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A comparative analysis of R&D trends in Japan, Germany, and the United States

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Innovation and the transatlantic productivity slowdown: A comparative analysis of R&D trends in Japan, Germany, and the United States

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1. Introduction

In the long run, productivity is the key driver of economic growth and improvements in standards of living. In the words of Nobel laureate in economics Paul Krugman, "Productivity isn't everything, but in the long run it is almost everything." In recent decades, however, despite the seemingly unstoppable technological progress that surrounds us, aggregate productivity growth has slowed down in most advanced economies, including the United States, Germany, and Japan—erstwhile considered the engines of global growth.

This slowdown is appreciable in both labor productivity and total factor productivity (TFP) growth, and it is not limited to only a few sectors or industries but rather it is widespread across economies. Moreover, the slowdown predates the global financial crisis of 2008, suggesting that it is a structural phenomenon. The literature is rife with efforts to understand and explain the causes of the observed transatlantic productivity slowdown. Several hypotheses have been cast, such as anemic capital investment, slowing technological progress at the frontier, weakening technology diffusion and adoption, and mismeasurement of productivity growth. There's some truth to all these explanations, albeit to differing degrees.

This paper is occupied with solving a different but related puzzle. Whereas since the end of World War II Germany and other European nations have roughly caught up with productivity levels in the United States, Japan never completed the catch-up process after achieving partial convergence during the 1980s and 1990s. In fact, the gap between Japan and the United States has widened in the last decade (Baily, Bosworth, and Doshi, 2020). Although both the U.S. and Germany have experienced sharp productivity growth slowdowns since 2004, the Japanese case is vexing because productivity growth decelerated just as sharply there even though productivity levels continue to lag well behind the United States and Germany's.

What could explain the productivity dynamics described above? While the growth literature has identified multiple theoretical and empirical determinants of productivity growth, this paper focuses on one in particular: innovation. This is because innovation is the fundamental source of technological progress, which in turn is the main driver of permanent increases in productivity.

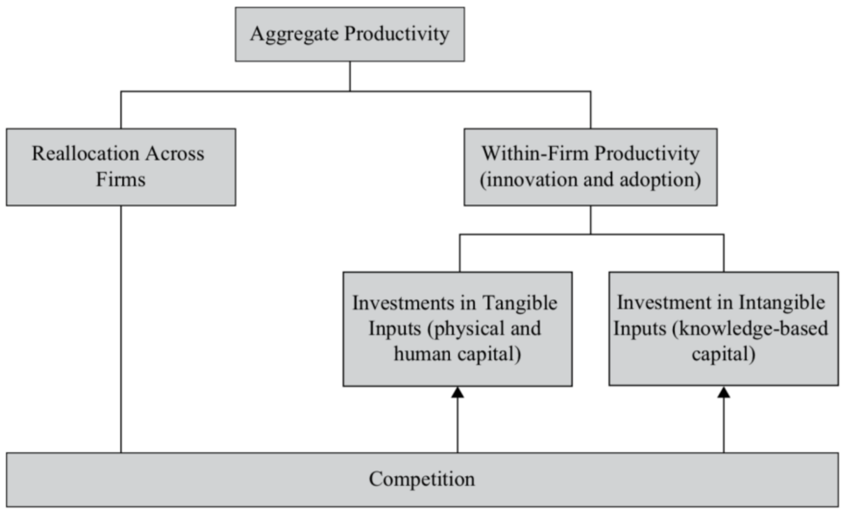
Our analysis points to an interesting finding: While Japan spends more resources on research and development (R&D) and files more patent applications than the U.S. and Germany, the quality of Japanese innovation severely lags behind that of the U.S. and Germany. We posit that this underperformance may be driven by differences in the nature of government incentives for private sector R&D and in the public-private composition of R&D expenditures in the three countries.

The paper is structured as follows. The next section introduces a simple conceptual framework to think about the different determinants of productivity, among which innovation stands out. Section 3 presents stylized facts on R&D trends. Section 4 explores possible links between R&D investment and productivity growth, while section 5 theorizes on potential barriers to R&D investment. Section 6 attempts to measure the innovation output of R&D using data on patent quality. Section 7 offers concluding policy prescriptions based on the preceding sections.

2. Conceptual framework

When trying to determine the drivers of differential patterns of productivity growth within countries and industries, it is useful to have a framework to keep track of the different determinants of aggregate productivity. Bahar and Foda (2019) suggest such a framework based on the economic literature, represented in Figure 1 below.

Figure 1. The determinants of aggregate productivity



Source: Bahar and Foda (2019).

Productivity growth for an industry in a country ultimately depends on the dynamics of the firms that make up that industry. The framework suggests that productivity growth responds to two main processes. First, reallocation of resources across firms: the extent to which the market efficiently allocates capital and labor (and other factors of production) from less productive towards more productive firms. And second, within-firm productivity improvements (whether through invention and innovation at the frontier or through diffusion and adoption elsewhere), which rely on firms' investments in both tangible and intangible inputs.

Allocative efficiency is achieved when there are no significant barriers (due to both policy and market failures) to distort the reallocation process. In a dynamic economy, the exit of the least productive firms from the market frees up resources to be acquired by the most productive firms. If for any reason—such as regulation (or lack thereof) resulting in lack of competition—unproductive firms remain in the market, that would be reflected as a slowdown of productivity growth at the aggregate level.

There is evidence from a number of countries pointing to a reduction in business dynamism, which could explain the transatlantic slowdown of productivity growth. Cirscoulo, Gal, and Menon (2014) show that the rate of new business formation has been on a declining trend across OECD economies over the past few decades. Davis and Haltiwanger (2014) show that in the U.S. after 2000, start-up rates in high-tech and information-processing firms fell, and those firms that did enter did not experience the same rapid growth as earlier cohorts.

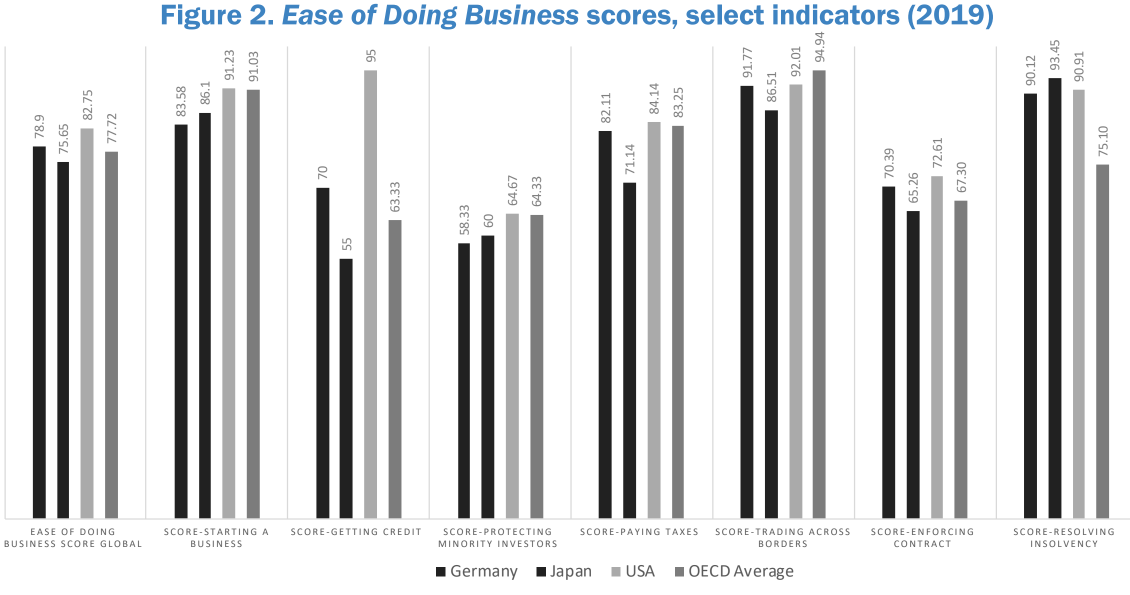
Typically, though not necessarily, one would expect that slow productivity growth due to inefficient reallocation responds to distortions in the overall economy, and therefore should affect all industries similarly. Yet data show significant variation in productivity growth rates across industries within the same country, which is likely a sign of industry-specific forces playing a role (Baily, Bosworth, and Doshi, 2020). However, it is possible that policy failures could generate distortions that hold back the reallocation process in the economy as a whole but that affect different industries to different degrees.

According to the framework, the extent to which firms improve their own productivity can explain a large proportion of aggregate productivity growth dynamics. Firms achieve higher productivity by investing in both tangible inputs (e.g., newer and better machinery, or more skilled workers and managers) and intangible inputs (new methods, processes, technologies, etc.). The extent to which firms can invest in inputs (both tangible and intangible) depends on a range of policy conditions such as access to credit, trade barriers, human capital abundance, and migration regulations, all of which typically affect all firms within the same country regardless of industry, albeit at potentially different magnitudes. For example, trade barriers will constrain firms in tradeable industries more than firms in non-tradeable industries.

Looking at the World Bank's *Ease of Doing Business* scores provide some idea of the existence of particular bottlenecks for firms when it comes to business dynamism or investment in inputs. Figure 2 compares relevant scores for Germany, Japan, and the United States as well as the OECD average.

In the main components for business dynamism such as starting a business and paying taxes, the three economies score similarly. However, Japan underperforms when it comes to access to credit. Credit barriers can negatively affect the ability of entrepreneurs to start and scale up their businesses, and the ability of potential businessowners to further invest in their firms (both in tangible and intangible inputs).

Figure 2. *Ease of Doing Business* scores, select indicators (2019)



Source: The World Bank.

In the components that can be particularly important for investment in tangible inputs, all three economies perform similarly: trading across borders, protecting minority investors, resolving insolvencies and enforcing contracts (here, though, Japan lags slightly behind). This suggests that firms in these economies confront only slight but, importantly, similar bottlenecks, at least at an aggregate level.

This conclusion also applies to investment in intangible inputs: many of these indicators should not, a priori, affect industries differentially. However, even in the absence of economy-wide distortions keeping firms from investing, the process of innovation and adoption involves industry-specific dynamics that strongly relate to risk, intellectual property protection, competition, and other areas that suffer from inherent market failures which can lead to underinvestment in innovation and negatively affect the productivity growth of firms.

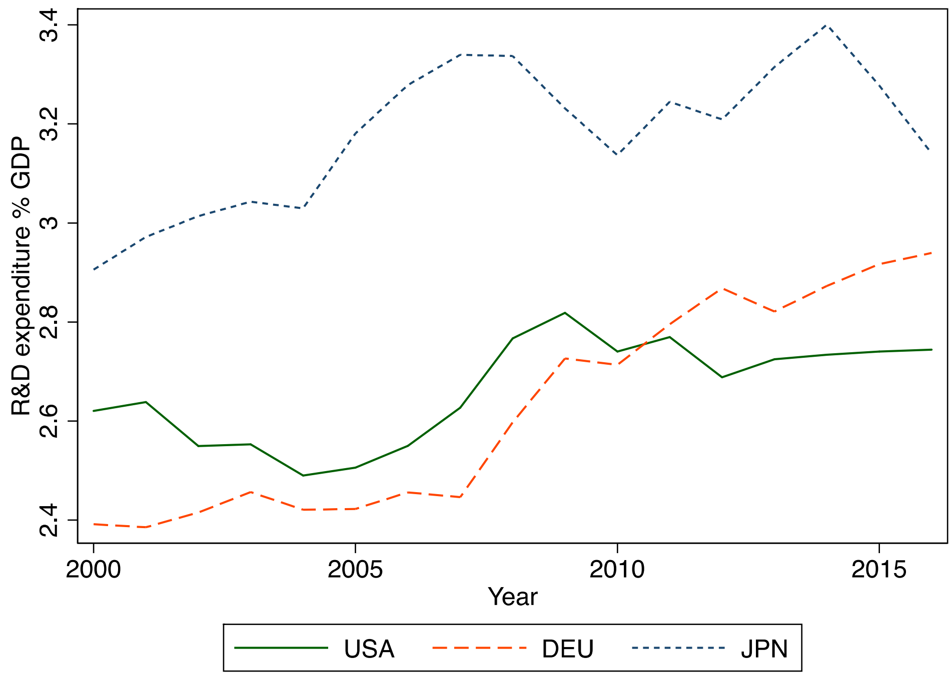
Ever since the digital revolution, investment in intangibles has emerged as an increasingly important driver of innovative activity and technology adoption. Brynjolfsson, Hitt and Yang (2002) estimated that for every dollar of investment in computer hardware, for example, firms needed to invest an additional $9 in intangible inputs, namely software, training, and business process design. This is all the more relevant for firms in industries that highly intensive in R&D investment.

In an effort to gain some insights on industry-specific innovation dynamics, the next section takes a deep dive on R&D behavior in Japan, Germany, and the United states.

3. Stylized facts

We start by looking at aggregate figures of R&D expenditure as a share of GDP, using data from the World Bank's World Development Indicators. Figure 3 plots this indicator over time for the U.S., Japan, and Germany. The figure shows that Japan has significantly outgrown both the U.S. and Germany in terms of R&D expenditure relative to GDP. Since the 2008 global financial crisis—which had its epicenter in the U.S.—Germany has overtaken the U.S. in relative R&D expenditures.

Figure 3. Total R&D spending, % of gross domestic product

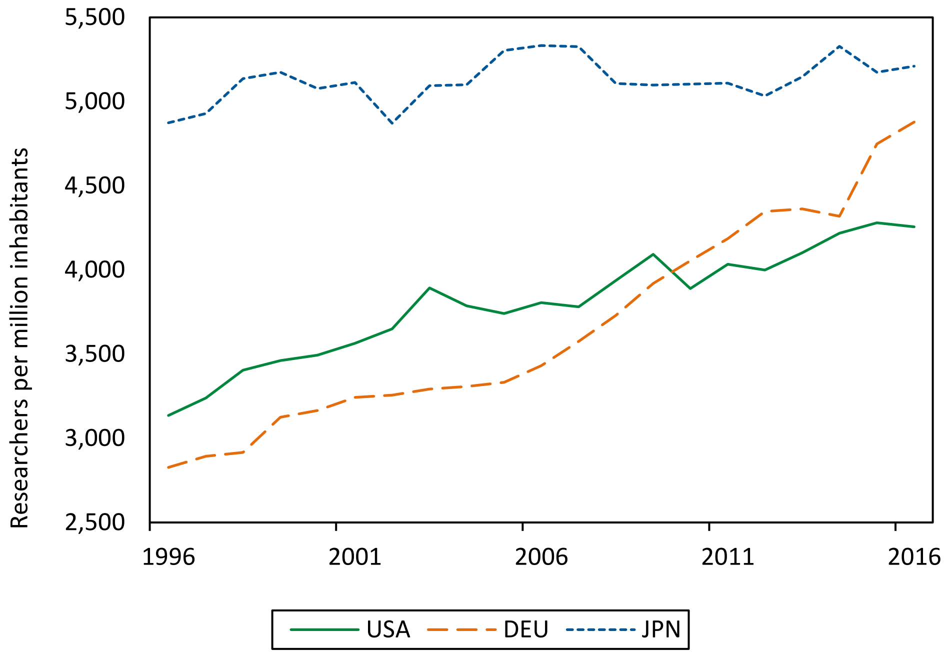


Source: The World Bank.

This chart is consistent with the trends displayed in Figure 4, which plots the number of researchers employed in each country per million inhabitants. Japan leads the pack throughout the period, while Germany has seen a steady increase in the ratio of researchers. The U.S. has too, albeit at a slower pace—allowing Germany to overtake it in the aftermath of the global financial crisis.

Of course, this doesn't say much about the total number of researchers in each country, as they have wildly different total population numbers. Not surprisingly, the U.S. has the highest gross number of researchers at almost 1.4 million. Meanwhile, Japan has almost 670,000 and Germany close to 400,000.

Figure 4. Researchers in R&D



Source: World Bank Development Indicators and UNESCO Institute for Statistics.

Naturally, aggregate comparisons of relative R&D expenditures are misleading, since different industry compositions require different levels of R&D investment. Thus, a more appropriate comparison is at the industry level.

The industrial composition in 2016 of these three economies is presented in Table 1, as it is important to provide context for the analysis that follows. In relative terms, as shown in the table, the U.S. stands out for having a much smaller manufacturing sector than Japan and Germany: 11.5 percent for U.S., and over 20 percent for Japan and Germany.

Conversely, the U.S. stands out by having other sectors representing a significantly larger proportion of its economy compared to Japan and Germany, such as Mining and Quarrying, Information and Communication Technologies (ICT), Financial and Insurance Activities, and Professional, Scientific and Administrative Services.

Germany stands out by having the largest manufacturing sector across all three economies, though Japan lags closely behind. Besides that, Japan's economy is the largest among all three countries in terms of agriculture, construction, wholesale and retail trade, and transportation services.

Table 1. Sectoral value added, % of gross value added (2016)

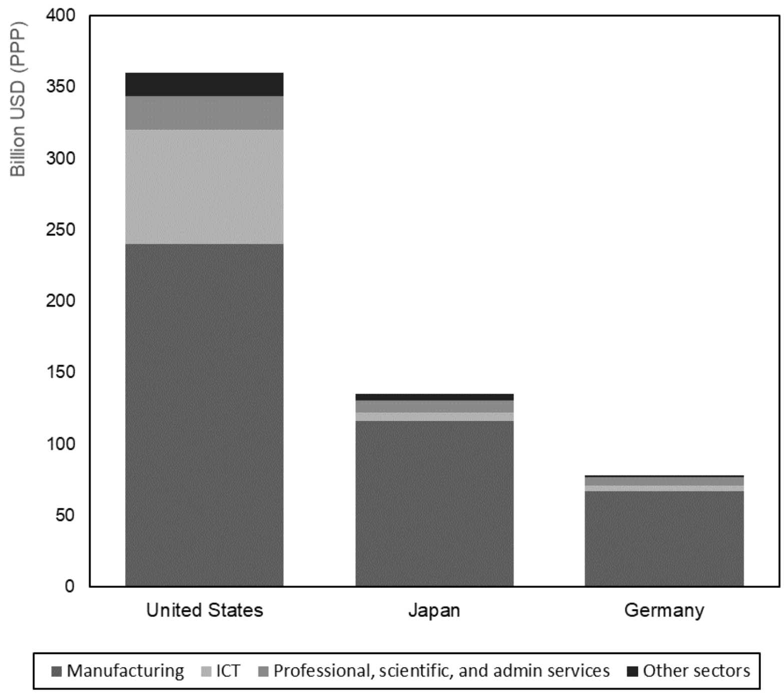
	United States	Japan	Germany
Agriculture, forestry and fishing	1.0%	1.2%	0.7%
Mining and quarrying	1.2%	0.1%	0.1%
Manufacturing	11.5%	20.8%	23.4%
Utilities	1.8%	2.6%	2.7%
Construction	4.1%	5.6%	4.7%
Wholesale and retail trade	10.3%	13.9%	9.8%
Transportation and storage	3.3%	5.1%	4.6%
Information and communication	7.0%	5.0%	4.7%
Financial and insurance activities	7.7%	4.2%	4.0%
Real estate	12.7%	11.5%	10.8%
Professional, scientific and administrative services	11.8%	7.5%	10.8%

Source: OECD System of National Accounts (SNA) Database.

Figure 5 presents nominal R&D spending in the U.S., Japan, and Germany for 2015 in purchasing power parity (PPP) adjusted U.S. dollars. The United States is, at $360 billion, by far the highest R&D spender in gross terms, compared to $135 billion in Japan and $78 billion in Germany.

Across all three countries, it is clear that manufacturing industries represent the largest chunk of R&D expenditures, followed by Information and Communication Technologies (ICT), and Professional, Scientific, and Administrative Services. Manufacturing alone comprises two-thirds of total business enterprise R&D in the U.S., and 85 percent in Japan and Germany. With the exception of Mining and Quarrying in Japan, which in some years ranks third-highest R&D spender above Professional, Scientific and Administrative Services, most other sectors in all three countries execute a minuscule share of economy-wide R&D spending. Therefore, we focus this analysis in these three sectors, which are also the most intensive sectors in R&D (when looking at R&D as a share of sector value added, as we show below).

Figure 5. Nominal R&D spending by major sector (2015)

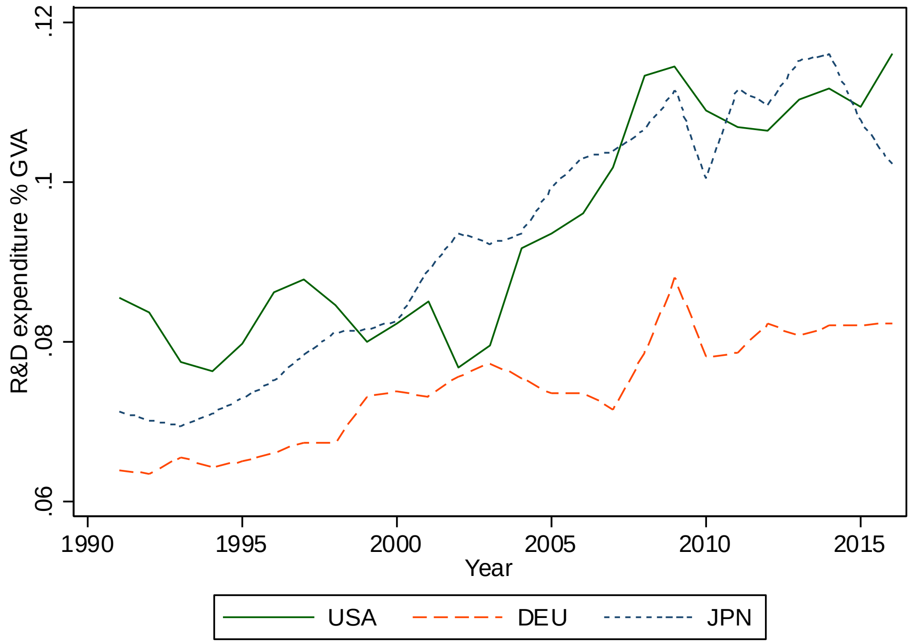


Source: Calculations based on OECD ANBERD and SNA.

While nominal magnitudes are somewhat informative, relative figures are a better comparative measure, as the relative size of these sectors could vary significantly. When looking at relative R&D expenditure (based on value added in the denominator), we see very different patterns than those documented in Figure 3.

For instance, when looking at the manufacturing sector in Figure 6, we see that both the U.S. and Japan hold a significant lead over Germany. Both the U.S. and Japan have experienced important growth in relative R&D expenditures in manufacturing, from 7 percent (Japan) and 9 percent (U.S.) in the early 1990s to about 10 percent (Japan) and 11 percent (US) in recent years. Given that, particularly for Japan, manufacturing represents an important share of the overall economy, Japan's R&D expenditure in this sector is particularly large. Germany, on the other hand, has continued to be the laggard among this group, with R&D as share of value added below 9 percent by year 2016.

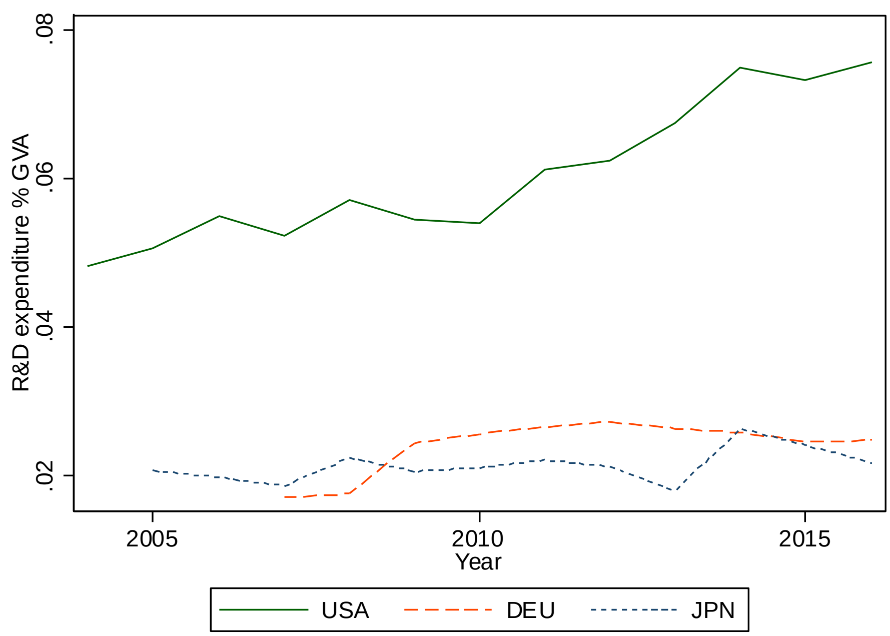
Figure 6. R&D intensity in Manufacturing



Source: Calculations based on OECD ANBERD.

When it comes to the ICT sector, a sector that represents between 5 and 7 percent across all three economies under consideration, the picture is quite different (see Figure 7). There, the U.S. stands out by having the largest relative R&D expenditures representing about 7 percent of value added by 2016. This compares to Japan and Germany, both significantly lagging, with the corresponding figure being about 2 percent.

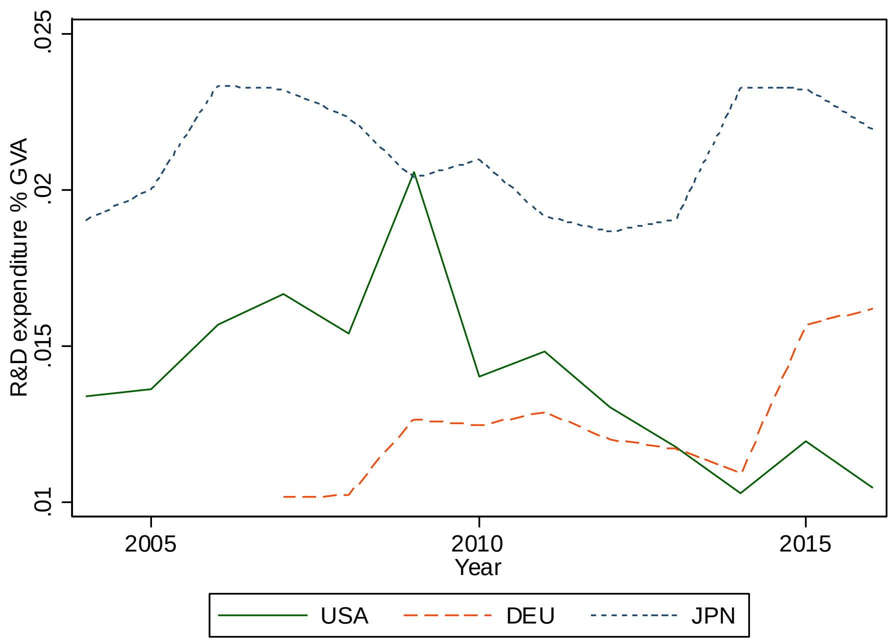
Figure 7. R&D intensity in ICT



Source: Calculations based on OECD ANBERD.

In the third largest R&D intensive sector—professional, scientific, and administrative services—we see in Figure 8 that Japan leads with R&D expenditures above 2 percent of value added, whereas Germany and the U.S. reach 1.5 and 1 percent, respectively. Note, however, that in the U.S. there is a sharp increase of relative R&D expenditures in the year 2009, which represents nothing more than the sharp drop in value added during the financial crisis, after which we see R&D adjusting downwards.

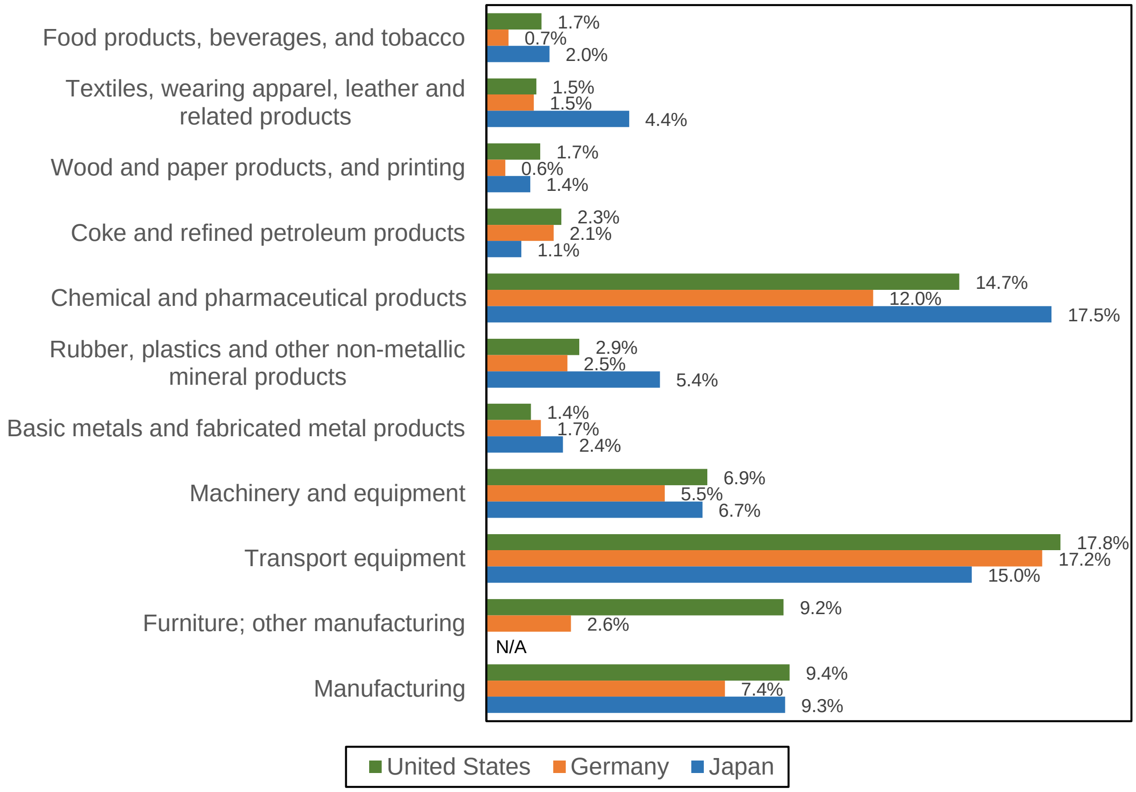
Figure 8. R&D intensity in Professional, Scientific, and Administrative Services



Source: Calculations based on OECD ANBERD.

Finally, a deeper look at the manufacturing sector also presents some interesting insights. Figure 9 presents the average of R&D expenditures as share of value added for the whole period 1991-2016 by manufacturing industry for the three countries under consideration. There, it can be noted that across all countries, industries such as chemical and pharmaceutical products, machinery and equipment, and transport equipment (which includes the auto industry) particularly stand out as being highly intensive in R&D.

Figure 9. Average R&D intensity by manufacturing industry (1991-2016)



Source: Calculations based on OECD ANBERD.

4. The link between R&D and productivity growth

Is there an observable link between industry-level productivity growth patterns and R&D expenditures in these countries? The raw data reveals some interesting patterns worth discussing. Table 2 summarizes, for each of the time periods defined in Baily, Bosworth, and Doshi (2020), labor productivity growth and the average level of R&D intensity (both based on value added) for all sectors and manufacturing industries.

While we are careful not to draw any causal inferences from this data, we believe there is informational value in identifying possible patterns that arise from it. First and foremost, it is important to notice that there is much more volatility in productivity growth rates than in mean R&D intensities. This is to some extent expected, as productivity growth might have an idiosyncratic component whereas R&D decisions are made by firms with a medium- to long-run perspective.

There are two main patterns we can try to recognize with the data at hand. First, whether there are any recognizable links between changes in productivity growth (for the same sector and country) across time and changes in R&D expenditures.

What we see in the Table 2 is that, across almost all sectors, R&D expenditures are increasing over time—or at least roughly kept at the same level—even in the periods of the productivity slowdown. This is more apparent, perhaps, for the manufacturing sector as a whole and all of its conforming industries—which represent the largest chunk of R&D expenditures in nominal terms.

Now, this pattern does not necessarily mean that R&D investments do not translate into higher productivity. It could very well be the case that the return to R&D investment has diminished over time. Indeed, there is some reason to believe that ideas are getting harder to find. As shown in Figures 3 and 4, the inputs to innovation have been growing, but the outputs do not appear to be keeping pace. In terms of inputs, spending on R&D has trended modestly higher over the last thirty years, and there are more scientists and engineers than ever before (Bahar and Foda 2019). Despite the overall rise in R&D investment, the output it has to show for in terms of innovation has trended downward. For instance, using U.S. firm-level data on R&D investments, patents, revenues, and other characteristics to estimate the value of R&D, Knott (2017) concludes that overall R&D productivity in the United States declined 65 percent over the last three decades.

This implies that while investment in R&D is still an important determinant of productivity growth, its effectiveness has been diminished, which might in turn explain the overall productivity slowdown experienced by advanced economies.

Table 2. R&D intensity and productivity growth

	United States						Japan						Germany					
	1991-1995		1995-2004		2004-2016		1991-1995		1995-2004		2004-2016		1991-1995		1995-2004		2004-2016	
	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D	ΔLP	R&D
Agriculture, forestry and fishing	1.3%	n.a	5.8%	n.a	3.4%	n.a	n.a	0.1%	2.0%	0.1%	1.4%	0.1%	-5.2%	0.3%	7.6%	0.4%	-1.0%	0.7%
Mining and quarrying	8.0%	n.a	-0.3%	0.6%	2.2%	0.8%	-6.4%	3.0%	4.0%	3.5%	-7.1%	2.7%	7.2%	1.3%	-0.6%	1.1%	2.2%	0.4%
Manufacturing	3.6%	8.1%	6.1%	8.4%	1.9%	10.7%	2.7%	7.1%	3.3%	8.5%	2.4%	10.7%	3.2%	6.4%	2.9%	7.2%	1.9%	7.9%
Food products, beverages, and tobacco	4.6%	1.2%	-0.8%	1.3%	-0.1%	2.2%	n.a	1.9%	-0.1%	2.0%	0.0%	2.0%	-0.9%	0.5%	-0.5%	0.6%	1.7%	0.8%
Textiles, wearing apparel, leather and related products	3.5%	0.6%	4.2%	0.9%	1.2%	2.4%	n.a	1.8%	-0.5%	2.3%	0.3%	7.4%	5.8%	0.9%	3.4%	1.5%	0.9%	1.7%
Wood and paper products, and printing	-3.1%	1.4%	2.2%	2.1%	1.3%	1.5%	n.a	1.3%	0.6%	1.4%	0.1%	1.4%	2.3%	0.5%	2.7%	0.5%	2.3%	0.7%
Coke and refined petroleum products	5.1%	6.1%	13.2%	2.5%	-1.0%	0.6%	n.a	1.6%	-0.3%	0.8%	-0.9%	1.1%	n.a.	3.4%	n.a.	1.3%	n.a.	2.1%
Chemical and pharmaceutical products	3.0%	11.8%	3.9%	11.5%	0.9%	18.2%	n.a	14.4%	2.5%	15.2%	1.5%	20.5%	8.1%	12.1%	4.7%	12.2%	0.9%	11.7%
Rubber, plastics, and other non-metallic mineral products	2.1%	2.5%	3.6%	2.3%	0.1%	3.5%	n.a	4.4%	2.7%	5.1%	-0.3%	6.0%	4.5%	1.8%	2.3%	2.4%	1.3%	2.9%
Basic metals and fabricated metal products	2.3%	1.3%	2.7%	1.4%	0.4%	1.4%	n.a	2.7%	0.9%	2.4%	0.3%	2.2%	3.2%	1.8%	2.4%	1.6%	0.7%	1.7%
Machinery and equipment	9.7%	4.4%	10.0%	6.0%	4.8%	8.5%	n.a	4.6%	7.2%	6.2%	5.5%	7.9%	3.9%	5.1%	3.6%	5.4%	1.4%	5.8%
Transport equipment	0.2%	18.9%	4.1%	15.4%	2.3%	19.2%	n.a	10.6%	2.1%	13.0%	0.5%	18.8%	1.3%	14.3%	1.4%	17.9%	4.5%	18.0%
Furniture; other manufacturing	0.7%	n.a	3.7%	7.3%	1.3%	9.7%	n.a	n.a	n.a	n.a	n.a	n.a	2.0%	n.a	3.4%	n.a	0.7%	2.6%
Utilities	1.3%	0.2%	0.5%	0.1%	-0.7%	0.1%	0.7%	0.8%	2.5%	0.6%	-3.5%	0.5%	1.0%	0.3%	3.1%	0.2%	0.6%	0.2%
Construction	0.6%	n.a	-0.7%	0.1%	-1.1%	0.1%	-3.2%	0.5%	-1.2%	0.5%	0.9%	0.4%	-1.0%	0.1%	0.5%	0.1%	0.1%	0.1%
Wholesale and retail trade	3.6%	n.a	5.1%	1.5%	1.0%	0.2%	5.0%	n.a	2.0%	0.1%	0.4%	0.1%	0.6%	0.0%	2.9%	0.0%	1.8%	0.1%
Transportation and storage	1.1%	n.a	1.6%	0.1%	-0.1%	0.1%	1.4%	n.a	-0.3%	n.a	-0.8%	0.2%	4.3%	n.a	3.6%	n.a	0.6%	0.1%
Information and communication	1.6%	n.a	4.1%	4.7%	3.9%	6.2%	7.9%	n.a	5.5%	n.a	-0.2%	2.1%	5.3%	n.a	4.7%	n.a	3.4%	2.4%
Financial and insurance activities	1.6%	n.a	4.1%	0.2%	1.3%	0.3%	0.6%	n.a	1.1%	0.0%	0.3%	0.0%	1.3%	0.0%	-2.0%	0.0%	1.1%	0.2%
Real estate	3.4%	n.a	0.7%	0.0%	2.0%	0.0%	0.0%	n.a	1.6%	n.a	0.3%	n.a	2.0%	n.a	1.6%	n.a	1.3%	0.0%
Professional, scientific and administrative services	-0.7%	n.a	1.5%	1.5%	0.6%	1.4%	2.7%	n.a	3.8%	2.0%	1.7%	2.1%	0.2%	n.a	-1.7%	n.a	-1.3%	1.2%
Community, social and personal services	-0.7%	n.a	-0.2%	n.a	0.1%	n.a	0.5%	n.a	-0.1%	n.a	-0.5%	n.a	1.8%	n.a	0.6%	n.a	0.4%	0.0%

Source: Calculations based on OECD ANBERD and STAN.

The second pattern that we can try to study in the data for these three countries and industries—being wary of the limitations of our approach—is whether there is any statistical relationship between productivity growth and R&D investment. According to the framework specified above as well as the economic literature, we would expect a positive relationship.

Several caveats apply. First, we are looking simply at raw observational data, which is not sufficient to establish any sort of causal relationship for many reasons. Second, the number of observations is small and therefore unfit to produce precise estimates, even when it comes to simple correlations.

Table 3. Correlation between R&D intensity and productivity growth

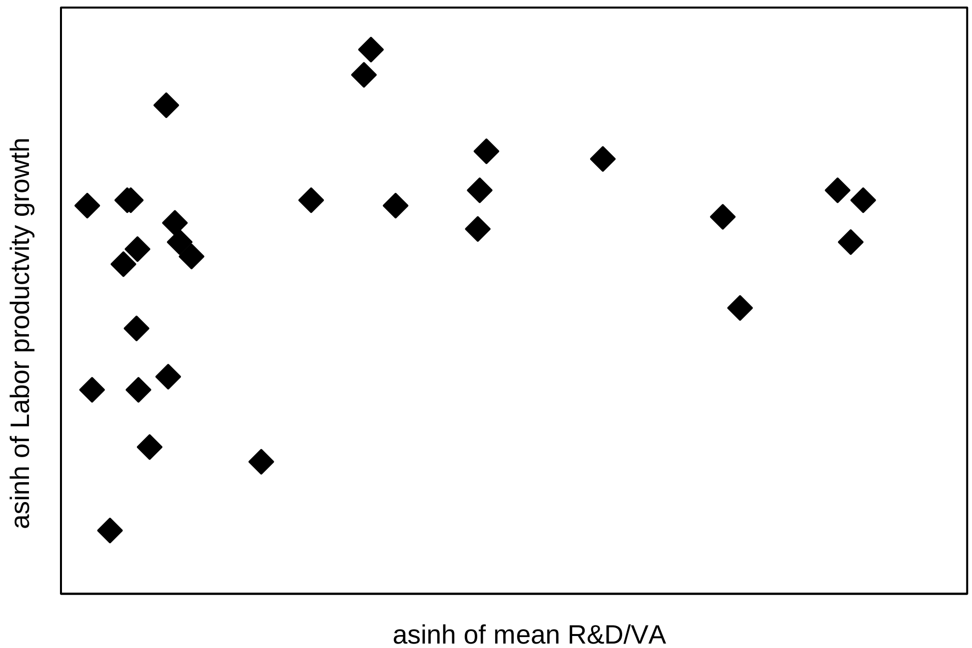
		Sectors	Industries
United States	1991-1995	n.a.	-0.13
	1995-2004	0.72	0.06
	2004-2016	0.53	0.44
Germany	1991-1995	0.44	n.a.
	1995-2004	0.50	0.43
	2004-2016	0.20	0.29
Japan	1991-1995	0.38	0.24
	1995-2004	0.10	0.17
	2004-2016	0.30	0.65

Source: Calculations based on OECD ANBERD and STAN.
Note: "n.a." applies when there is not enough data to compute the correlation coefficient.

With all these caveats in mind, Table 3 depicts the correlation coefficients between mean R&D intensity and labor productivity growth (both based on value added) for each country and time period, separately for the 12 sectors and 10 manufacturing industries. While these correlation coefficients are not, again, indicative of a causal relation, it is comforting to see that productivity growth and R&D intensity go hand in hand in terms of the sign, with the exception of the manufacturing sector in the U.S. in the first period 1991-1995.

Since industries in the manufacturing sector make up for most of the R&D expenditure in all three countries, we plot in Figure 10 the values of both R&D investment and productivity growth during the entire period 1991-2016 for all three countries pooled together. The exercise offers a visual representation of the relationship between mean R&D intensity and labor productivity growth, both scaled by the asymptotic hyperbolic sine transformation (similar to a logarithmic transformation, but defined for zero and negative values) to minimize the distorting effect of outliers on correlations.

Figure 10. R&D intensity and productivity growth (1991-2016)



Source: Calculations based on OECD ANBERD and STAN.

Two clusters of observations can be made out in the figure: industries with low levels of R&D intensity tend to have much more variance in terms of labor productivity growth, while industries with higher levels of relative R&D investment all experienced higher levels of productivity growth.

Naturally, it is important to stress again that this relationship is suggestive only, and with the data at hand it is not feasible to estimate a causal relationship between these two components, which not only refers to the magnitude, but also to the directionality (e.g., is higher R&D resulting in higher productivity, or more productive sectors invest more in R&D?). However, this evidence does suggest (if weakly) that R&D expenditures and productivity growth go hand in hand.

5. Barriers to R&D investment

While R&D investment is a key input in the process of innovation and technological adoption, there are plenty of market failures that might be preventing firms from making these investments.

Knowledge externalities are the main market failure that economists think of when analyzing R&D dynamics. In particular, if one firm invests in innovating a particular technology that can significantly improve its productivity, other firms could free ride and adopt such innovation without paying for it. Therefore, there are a number of policies put in place by governments to prevent this, such as protecting innovations from being stolen with intellectual property laws. In rich countries like the ones we are examining, intellectual property regulations typically work well, mostly through functioning patent agencies.

In practice, however, there are always imperfections in systems protecting intellectual property, even in rich countries (where most of the patenting occurs, anyways). Even if ironically, often "too much" protection might be counterproductive. The process of registering and enforcing intellectual property can be quite costly, particularly for smaller firms. The costs associated with globally protecting a patent quickly add up with the number of countries where the patent is to be registered in, and could reach, in some cases, hundreds of thousands of dollars. These costs could be prohibitive for small and medium firms relying on R&D investment to adopt technologies that could then be appropriated by others.

Difficulties associated with adoption of technologies from the frontier can also be associated with too much patent protection, which slows the pace of technological diffusion. Given that large firms are able to protect their intellectual property much more effectively, this would discourage small firms from adopting existing technologies originated by large firms in order to avoid the risks associated with legal battles that may follow. In the United States, the number of firms involved in patent conflicts, being sued by "patent trolls" (companies that are fully devoted to initiating legal battles against firms, mostly small ones, that are, presumably, violating intellectual property laws) grew by a factor of nine in the decade that followed. Research suggests that firms that have been sued on the basis of intellectual property violation by patent trolls reduce their R&D investment and get less external funding following the episode (Bessen 2014).

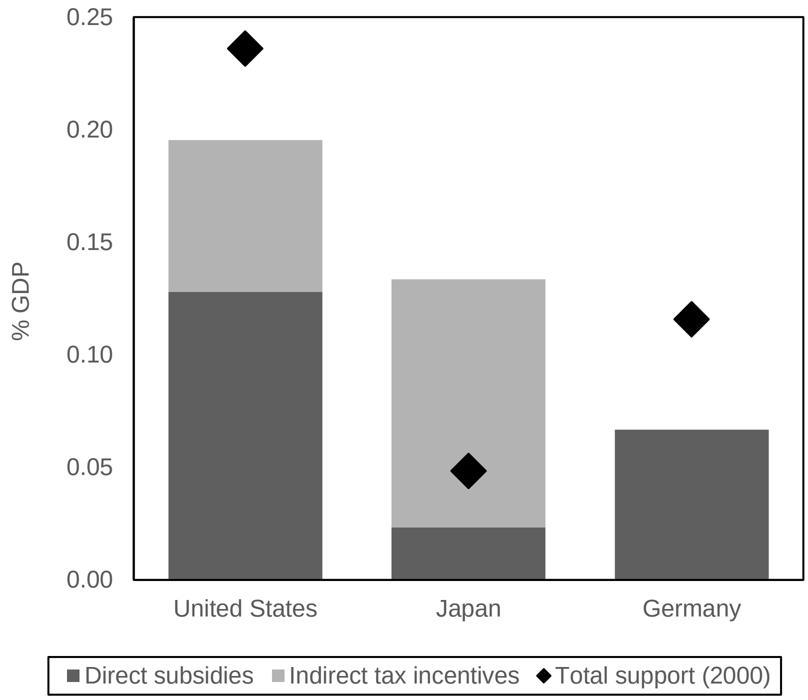
Intellectual property protection has clear tradeoffs. Without proper protection of intellectual property, there is underinvestment in R&D. At the same time, abuse of the system can make adoption of existing technologies legally problematic and costly. Some authors have suggested rethinking the patenting system to deal with possible frictions faced by small firms when adopting innovations in the industry (Baily and Montalbano 2016). A more efficient patenting system, which allows small firms to adopt technologies without risking losing all their capital in legal battles, could fuel productivity growth.

Until that reform occurs, however, countries have at their disposal a limited set of tools that allow the government to share the burden of investment in R&D by providing tax credits or direct subsidies, so that firms do not underinvest in their pursuit of innovation and technology adoption.

These financial incentives are particularly important particularly for investment in intangible assets, as they, by definition, represent no collateral required by financial institutions and therefore, without access to credit, firms would underinvest in R&D. Bloom, Van Reenen and Williams (2019) present a complete discussion about this.

Figure 11 shows the extent of government funding of business R&D for the U.S., Germany, and Japan, distinguishing by the type of funding provided. The U.S. stands out by providing the most generous support at almost 0.20 percent of GDP, followed by Japan. Since the year 2000, the U.S. and Germany have decreased their public funding of private R&D, while Japan has meaningfully increased it from about 0.05 percent to almost 0.15 percent of GDP (as noted in the black markers in the figure). Notably, the U.S. utilizes a mix of direct funding and indirect tax incentives for R&D, whereas Japan relies mostly on the latter and Germany exclusively makes use the former.

Figure 11. Government funding of business R&D (2016)



Source: OECD R&D Tax Incentive Database.

The mix of government support for R&D has significant implications for its effectiveness. Indirect tax incentives encourage R&D by writing off the expenditures used in the innovation process. While several studies have shown that this type of support does result in higher R&D investments (e.g., Bloom, Griffith, and Van Reenen, 2002; Wilson 2009), there are some disadvantages to this approach. First, it is not very efficient, as the tax credit applies to innovations that are both important and those that are less so. Second, often firms relabel expenditures are R&D when they are really not incurring in innovation, just to take advantage of the tax. This is very difficult to track and enforce.

Direct subsidies might solve some of these issues, by using government agencies to provide grants to either academic researchers or private firms engaging in innovation on a per project basis. Yet, there is an important concern that these subsidies are crowding out R&D investment that would have happened anyway, regardless of the subsidy. It is hard to measure whether these programs are effective, as typically government agencies would tend to target programs with high probability of success. Yet, there is evidence—though thinner than for tax subsidies—of R&D grants translating into larger R&D investments and innovation (e.g., Jacob and Lefgren, 2011; Azoulay, Graff Zivin, Li and Sampat, 2019; Moretti, Steinwender, Van Reenen and Warren 2019).

What is the most effective way to boost R&D such that it translates into productivity growth? There is no clear-cut answer. After surveying the literature and going through all the different policies aimed to boost R&D (beyond tax incentives and subsidies), Bloom, Van Reenen and Williams (2019) present some insights in their Table 2. In particular, they claim that while R&D tax credits have positive impact with a high degree of certainty based on the available evidence, the effect seems to be more concentrated in the short-run. On the other hand, direct

R&D grants, while the evidence available is less conclusive, seem to have a positive effect that tends to kick in on the medium term.

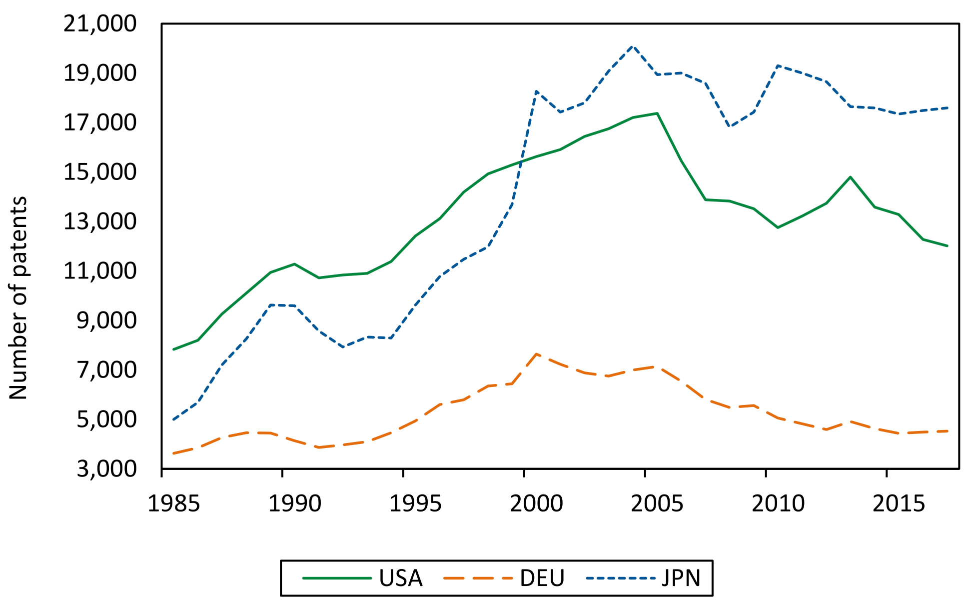
6. R&D productivity: Measuring the quality of innovation

A question that remains is whether there are some recognizable patterns in terms of innovation that might reflect the important compositional difference of government R&D funding, as well as all other aspects that affect the innovation ecosystem in these three countries.

We rely on patenting data to analyze some of these trends, as patenting is widely recognized to be a proxy for innovation activities. In particular, we look at patents that have been filed in all three patent offices: the U.S. Patent and Trademark Office (USPTO), the European Patent Office (EPO) and the Japanese Patent Office (JPO), taken from the OECD Patent Statistics database. These are known as triadic patent families, which improve the quality and the international comparability of patent indicators. Since only patents applied for in all three countries are included, home advantage and influence of geographical location are eliminated.

Figure 12 shows that after a sharp increase in the 1990s Japan leads in patent issuance, followed by the U.S., which has recorded declining patent registrations since 2006. Germany trails far behind. All in all, Japan stands out by being the country with the most patenting activity, which is consistent with its high R&D investment as a share of GDP, as shown above.

Figure 12. Patents registered in the U.S., Europe, and Japan



Source: Triadic patent families by inventor country of residence from OECD Patent Statistics.

However, this pattern does not hold when looking at the average resources invested per patent, gleaned after performing some back-of-the-envelope calculations. Table 4 suggests that even though Japan patents more than the U.S. and Germany, Japan's resource allocation for each patent is lower, both when measured in terms of R&D expenditure per researcher as well as in terms of the average number of researchers in R&D per patent (note that because the number of researchers in R&D by country and year does not measure the number of inventors but rather all of the research workers employed in R&D activities, we see figures for R&D researchers per patent that are much higher than the average number of inventors per patent).

Table 4. R&D spending in perspective

	R&D spending per researcher	R&D spending per patent	Researchers per patent
	(current PPP $)	(current PPP $)	
United States	376,473	42,060,807	112
Japan	253,386	9,640,707	38
Germany	295,910	26,323,330	89

Source: Calculations based on World Bank Development Indicators, OECD Patent Statistics and UNESCO Institute for Statistics.

These patterns could be interpreted in one of two ways. On one hand, using fewer resources Japan may be able to produce many more patents than the two other countries under consideration. This could mean that Japan is more productive in innovating. On the other hand, it is possible that fewer resources could result in patents that are of lesser quality or impact.

Fortunately, we are able to look at several measures of patenting quality over time for these three countries, drawn from the OECD Patent Quality Indicators database (Squicciarini, Dernis and Criscuolo, 2013). Our exercise starts with the whole universe of patents filed to the USPTO between 2005 and 2015. We focus on nearly 1.8 million patents for which at least one inventor is located on either the U.S., Germany, or Japan. On average, each one of these patents has 2.53 inventors based on these three countries (there could be more inventors from other countries who we are not considering for this exercise, as including them wouldn't change the results of our analysis).

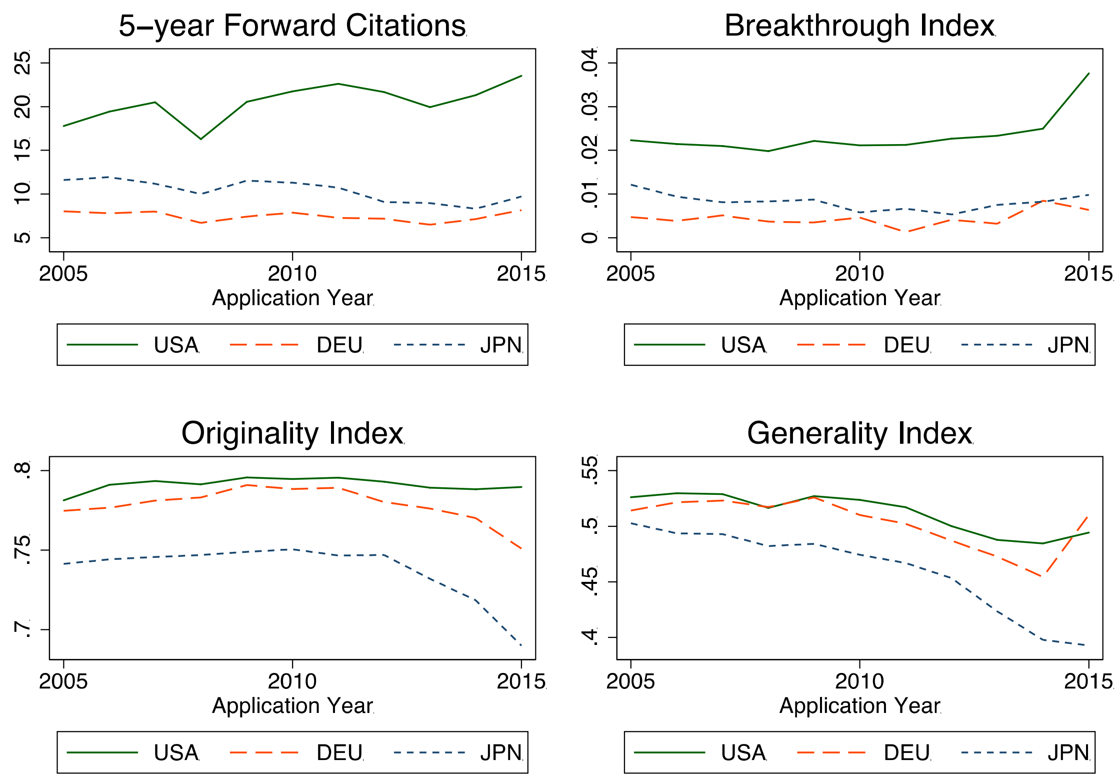
We merge this sample with the OECD quality measures, defined at the patent-level, and compute country-level averages. Here we focus on four main indicators of patenting quality:

- 5-year Forward Citations: average number of patent citations received up to 5 years after publication (based on citations included by the inventors only).
- Breakthrough Index: share of patents that belong to the top 1 percent most-cited patents up to 5 years after publication.
- Originality Index: measure of the breadth of the technology fields in which a patent relies, first proposed by Trajtenberg et al. (1997). Inventions relying on a large number of diverse knowledge sources are supposed to lead to original results.
- Generality Index: used to identify general purpose technologies, by measuring how often is cited by patents in a breadth of technological fields, mirroring the originality index by Trajtenberg et al. (1997).

These four measures are plotted, averaged for all patents by inventors in each country and year of patent application, in Figure 13.

Here, we see a very different picture emerge: the U.S. leads in terms of patent quality across all measures, on average, whereas Germany lags slightly behind in both average originality and generality of patents and underperforms the other two indicators. Japan consistently lags behind in all four averaged indicators, implying that despite producing a larger number of patents, those innovations are of significantly lesser quality.

Figure 13. Selected patent quality indicators

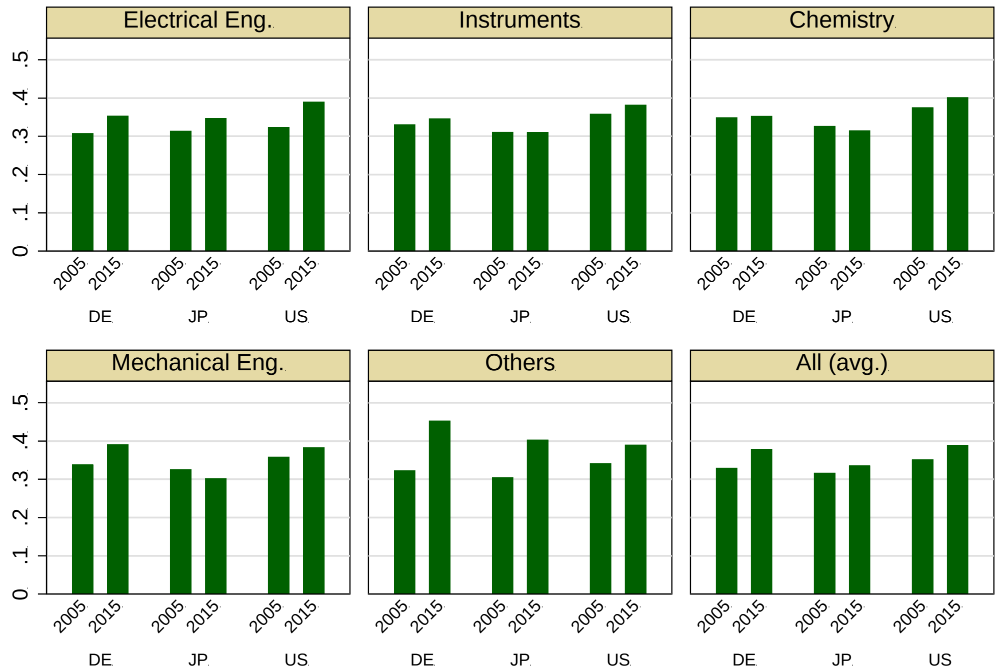


Source: Calculations based on USPTO and OECD Patent Quality Indicators databases.

This pattern holds when looking at patents divided by (broadly defined) technology classes. Figure 14 plots the average quality for all patents by country of inventor in 2005 and 2015, based on the composite index Quality-6 suggested by Squicciarini, Dernis, and Criscuolo (2013) for five different technology classes, as well as overall.[1] Here, a consistent pattern emerges: In technologies such as Instruments, Chemistry, and Mechanical Engineering, the quality of Japanese patents has gone down between 2005 and 2015, while the opposite has happened for the U.S. and Germany.

[1] The patent Quality-6 index includes six components: number of forward citations (up to 5 years after publication); patent family size; corrected claims; generality index; backward citations; and the grant lag index. The index is computed only for granted patents. For more information see Squicciarini, Dernis, and Criscuolo (2013).

Figure 14. Patent Quality-6 Index by country and technology (2005 and 2015)



Source: Calculations based on USPTO and OECD Patent Quality Indicators databases.

While it is not possible with the data at hand to understand what the exact drivers of these observed gaps in the quality of Japanese innovation are, they consistent with the evidence presented in the previous section in terms of the composition of government funding for R&D activities, as tax-based innovation subsidies are typically targeted to any firms performing R&D regardless of the future potential of the innovations that will arise from such investment. The U.S. and Germany, with government funding for R&D that heavily relies on direct subsidies, might be able to more precisely target the most promising innovations. These differences may explain why while Japan outdoes the U.S. and Germany in terms of gross R&D investment and patent filings, it *does not* outperform in terms of productivity growth.

7. Policy recommendations

The previous sections suggest that Japan's over-reliance on R&D tax incentives might be blunting the innovation and productivity impact of its R&D-related outlays. By contrast, both the U.S. and Germany, through their direct subsidies to targeted innovation projects, might be encouraging investments that translate into innovation in the medium to long-term.

According to OECD data, most business enterprise R&D in Japan is funded by private businesses themselves, with only 0.95 percent financed by the government in 2016 compared to 3.36 percent in Germany and 6.39 percent in the United States. The short-term profit imperative makes it such that businesses have an incentive to invest more heavily in product development than in risky innovation. Japan's over-reliance on private sector R&D for its innovative activities could therefore explain some of the country's productivity rout.

In fact, a burgeoning body of literature pioneered by Mariana Mazzucato makes the case that historically, most technological revolutions have come from ambitious public-private partnerships (e.g., NASA, DARPA, NSF, SBIR) undertaken by governments in their capacity as lead risk-takers and investors—what she terms an “investor of first resort”—without near-term profitability in mind (Mazzucato 2013). The so-called “moonshot” approach (named after NASA’s moon-landing mission) persuasively proposed by Mazzucato essentially consists of expanding public-sector investment in disruptive and high-risk basic research within a mission-oriented framework (Mazzucato 2016, 2018).

What this suggests for Japan is that the way to address anemic growth and revive productivity may be for the government to actively take on the role of a strategic, long-term and mission-oriented investor, stepping in not just to fix market failures but rather to shape and co-create markets in the first place.

The Japanese government’s announcement in 2019 of the launch of a ¥100 billion program (corresponding roughly to USD 1 billion) to support “moonshot” research goals, the Moonshot Research and Development System, is step in the right direction. Modeled after other large-scale international projects such as the European Commission’s Horizon Europe and the U.S. National Science Foundation’s 2026 Idea Machine and 2050 Fund, this ambitious mission-oriented program has the potential to revitalize innovation in Japan.

However, just as in the case of venture capital, because innovation is inherently uncertain and risky, to be effective it is important that Japan actively encourages risk-taking and is tolerant of errors and open to failure. At the same time, because radical technologies—especially general-purpose technologies—may take a while to diffuse to the wider economy and show up in productivity statistics, Japan ought to be patient when evaluating the success of the program writ large.

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