087***	-0.057***	-0.042***	-0.066***	-0.030***
age65+	0.218***	0.051	0.080***	0.069***	-0.263***	0.021
married	0.165***	0.020***	0.187***	0.045***	0.294***	-0.013
ptime	-0.416***	-0.194***	-0.099***	-0.095***	-0.603***	-0.544***
loghours	1.000	1.000	1.000	1.000	1.000	1.000
_cons	4.318***	4.139***	5.300***	5.429***	9.461***	10.259***
N	88965	86361	584660	537946	20448	15508
rmse	0.656	0.704	0.739	0.710	0.652	0.716

Source: Authors' calculations using data supplied by Luxembourg Income Study and the Panel Data Research Center at Keio University.

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