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The World as Our Technologist: Visualizing Worldwide Sources of Technologies Patented in the United States

Richard S. Gruner, *John Marshall Law School*

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by

Richard Gruner
Emeritus Professor of Law
John Marshall Law School

ABSTRACT

Patent rewards in the United States incentivize and attract the overseas development of many new technologies used in this country. The United States – as the world’s largest economy – is the primary driver of technology development worldwide. The strength of United States patent laws, court systems, and civil law enforcement processes ensure that parties who produce new inventions of commercial value and who patent and popularize the inventions in the United States can count on patent enforcement and rewards regardless of where the patented inventions were made. In short, the United States pays for technological value through its patent system and has benefitted from international attention to its technological needs as a result. In the process, it has also incentivized the creation of new technologies of international importance and commercial value. In this, persons and businesses in countries with weaker patent systems are incidental beneficiaries – some would say underpaying incidental beneficiaries – of the successful research and production of valuable new technologies that the United States patent system has incentivized and rewarded.

This article uses data visualization techniques to explore the degree to which foreign inventors have taken the United States up on this bargain by patenting and commercializing foreign-generated technologies in the United States. The article identifies countries that have been particularly efficient and effective sources of new technologies patented in the United States. Countries are analyzed here in terms of their invention outputs per home country gross domestic product (GDP) measured in constant United States dollars. This technique treats various countries as if they have equal economies backing their research and technology development efforts. Countries that are particularly efficient technology sources have high United States patent counts per GDP dollar. These countries are identified in this study primarily through data visualization techniques that compare the productivity of foreign inventors in different countries. The technology production efficiencies of foreign inventors in the countries that are the top ten sources of patented technologies in the United States are compared across countries, in different technology areas, and over time.

The results seen through data visualization are striking in three respects. First, United States innovators seem somewhat less efficient in producing new patented technologies in some technology categories than their foreign competitors (taking into account differences in the sizes of the economies of the countries involved). Second, changes in technology production efficiency have evolved over time very differently in different technology areas, suggesting that some areas have seen surges of intense productivity while others may have hit barriers that have slowed invention production over earlier levels. Third, a few relatively small countries – particularly South Korea and Switzerland – have been highly effective in producing new technologies patented in the United States, suggesting that inventors and companies there have targeted technology needs and commercial markets in the United States as innovation targets in particularly aggressive ways, a strategy that innovators in other small countries may wish to emulate.

I. Introduction

A. Viewing United States Patents as Rewards for New Technology Imports

Patent laws and associated commercial rewards in countries with strong patent systems and large economies serve as world-wide inducements for technological progress. Due to the national treatment requirements of patent laws in most developed countries – specifying that foreign inventors be treated equally with inventors who are citizens of the countries enacting the laws – foreign inventors and companies gain access to patent-mediated market influences and commercial rewards in the world’s strongest economies. The result is that the patent systems of our strongest economies such as those in the United States, Japan and the larger European Union countries serve as technology markets and drivers not only for inventors in those countries but around the world. Hence, inventors worldwide (including in countries with substantively weak or poorly enforced patent laws) can look to patent filings and enforcement in the countries supporting the world’s great economies for innovation rewards. Conversely, the parties in countries with large economies can look to innovators around the world for new technologies, provided that the parties in the leading economies are willing to pay for those new technologies through patent enforcement in the large economies.

This article considers the inbound supply of new technologies into the United States in light of this international system of technology production and rewards. It focuses on foreign sources of new technologies patented in the United States, treating such patenting as means to apply United States markets and commercial gains to incentivize and reward technology innovation from foreign sources. In this way, the United States patent system serves as the linchpin not only for incentivizing in-country innovation, but also for external technology production and importation into the United States of new technologies desired by United States technology users. Commercial value to these users becomes a worldwide signal to potential technology innovators everywhere regarding the proper focus and intensity of efforts to produce new, patented technologies to serve United States interests.

The study described here is based on data on over 2.7 million United States utility patents that reflect inventions by domestic and foreign parties over the period 1977 to 2001. The study compares the efficiency of various countries' economies (on a per gross domestic product (GDP) basis) in generating patented technologies, using United States patent counts as rough measures of both invention production and resulting patent-mediated controls over United States markets. While this study focuses exclusively on patenting practices in the United States, the patterns identified are indicative of the rewards that foreign innovators are probably also gaining elsewhere in the world through patent rights obtained in other countries with major economies such as Japan and the larger European Union countries.

B. Reasons to Study Foreign Sources of United States Patenting

1. Considering the Effectiveness of the United States Patent System in Prioritizing and Rewarding International Innovation

Analyses of foreign sources of United States patenting are worthwhile in part because United States markets – and the payments for new technologies derived from those markets through patent rights – are the largest and most important sources of rewards and incentives for technological advances worldwide. United States technology agendas have the capacity, via associated patent-mediated commercial rewards, to strongly influence the focus and extent of new technology production worldwide. Determining how extensively – and where – foreign technology innovators have responded to United States technology needs and inducements of United States patents provides some indication of whether our patent system is providing effective signals to foreign innovators about our needs and about whether these signals are being translated into responsive innovation programs.

Measuring the response of foreign innovators to United States patents may be a simple and useful means to measure the response of the innovators to worldwide patent incentives generally. This is because seeking a United States patent will typically be part of any international scheme to develop and commercialize a new technology. In areas of shared technological need, innovators may seek patents in other countries in addition to seeking United States patents, but they are unlikely to seek patents in other countries instead of or without seeking similar United States patents. To fail to seek United States patents would be to turn away from the largest single source of patent rewards given the number one size of the United States economy and the relative strengths of the United States patent system and civil law processes for the enforcement of patent rights.

While rewards associated with patents in other countries may increase the size of commercial gains from patented advances, it is unlikely that the range of inventions receiving patents in other countries will be broader or different than the range being patented in the United States (except for those few technologies that are only of strong interest in other countries and not in the United States). Put another way, inventions influenced by United States patenting

opportunities and appearing in United States patents are generally inclusive of inventions being patented elsewhere. Hence, studies of foreign inventions being patented in the United States are indicative of the full range of inventions influenced by patent rewards worldwide, although the strength of incentives for some inventions already encouraged by United States patents may be augmented by the parallel incentives of patents in other countries.

2. Analyzing Specialized Sources of Technologies through Comparative Case Studies by Country

The track records of innovators in particular foreign countries in seeking and benefitting from United States patent rights can also support comparative case studies in how to develop and commercialize technological strengths in particular regions and localities. Recent studies of research communities have emphasized the importance of physical proximity among researchers in producing successful research and inventive results. By studying the track records of various foreign communities in producing technologies that have qualified for United States patents, we can identify particular geographic communities that have been particularly successful in producing specific types of technologies.

Each of the countries studied here as a significant source of United States patents can be treated as a case study in technology production. By adjusting (that is, normalizing) the size of patent outputs of various countries by measures of economic power and commercial activity (such as by dividing the number of patents for each country by the Gross Economic Product (GDP) for that country), we can treat the various countries supplying patented technologies to the United States as relatively equal potential sources of patented technologies and compare their track records and technology production efficiencies. This approach effectively treats countries with large and small economies as equally promising sources of new technologies per dollar of economy size and then looks to how well various countries have followed through on this promise. This permits comparisons of efficiency in producing patented advances. It also assists with the identification of concentrations of especially effective progress in particular technology areas without the potential confounding effects of large patent volumes that simply reflect the large economies of some source countries and the fact that large economies generally produce extensive research programs and large numbers of resulting patents.

By identifying countries that appear to be particularly efficient sources of new technologies (perhaps in only one technology area), further research regarding the practices in that country can be conducted to determine why researchers there are able to produce patented advances more effectively than elsewhere. These further studies should produce insights into effective research techniques and environments that will prove valuable to a wide range of researchers and companies seeking to improve their efficiency and total production of new inventions.

3. Providing a Patent Protection Baseline for Protection Studies Elsewhere

Examining the patent protection practices of foreign parties filing for United States patents can establish a baseline for further studies of patent protection practices of the same parties in other major patent systems. The tendency of, say, German technology producers to seek protection in the United States can be compared to the efforts of the same parties to seek protection in Japan and major European Union countries other than Germany. These studies may aid in determining the most prevalent patterns of patent coverage for different types of technologies.

4. Evaluating Potential Patent-Mediated Control Over United States Trade by Foreign Parties

Patenting by foreign parties in the United States can also provide insights regarding the locations and strengths of international trade controls. Countries that are obtaining large numbers of patents in the United States (perhaps only in a few technology areas) stand to have major impacts in future commercial activities in the United States markets affected by the patents. Foreign companies that stake out particularly strong patent positions with patents that cover highly attractive product features will be in a position to gain large sales volumes by offering products with features that cannot be offered by others. Consequently, these companies may be highly powerful figures in dominating and controlling (at least to the extent of their patent rights) certain United States markets and trade practices. In short, extensive foreign patent rights – coupled with apparent efficiency in the production of those rights suggesting that the foreign parties involved will continue to generate similar United States patent positions in the future – may be a source of concern in limiting the competitiveness of United States markets and in placing control over key United States products in foreign hands.

5. Extending the Trans-Border Model to Intra-Country Technology Development

Finally, although the emphasis in the discussion above has been on the importance of studying foreign inputs to United States patenting as a means to better understand country-level differences in technology production, the lessons learned from these studies may also have importance for regional technology production policy and practices in the United States and larger foreign countries. To understand how these country-level lessons may translate to a regional level, assume that an assessment of the patenting practices of various foreign countries shows that inventors in country X have been particularly efficient (on a patents per GDP basis) in producing patented advances in a specific technology area. A careful study of the technology efforts in country X has identified several distinctive research practices or circumstances that seem to account for the country's success in the technology area. Other regional research communities may wish to consider these same techniques to further technology research generally (assuming that the circumstances or practices in country X are potentially applicable and translatable to all types of research) or to at least further research in the particular technology area emphasized in country X (assuming that the circumstances or techniques accounting for the

success of research in country X are peculiar to one field of technology and associated research). In short, if technology development practices work particularly well in a relatively small economy like that in Switzerland (as later discussions in this article will describe), these same techniques may have similar value if replicated in regions or local areas of countries with larger economies.

II. Methods for Evaluating Patenting in the United States by Foreign Inventors

A. Study Design

The empirical study described here focuses on the countries (including the United States for comparison purposes) that are the top ten sources of patented inventions covered by over 2.6 million United States utility patents (hereinafter “patents”). The study includes all patents resulting from patent applications submitted in 1977 to 2001, reflecting inventions made in approximately those same years. Patents were grouped by application years so as to compare relatively contemporaneous inventions and technology advancement processes in the various countries studied. The countries comprising the top ten sources of United States patents in the period of the study were (in alphabetical order) Canada, France, Germany, Italy, Japan, Korea, Switzerland, Taiwan, the United Kingdom, and the United States. Table 1 summarizes the fractions of United States patents in the dataset from these ten countries, as well as from all the additional countries supplying at least .1 percent of United States patents between 1977 and 2001.

TABLE 1

US Utility Patents from Applications in 1977-2001

Country Source	Patent Count	Percent
United States (US)	1200911	44.24%
Japan (JP)	543244	20.01%
Germany (DE)	171411	6.31%
France (FR)	66281	2.44%
United Kingdom (GB)	51057	1.88%
Canada (CA)	33335	1.23%
Korea (KR)	30369	1.12%
Switzerland (CH)	28675	1.06%
Italy (IT)	23881	0.88%
Taiwan (TW)	21324	0.79%
Sweden (SE)	21278	0.78%
Netherlands (NL)	17769	0.65%
Finland (FI)	10155	0.37%
Australia (AU)	8465	0.31%
Israel (IL)	7002	0.26%
Belgium (BE)	6708	0.25%
Denmark (DK)	5437	0.20%
Austria (AT)	5473	0.20%
Norway (NO)	2793	0.10%
Total	2714651	100.00%

These countries are the locations of the assignees of the patents in the dataset (with almost all of the assignees constituting business corporations). The countries of the assignees were treated for purposes of this study as the countries of the inventors of the patented inventions. While this is not always so – it is possible for an invention made in Japan to be assigned to a corporation in the United States – in most cases the country of the inventors matches the country of the assignees. An inspection of the patent records in the dataset confirmed that this assumption generally held true (that is, few patents recorded an inventor or inventors in one country with an assignee in a different country). Patents without assignees at the time of patent issuance were not included in the country-specific patent totals used in this study. Had the patents without assignees been included, they would probably have primarily increased the figures for inventions by United States inventors. The totals for inventors from foreign countries would have been largely unaffected as foreign individuals, acting with no financial backing of patent assignees, were unlikely to have pursued the extreme expense of a foreign patent filing in the United States on their own.

The use of United States patent counts as the focus of the analyses here had several advantages. First, the focus on United States patents puts the study within a single legal system, which should minimize potential biases that might confound the analyses if patenting in multiple countries were compared. Patent counts in multiple countries might be different simply because of differences in the legal standards or patenting practices in those countries. The limitation of the study to results within the United States patent system avoided any concerns about differences in patent law requirements or patent drafting strategies from country to country. All of the applicants who submitted the patent applications leading to the patents measured here were working within the same patent system and seeking to comply with the same United States laws regarding the necessary features of patentable inventions and patent applications. All of the applications were subject to the same filtering process in examination – that is, the applications were all assessed against the same United States patent laws for sufficiency in reviews by USPTO patent examiners before resulting in issued patents and entering the data set considered here. Hence, the same legal requirements and legally-influenced strategy choices should have exerted similar force on applicants from the different countries studied, resulting in no legally-induced country-specific biases in the data.

Second, all of the applicants for patents recorded in the data set faced the same commercial incentives and potential rewards. In deciding whether to seek a United States patent, potential patent applicants would have looked to the same range of later enforcement throughout the same United States economy to gauge the projected value of a United States patent and to decide whether or not such a patent seemed worth the cost of obtaining it. The projected commercial value for two similar inventions emerging from different countries would be the same since the inventors of both inventions could seek and enforce the same United States patent regardless of the country in which they were located. Hence, the same commercial attractions

and perceived value of United States patents would have influenced innovators across the world, first to consider the range of advances that were commercially valuable in the United States and then to seek United States patents once viable designs for useful advances were realized. These similar commercial forces and attractions facing parties across the world should have resulted in similar likelihoods of United States patent filings for rationally motivated inventors in various countries regardless of the actual countries of invention.

Each patent recorded in the data was viewed as representing one invention (nominally a requirement of United States patent laws). The study design treated the various inventions reflected in the data as being of equal importance. While the inventions covered by all United States patents are clearly not all of equal importance – varying significantly in complexity, commercial value, and societal importance -- there is no reason to believe that the importance of inventions along any of these dimensions is correlated with inventions emerging from any particular country. Any differences in importance should be distributed roughly equally across the various countries studied and country-specific differences in invention importance should not affect the value of the findings in this study. Putting the same point in another way, even assuming that inventions have varying importance, the distribution of importance emerging from each country will be about the same which means that the average importance across various countries will be about the same. The patents considered here can each be interpreted as recording an invention with about this shared level of average importance without undercutting the significance of the conclusions reached here based on patent counts.

This section presents data visualizations of numbers of patents resulting from patent applications over the period from 1977 to 2001. These visualizations were prepared to assess the changes in patented invention production over time for the various countries studied. The visualizations were designed to minimize the effects of economy size on invention outputs and to treat the various countries under study as if they were invention sources with equal resources at their disposal in producing patented advances. This was achieved in part by focusing on patent production per GDP as a measure of invention production efficiency. GDP size was used as a scaling factor to normalize the analyses based on economy size and to eliminate the impact of large economies producing high volumes of inventive efforts and high volumes of resulting patents. As normalized, the economies of small countries (such as Switzerland) can be evaluated in their use of resources to produce patented advances on the same level resource plane as much more resource-intensive countries (such as the United States, Japan, and Germany). As described below, small countries such as Switzerland are remarkably productive sources of patented technologies in some fields when viewed from this resource neutral perspective. Across the set of countries studied, substantially different patterns of invention production were found over time and in different technology categories. The data visualizations were constructed so as to highlight these differences.

B. Data Sources

This study relies on a dataset describing United States utility patents compiled by the National Bureau of Economic Research (NBER).¹ The NBER dataset includes information on patent application dates, issue dates, numbers of claims, patent assignee countries, and technology types.² The dataset used in the present study was released in 2010 and covers all United States utility patents issued from 1976 to 2006. This dataset updated a prior NBER dataset on patents granted between 1963 and 1999. These datasets are the products of a long-standing project studying patent citation patterns and other aspects of patented inventions.³

The NBER dataset is particularly useful as it records NBER researchers' classifications of patented inventions within six broad technology categories. The six categories were created by mapping the 443 technology categories used by the USPTO to classify the primary technology area of each patented invention into the NBER's six technology categories.⁴ The six technology categories include advances in the following areas: 1) chemical (excluding drugs), 2) computers and communication, 3) drugs and medical, 4) electrical and electronic, 5) mechanical, and 6) other technologies.⁵

¹ The present project relied on the pat76_06_ipc dataset created by the NBER. This dataset contains information on each patent issued from 1976 to 2006 and is available for downloading from the NBER website. See National Bureau of Economic Research, Patent Data Project Downloads, <https://sites.google.com/site/patentdataprotect/Home/downloads> (last visited on 4/6/2012).

² National Bureau of Economic Research, patn data description, <https://sites.google.com/site/patentdataprotect/Home/downloads/patn-data-description> (last visited on 4/6/2012).

³ The background and potential uses of the NBER patent data are described in Bronwyn H. Hall, Adam B. Jaffe, and Manuel Trajtenberg, *The NBER Patent Citations Data File: Lessons, Insights, and Methodological Tools*, <http://elsa.berkeley.edu/~bhhall/pat/NBERpatdata.pdf> (last visited on 4/6/2012).

⁴ These six technology categories were defined and used by NBER researchers for earlier studies of patent citation patterns. The six categories group together multiple USPTO primary technology classes in each of the NBER categories. The USPTO classifies the technology involved in every patent application as part of processing that application. Each patent is assigned a primary technology class code that reflects the primary field of the invention covered by the patent. A patent may also be assigned additional technology class codes if an invention involves advances in multiple fields. These technology categories and codes are used by the USPTO to aid patent examiners and others in finding relevant patents when researching advances in particular technology fields. Because research tasks and efforts to properly classify patents to support such research are important to the USPTO, this technology classification system is the object of considerable efforts and care on the part of USPTO personnel.

The six technology categories used by the NBER (and relied on in the present study) are determined directly from USPTO classes. Several USPTO technology classes are mapped into each of the six NBER technology categories. Information on the mappings of the USPTO technology classes into the NBER technologies categories (including which NBER category includes each of the USPTO classes) is available in NBER, *classification_06*, https://sites.google.com/site/patentdataprotect/Home/downloads/patn-data-description/classification_06.xls?attredirects=0&d=1 (last visited 4/6/2012).

⁵ The "other technologies" category contains a very diverse mixture of invention types, with advances ranging from textiles to toilets. Hence, conclusions based on patent records grouped in this category may have limited value as the inventions being assessed varied vastly in types and inventive environments. See *id.*

The research design was tailored to avoid possible problems with truncation effects concerning patent applications submitted at the end of the period covered by the dataset. The full dataset contained information on patents issued between 1976 and 2006. The possible truncation effects of concern in the study design stemmed from the use of patent application dates as a grouping criteria. To ensure that roughly contemporaneous inventions were grouped for analysis in the present study, inventions were grouped and analyzed by the year of their patent applications.⁶ However, some of the patent applications submitted in the years immediately preceding 2006 were still under consideration by the USPTO as of the end of 2006 and then resulted in patents in later years. These successful applications, submitted in the years just before 2006 but resulting in patents after 2006, did not produce records in the dataset (which includes no patents issued after 2006). In this way, data on patents stemming from applications submitted in the years approaching 2006 were artificially cut off or “truncated” due to the absence of corresponding records in the dataset. The solution to this problem was to include only data on patents applied for through 2001 in this study (on the ground that analyses of the data showed clear truncation effects for patents applied for in years later than 2001, meaning that data for these patents could not reliably be compared to the more complete data for patents resulting from earlier applications).

One other restriction on the data included in the study resulted from the apparently incomplete country coding for patent applications submitted before 1977. This appears to affect the coding of records for patents resulting from inventions in some countries (e.g., Japan, Germany, and Great Britain) but not for inventions from other countries (e.g., France, Switzerland, Canada, and Italy). To avoid difficulties with this apparent coding incompleteness, only data on applications submitted in 1977 and after were included in the study analyses.

Given these considerations, patents resulting from applications earlier than 1977 and later than 2001 were excluded from the data considered here. A rich and extensive patent record remained after these exclusions, covering all utility patents issued for all technology types in the years 1977 to 2001. This amounted to records on over 2.7 million patents reflecting inventions from around the world. The breakdown of the patents studied by the country of the inventors is shown in Table 1 above. The breakdown of the patents studied by technology types is shown in Table 2 below.

⁶ The application dates used for grouping the patents were roughly the same as the invention dates for the patented inventions or, at least, similarly offset from those invention dates by the similar application preparation delays for the various applications. Thus, grouping the patents by application dates achieved comparisons of roughly contemporaneous inventions.

TABLE 2

Technology Category Breakdown

Technology Category	Patent Count	Percent
Chemical	473220	17.43%
Computer and Communications	457256	16.84%
Drugs	269075	9.91%
Electrical and Electronic	503880	18.56%
Mechanical	503151	18.53%
Other	508061	18.72%
Total	2714643	100.00%

III. Data Visualization Analyses of Innovation Efficiency

The analyses described here used data visualization software (Tableau Public 7.0) to generate displays reflecting the relative efficiency of inventors in ten countries as sources of patented advances. The data shown in these visualizations corresponds to the ten countries that were the top sources of inventions leading to United States patents in the period of this study. These include (in descending order of GDP at the end of the study) the United States (US), Japan (JP), Germany (DE), France (FR), Great Britain (GB), Italy (IT), Canada (CA), Korea (KR), Taiwan (TW) and Switzerland (CH). An eleventh data point is displayed to reflect inventions from all other countries in the world (with the label of Other or OT). This data point was plotted as if all of the other invention sources (with their aggregated GDP) were one additional country.

Each of the data visualizations reflects variations in the patent data across three dimensions: 1) country GDP (accounting for variation across the horizontal axis), 2) patents per GDP dollar (accounting for variations across the vertical access), and 3) total patent count contributed to the pool of United States patents (accounting for the size of the circular dots plotted for each country).

A. All Inventions

Figure 1 reflects the production of patented advances in 1977 from the indicated countries. The vertical axis in this graph reflects the number of patents from each country divided by the GDP (in constant United States dollars) for that country. This value is a measure of the efficiency of invention production per GDP dollar. A higher point reflects greater invention generation efficiency per GDP dollar than a lower point. The horizontal axis reflects the raw GDP values for the countries displayed on a logarithmic scale to better spread the GDP values for countries varying greatly in economy size (including such diverse economies and

GDP figures as those of Switzerland and the United States). Higher GDPs are plotted to the right along this axis. The size of the circles plotted along these vertical and horizontal axes reflects the raw counts of patents resulting from inventions in each country. A bigger dot means that the country involved accounted for more patented inventions than a country with a smaller dot.

Figure 2 reflects the same type of data display for the production of inventions in 2001. By comparing these two displays, changes in invention production efficiency between 1977 and 2001 (as reflected in the rise or fall of individual country dots) can easily be seen. To make these changes more clearly apparent (and to track the year-by-year changes that account for the overall changes from 1977 to 2001, Figure 3 displays the 2001 data with history “tails” that track how the country dots moved through the chart as the data moved year-by-year from their 1977 values to their 2001 values. This type of display provides a direct visual record of the international history of invention productivity over the period of this study.

FIGURE 1
All Patents 1977

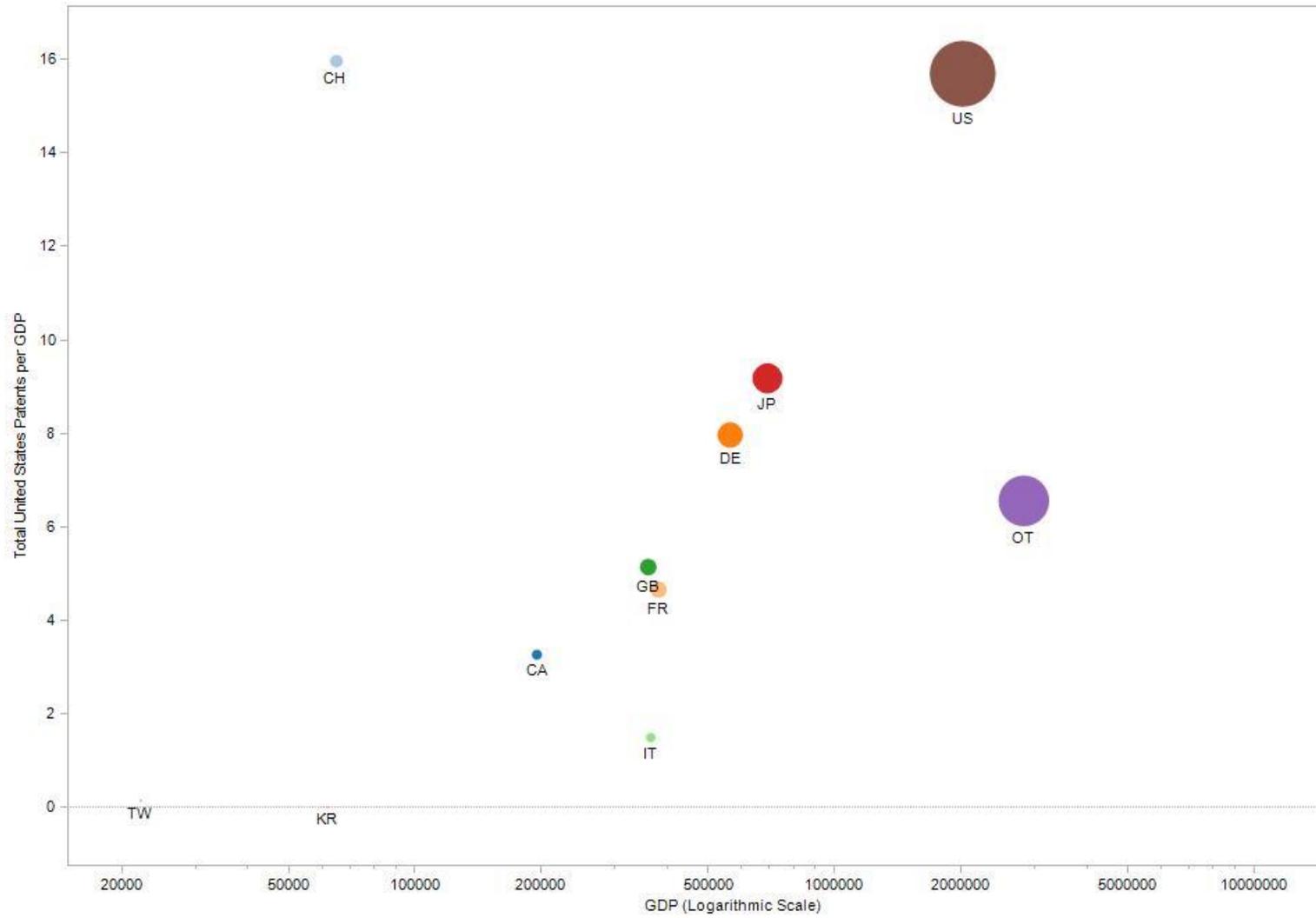


FIGURE 2
All Patents 2001

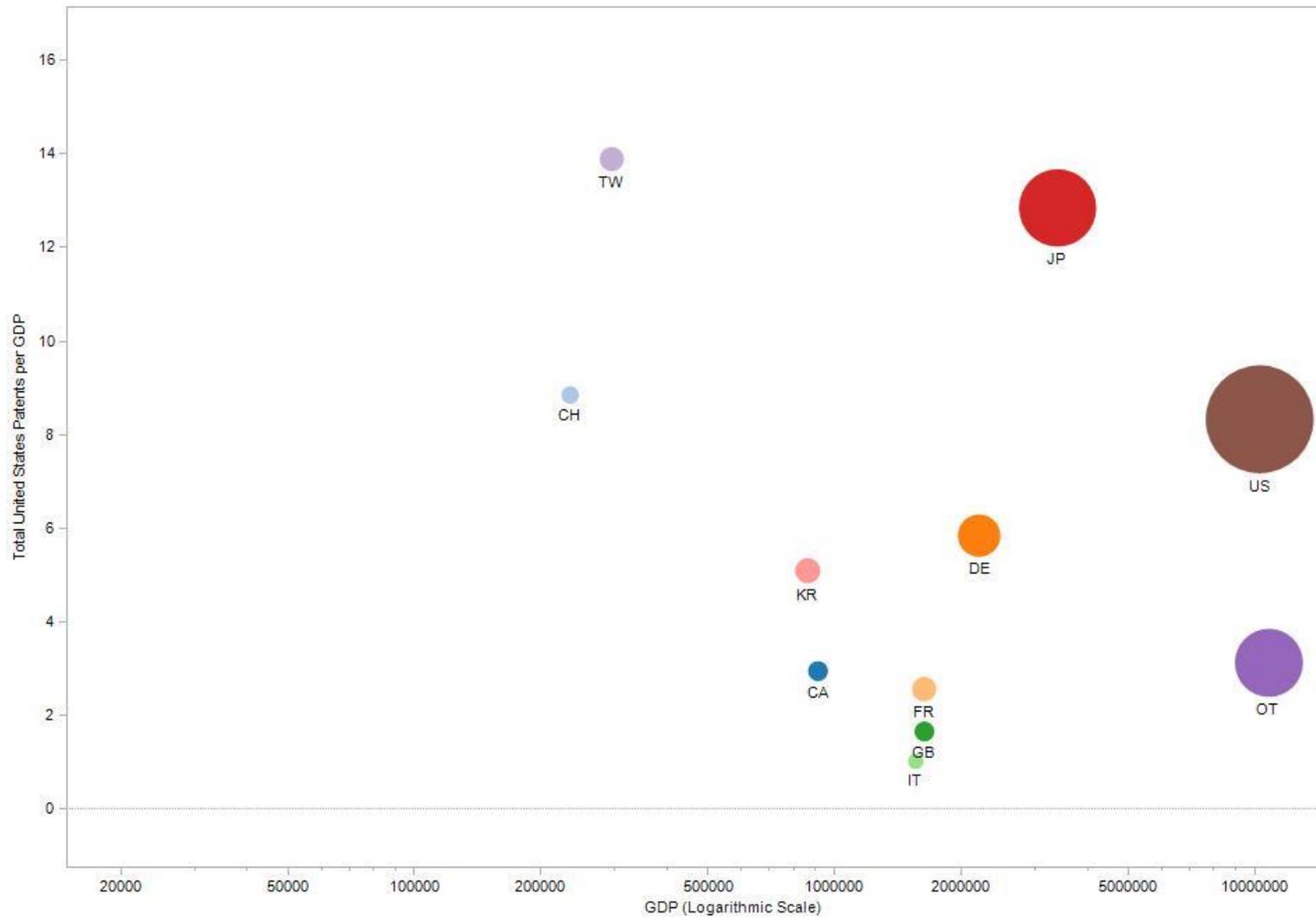
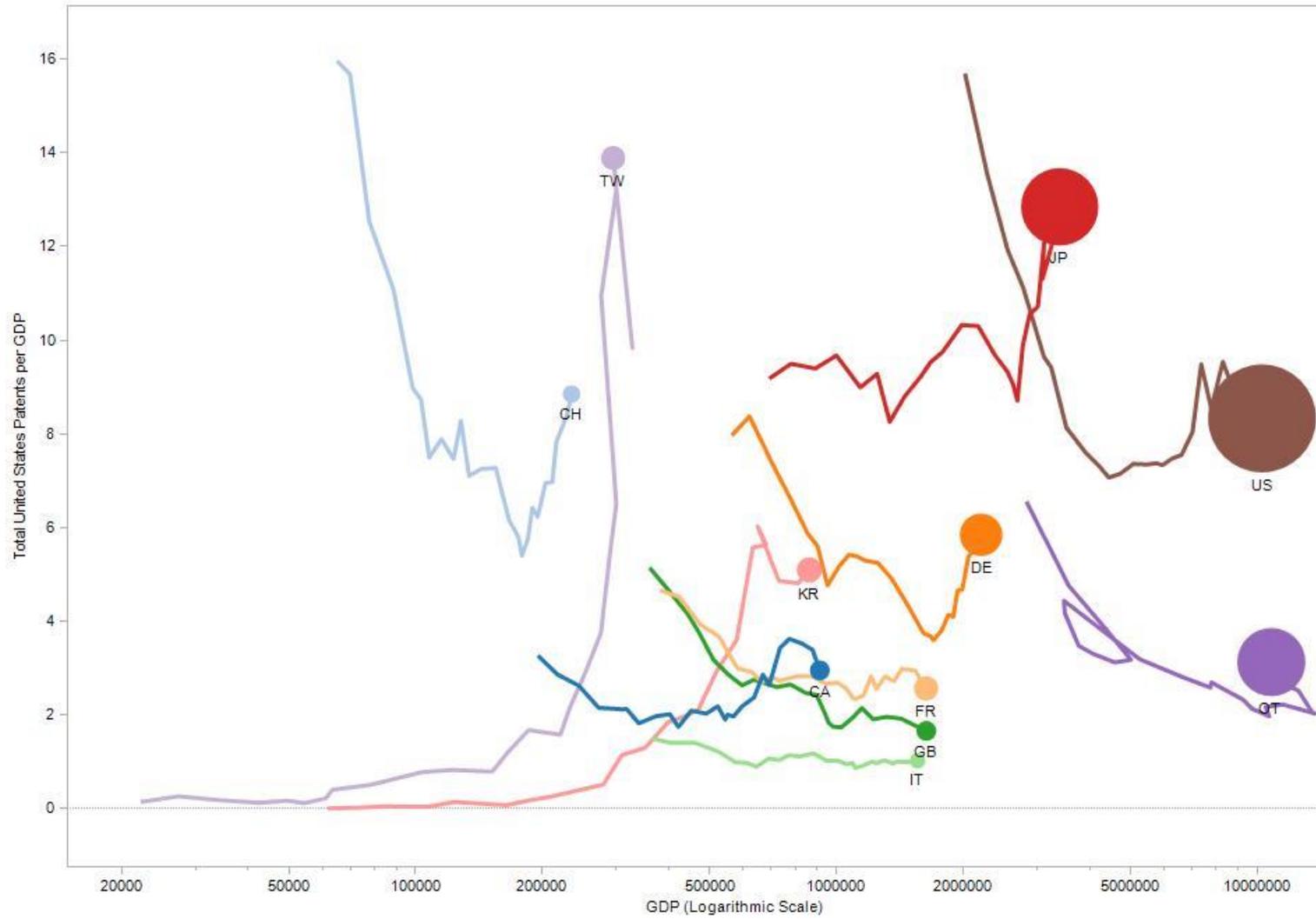


FIGURE 3
All Patents 2001 with History



The patent production histories reflected in Figure 3 support several interesting findings. In interpreting these findings, it is important to remember that because the economies of all the countries studied grew over the period of this study (with a few rare exceptions in particular years), the movement of country data points from left to right across the graphs corresponded to the passage of time between 1977 and 2001 (although the starting and ending points of the GDPs for each country were different, as were their rates of GDP change over time). For convenience, the history charts in this study (such as Figure 3) will sometimes be referred to as reflecting the changes of patenting levels and efficiency over time (moving left to right in the history graphs) even though the charts are graphed in terms of changes in country GDPs. Careful examination of the above figures in light of these features supports the following findings.

First, the efficiency of invention production by United States inventors (as recorded in the brown dot and history trail) seems to have gone down substantially over the period of the study. There is substantial evidence here that there are not enough patented advances being produced in recent years relative to the United States own prior per GDP levels of invention production. Innovation in this country appears to be weakening over time – or at least not keeping up with the growth and evolution of our GDP. While there has been considerable public debate and concern about rising levels of patenting in the United States, what has been missed in this debate is that our production and patenting of United States-originated technologies has apparently not kept up with our even larger growth in GDP. “Adequate” or “normal” patenting based on United States-sourced inventions is a moving target. If adequate patenting means in accordance with historic levels, we are falling behind.

Second, the production of several other countries does not seem to have reflected similar drops in invention productivity. The production of advances by innovators in Japan (red) and Germany (orange) produced relatively flat lines over several years and extensive changes in their economy sizes, meaning that the number of advances produced in these countries grew at about the same pace as their economies over the period of the study. Again, there is reason to be concerned about the technology generation reductions in the United States because some of our primary competitors have not experienced similar reductions but rather have grown their production of protected technologies along with their economies.

Third, there are some countries that appear to have maintained substantially higher levels of invention production efficiency than innovators in the United States (at least in some years). Early in the period 1977 to 2001, Switzerland (light blue) produced inventions with higher efficiency than the United States’ production (as indicated by the higher position of the left-most portions of the history tail for Switzerland in the chart than the corresponding left-most portions of the history tail for the United States). Later in the period studied, innovators in Taiwan (light purple) rapidly increased their efficiency of invention production to achieve higher efficiency than inventors in the United States (as reflected in the much higher position of that country’s dot for 2001 relative to the similar dot for the United States in 2001). Japan (red) started with a lower efficiency than the United States, but ended the period of the study also with an invention

production per GDP at a higher level than the United States (as reflected in the higher position of the dot for Japan in 2001 than that for the United States).

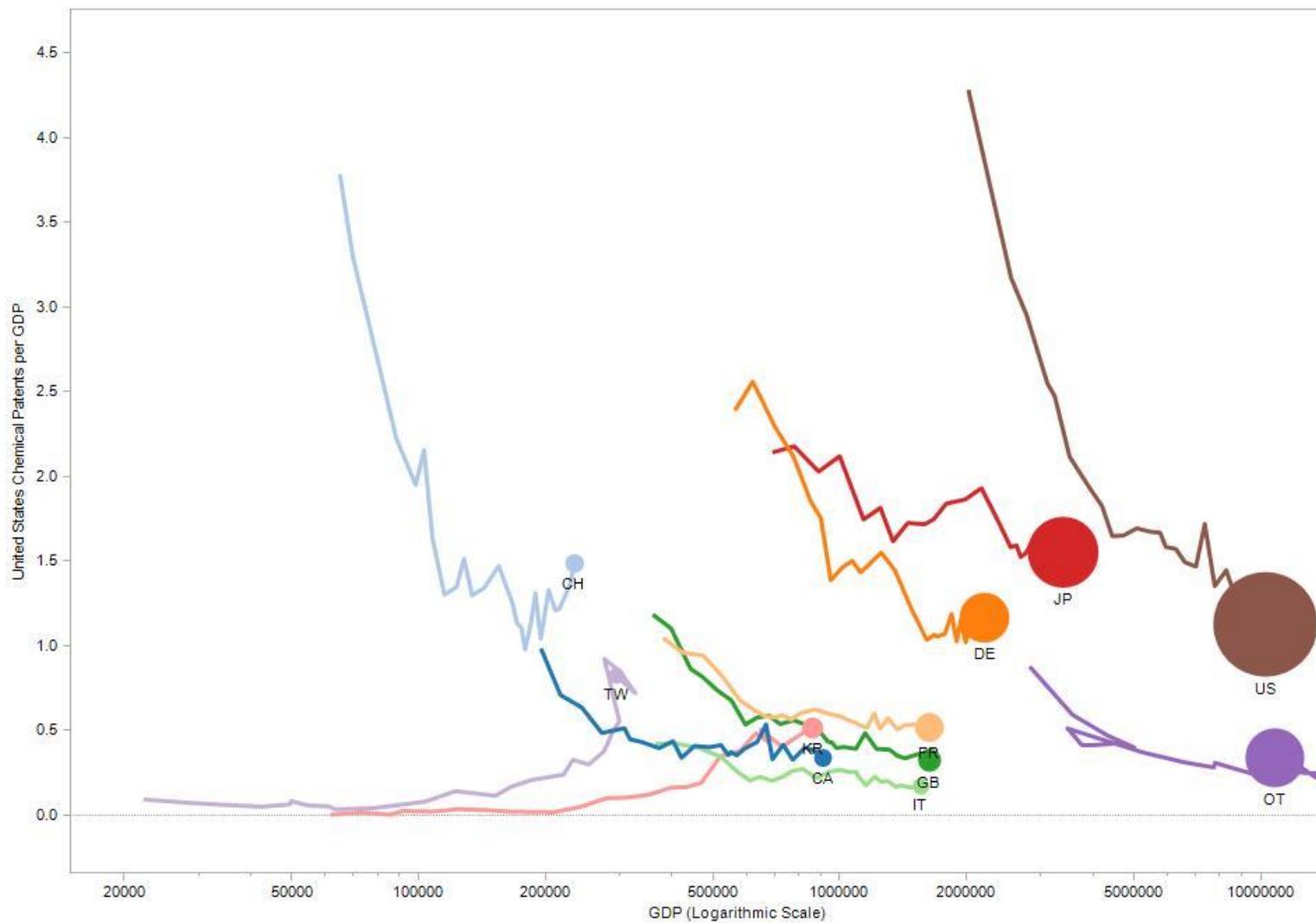
Fourth, the invention efficiency levels for most countries addressed in this figure are remarkably low across all the years of the study. The efficiency levels for several European countries, including France (beige), the United Kingdom (dark green) and Italy (light green) are substantially lower than Germany despite their geographic proximity and similar access to European Union resources. Two other countries stand out as being relatively high in their invention production efficiency. Canada (dark blue) demonstrated similar invention production efficiency to France despite having a much smaller economy. This success by Canadian innovators may reflect some advantages of physical proximity to United States innovators or United States commercial resources and relationships. The upward movement of innovation efficiency in Korea (light pink) brought it to levels similar to Japan and the United States although there has apparently been a drop off in recent years. Even with this drop off, Korea matched the innovation efficiency of Germany in 2001.

The results displayed in the above figures illustrate some differences in the overall technology development patterns during the years of this study, but raise the possibility that the changes seen in this overall data reflect different mixes of technologies under development in the different countries studied. To eliminate the potential effects of differences in the technologies produced in different countries, the production efficiency of these same ten countries was evaluated for each of the six technology types recorded in the NBER dataset. The results of these technology-specific analyses are presented in next six sets of figures displayed and discussed below.

B. Chemical Inventions

Figure 4 plots chemical invention production from 1977 to 2001 for the countries under study. The vertical axis, horizontal axis, and dot size characteristics are the same as in the prior figures except that the values reflect only inventions in the chemical technology category. Separate figures for 1977 and 2001 data are not shown here (as was the case for all inventions) for the sake of brevity. However, the values for the 1997 and 2001 chemical patent data can be determined from the history traces in Figure 4.

FIGURE 4
Chemical Patents 2001 with History



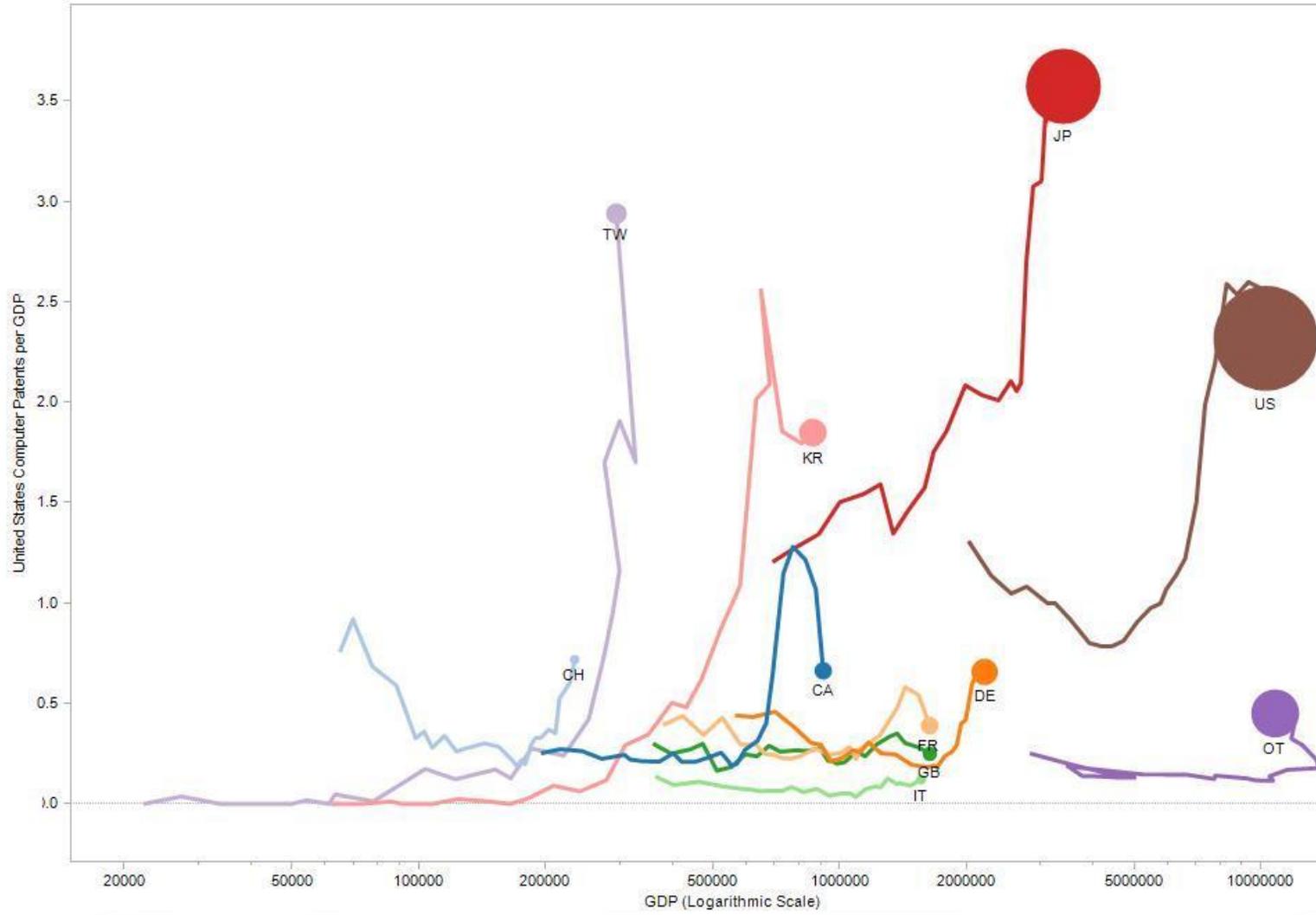
One striking feature of the data shown in Figure 4 is the significant drop over the period of the study in the efficiency of production of chemical inventions in many of the countries assessed. On a per GDP basis, Switzerland and the United States (the most efficient producers at the beginning of the study) drop substantially. Other major producers of chemical patents such as Japan and Germany also dropped from their highest levels although less rapidly. At the end of the period, several countries (including Switzerland, Taiwan, Germany, Japan and the United States) were producing patented chemical advances at about the same rate on a per GDP basis. The rates in the other countries under study were much lower (at less than half the levels for the United States).

The similarity in 2001 of the chemical invention production efficiencies in Switzerland, Taiwan, Germany, Japan and the United States suggests that innovators in the United States were keeping up and holding their own in the production of chemical advances at the end of the study. However, the large drop in production efficiency from earlier periods is troubling in that it suggests much higher levels of invention production efficiency were once common in United States firms. Further studies of practices and challenges in the field of chemical product innovation will be needed to determine why United States (and Swiss) production levels dropped so substantially over the years of this study. The aim for United States innovators concerning chemical advances is to consider what has changed in inventive resources, methods, and challenges in the chemical field since the 1970s and to determine whether it is possible to move the United States back to increased invention efficiency on a per GDP basis of the sort that was prevalent for United States researchers in these earlier, more productive days for chemical research and patented invention development.

C. Computer and Communication Inventions

Figure 5 presents data on the production of patented inventions in the computer and communication fields.

FIGURE 5
Computer and Communications Patents 2001 with History



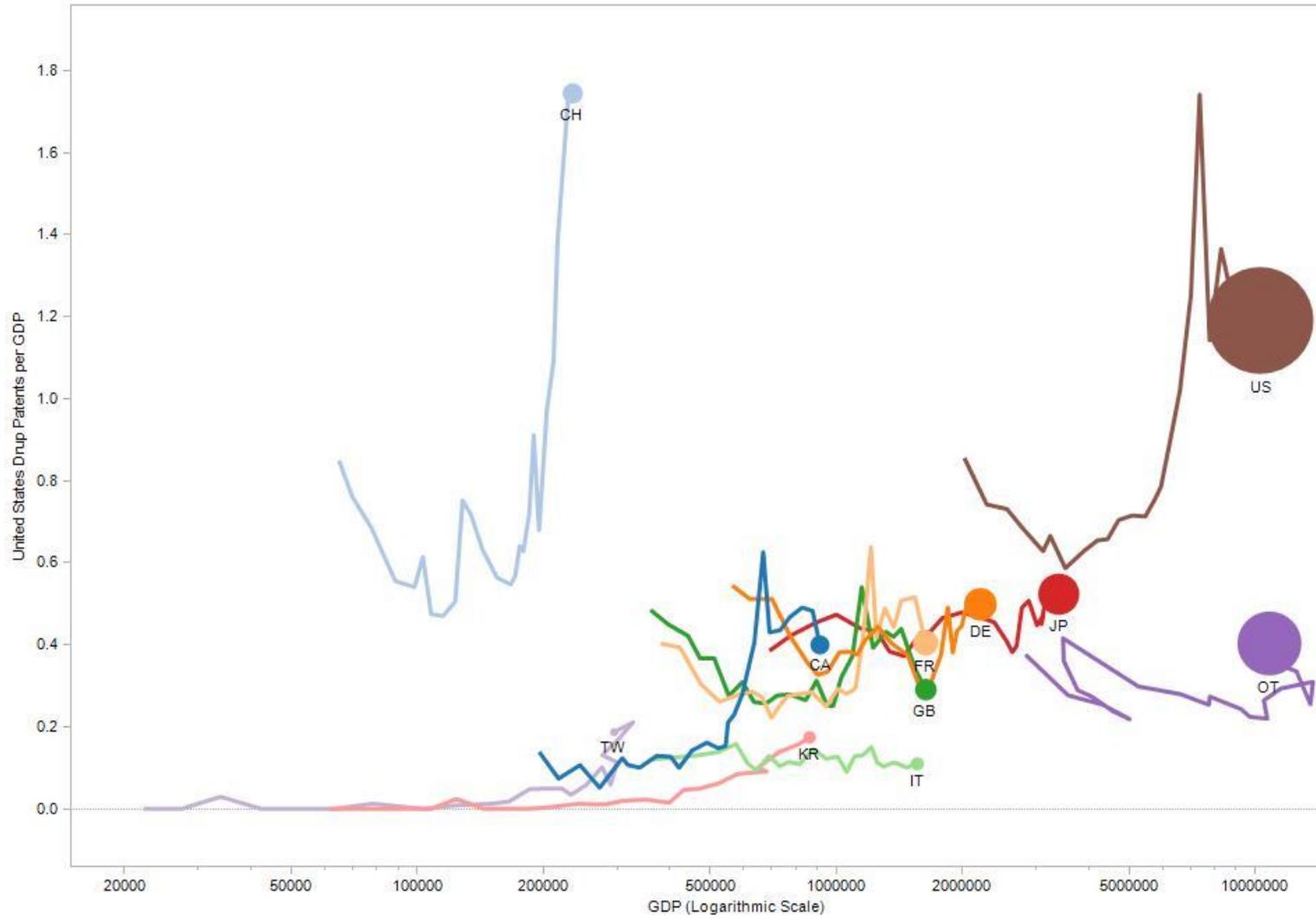
Invention development patterns for these fields reflect rapid rises in efficiency in some countries. Taiwan, Korea, Canada, Japan and the United States showed big jumps in their production of patented advances during the period of the study (although production efficiency in all of these countries other than Taiwan dropped somewhat towards the end of the study period). These widespread increases suggest that innovation trends in the computer and communication fields were driven by technology characteristics that parties could capitalize on in diverse research settings and country environments. The ability of innovators in multiple countries to respond similarly to these forces and to rapidly increase their production of patented advances concerning computer and communication devices and processes suggests the inputs and facilitators of research in these technology areas may be relatively easily transferable and applicable in other countries with wide variations in local workforces and other conditions. At the same time, the lack of similar increases in the efficiency of computer and communication invention production in the European countries included in the study is a puzzling, suggesting that there are geographically-linked or culturally-linked characteristics that hinder computer and communication innovation in these countries.

At the end of the study period, innovators in the United States were being out produced on a per GDP basis in the computer field by their counterparts in Taiwan and Japan and were only roughly equal to their counterparts in Korea. To stay ahead in these highly important commercial fields, United States firms and innovators should pursue inventions at rates at least as productive as their counterparts in other countries. This may require some substantial learning about innovation targeting and pursuit from Taiwanese and Japanese innovators and corresponding improvements in United States invention programs concerning computer and communication advances. There are simply too few patented advances emerging in these fields from United States sources given the increasing strength and size of the United States economy.

D. Drugs and Medical Inventions

Productivity data for inventions in the drugs and medical fields are displayed in Figure 6.

FIGURE 6
Drugs and Medical Patents 2001 with History



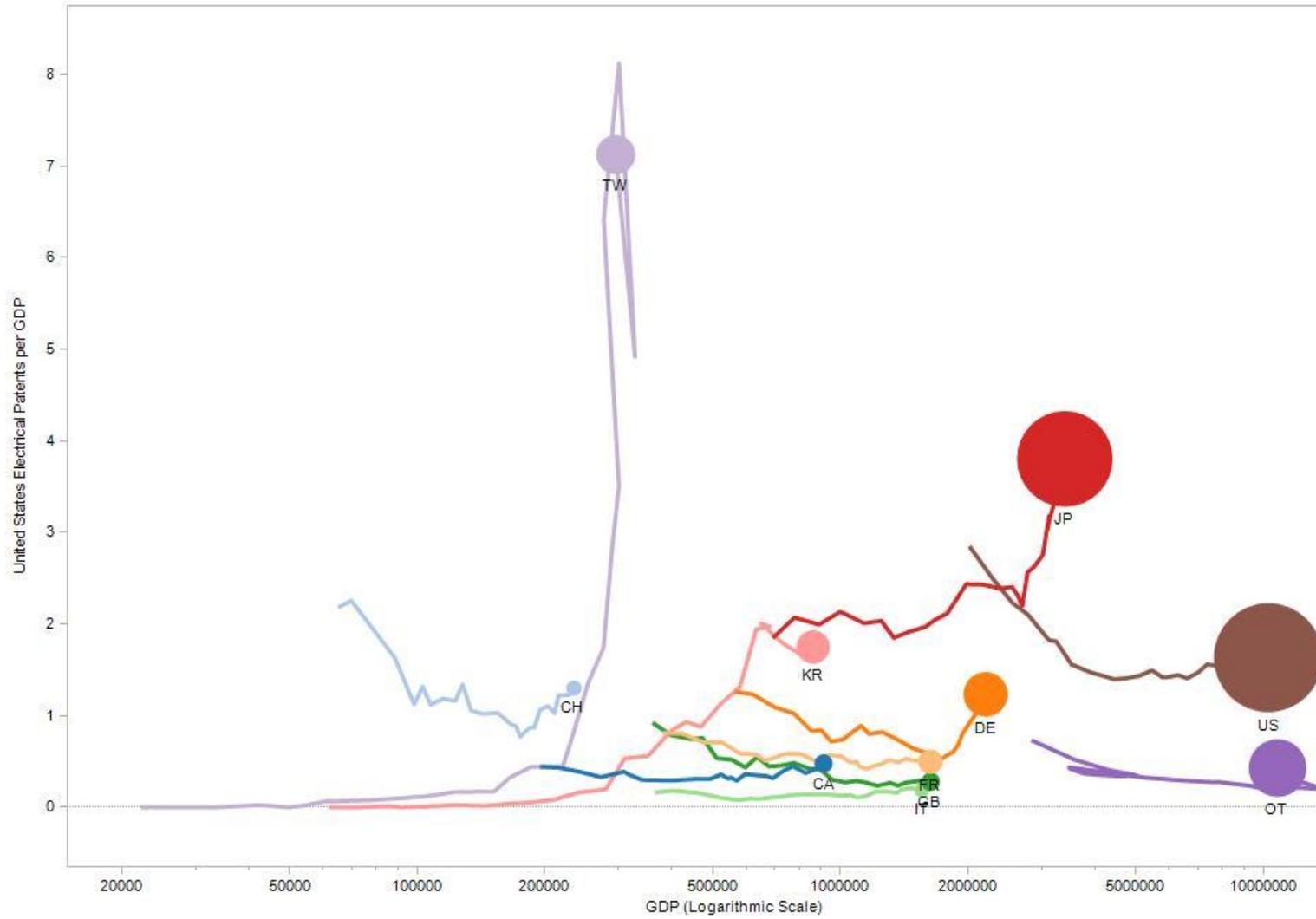
The data reflected in this figure show yet another pattern of technological development. Innovators in Switzerland and the United States showed substantially higher efficiency in producing patented inventions involving drugs and medical advances than innovators in the other countries studied. The efficiency of innovators in these two countries rose dramatically during the middle of the study period (suggesting some common practices or innovation drivers that influenced research in these two countries), but fell during the last few years. Surprisingly, production efficiencies in most of the other countries were relatively low and constant during the period of the study. Why innovators in none of the other major technology producing countries (such as Japan and German) were not able to make use of the same invention-facilitating practices that spurred medical and drug research in the United States and Switzerland is a major question for future evaluation raised by the findings in this study.

Advances concerning drugs and medical innovations represent a bright spot for the United States among the various technologies addressed in this study. The United States is by far the most efficient producer of patented inventions in the drugs and medical areas, with the exception of Switzerland. Swiss innovators were even more efficient, but accounted for only a small fraction of the number of patented advances that innovators in the United States produced. The techniques used by the Swiss to achieve even higher efficiencies than United States researchers may be worth study to help adjust United States levels to even higher efficiencies matching those that the Swiss have already achieved. However, in general, researchers in the United States and Switzerland are the leaders in these fields and innovators in other countries should learn from these leaders to raise their respective levels of innovation efficiency regarding patented advances in the drugs and medical fields.

E. Electrical and Electronic Inventions

Figure 7 displays country-specific efficiency data on the production of electrical and electronic inventions.

FIGURE 7
Electrical and Electronic Patents 2001 with History



This figure points up the great success (and rapid increases in efficiency) that innovators in Taiwan have been able to achieve in recent years. Taiwanese innovators have realized a much higher level of efficiency of patented invention production than innovators in any other country at any time during the period of the study. Other countries – notably Japan and Korea – rapidly increased their invention production efficiency at certain points in the study period, but stayed at relative flat levels near the end of the study period (which still meant that their increases in invention production were keeping up in proportion to their increases in economy size). The United States, by contrast, showed a marked drop in invention efficiency, ending up the period at about the same levels per GDP as the other major producers in these fields (i.e., Japan, Korea, and Germany). The remaining European countries in the study and Canada were never large producers of advances in this field and did not realize the same type of growth seen by the other countries just mentioned.

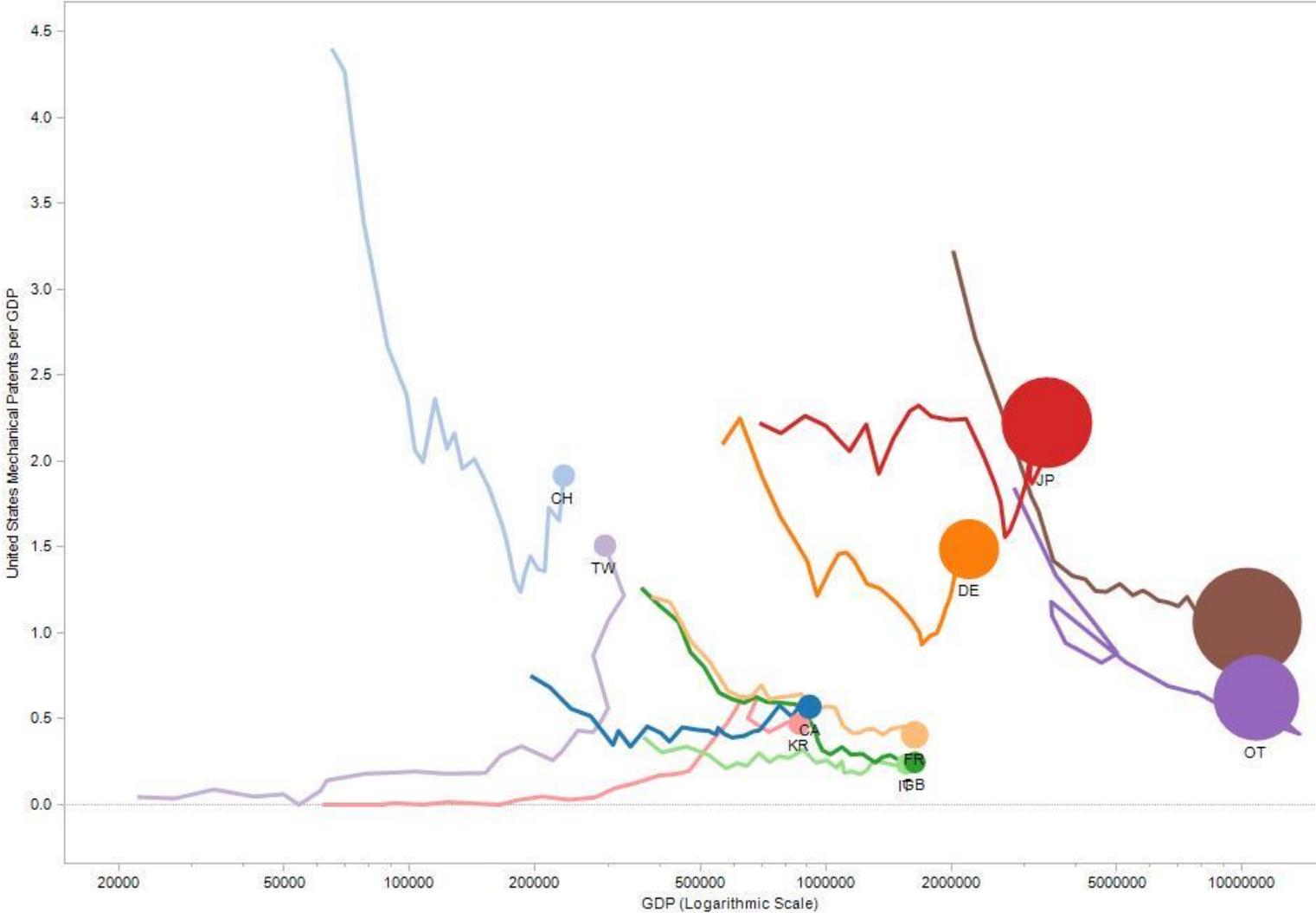
The reasons why innovators in Germany were able to increase the efficiency of their production of patented advances concerning electrical and electronic inventions when nearby innovators in France, Great Britain, and Italy achieved no parallel increases would be interesting to determine. The reasons for Germany's particular success in these fields may suggest research techniques or environments that other countries can use to enhance their methods for electrical and electronic technology development.

Interpreted from a United States perspective, these figures raise questions about the sufficiency of United States production of patented advances in the electrical and electronic fields in recent years. On a per GDP basis, Taiwanese and (to a lesser extent) Japanese innovators seem to be substantially more productive than their American counterparts. The Koreans and the Germans, with much smaller economies, are about our equals in their rates of production of advances in the electrical and electronic fields. The reasons for the drops in efficiency in United States research and for the ascendancy of these other countries in rates of inventions produced per GDP deserve further study and attention.

E. Mechanical Inventions

Mechanical inventions – involving arguably the simplest types of technology addressed in this study – had invention production efficiency levels shown in Figure 8.

FIGURE 8
Mechanical Patents 2001 with History



The most remarkable finding that this figure supports is that the United States is again bested in invention production efficiency as of 2001 by innovators in several other countries. United States' innovation efficiency regarding mechanical inventions, while starting the period of the study at a high level (matched only for much smaller invention volumes by innovators in Switzerland), dropped markedly during the period of the study. In this same interval, innovators in Japan and Germany were able to increase their invention efficiency regarding mechanical inventions and then to hold their efficiency at relatively constant levels over the period of the study even as the economies of these countries grew (which means that innovators in these countries were producing more mechanical inventions in proportion to the growth in their economies). Innovators in Taiwan were able to markedly increase their production of mechanical inventions late in the study period to bring their efforts up to about the invention efficiency level as United States innovators achieved at the end of the period.

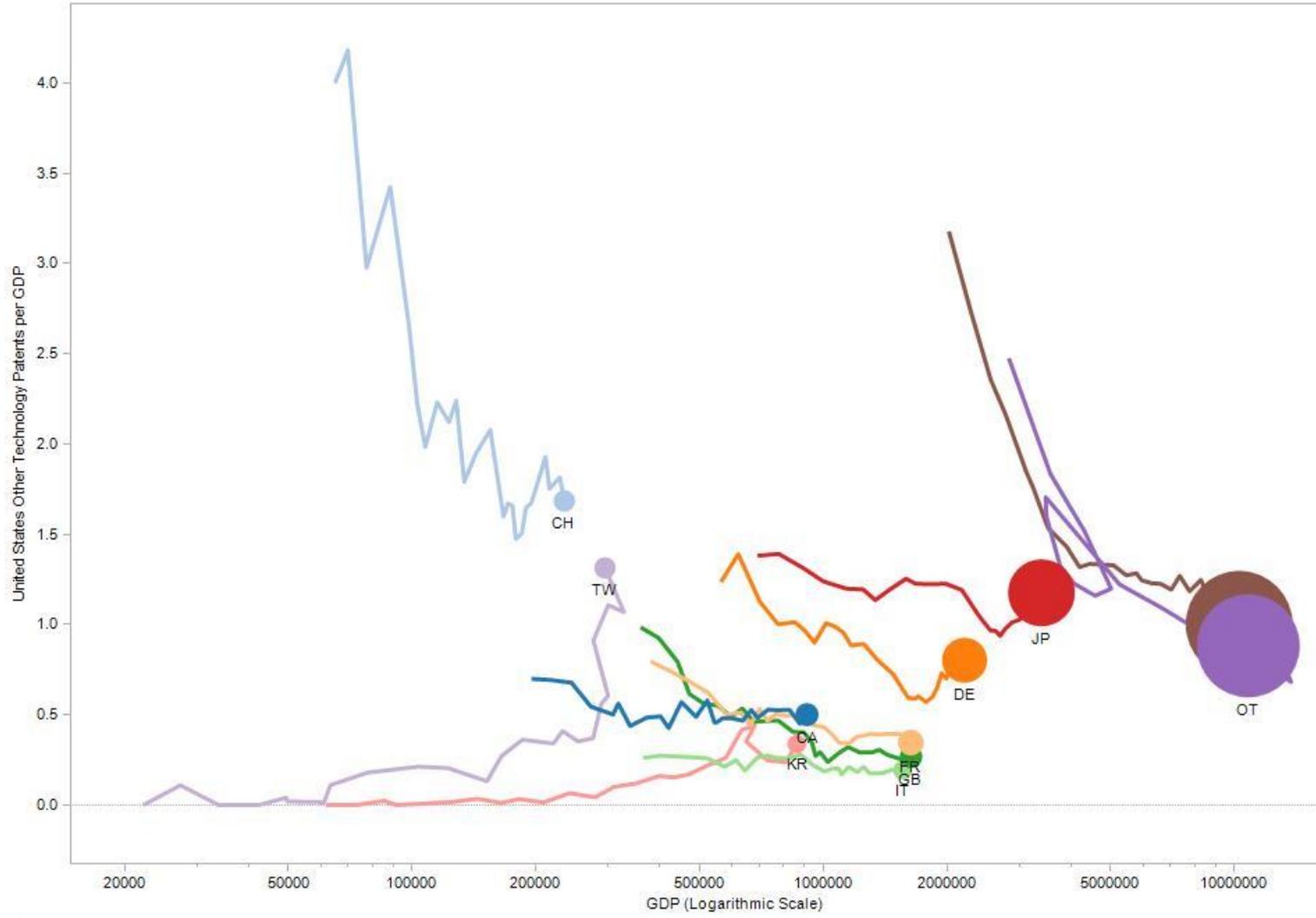
The ability of innovators in other countries to support higher levels of invention production per GDP (as well as the ability of United States' innovators to support higher levels prior to 2001) suggests that, as with some other areas of technology previously discussed, United States innovators and policy makers should be concerned by the low numbers of mechanical innovations and patents emerging from research in this country. We are, put simply, not keeping up with the Japanese, Germans, and others in producing mechanical inventions at rates commensurate with the size of the United States economy.

F. Other Technology Inventions

The final data visualization presented in Figure 9 concerns technologies recorded by the NBER as falling in the "Other Technology" category. This technology category contains miscellaneous types of technologies – that is, all technologies left over when inventions in the other five, more specific categories are removed from United States patent records. Because the Other Technology category contains highly diverse types of technologies emerging from what were probably highly diverse research personnel, resources, and settings, it is difficult to draw many conclusions about the trends seen in the data on Other Technology patents and inventions.

One possible way to think of the results for this mixed technology category is that these reflect forces and changes across diverse technologies, which may be generally applicable trends on top of which other technology-specific changes worked additional increases or decreases. In this way, the changes seen for other technology advances may be thought of as indicative of foundational changes in invention efficiencies, from which the size of changes in other technologies can be measured.

FIGURE 9
Other Technology Patents 2001 with History



Taken as indicators of changes in technology production seen across diverse technologies, the data on Other Technology advances shown in this figure support at least three conclusions. First, there appears to have been a substantial drop in invention efficiency in the United States over the period of the study. This was matched worldwide by a similar drop in efficiency in the numerous countries included in the OT country group (which is made up of all countries in the world generating advances patented in the United States other than the ten countries specifically addressed in this study). These downward trends in invention efficiency may reflect a decreased emphasis on the types of inventions in the Other Technology category at the same time as increases in non-innovative commercial activities (or increases in innovation in other fields) produced growth in the relevant countries' economies. Such a combination of relatively static (or reducing) innovation in the Other Technology fields, coupled with increasing economy size, would produce a reduction in innovation efficiency levels as measured by the numbers of Other Technology patents per GDP dollar.

Second, despite the drop in efficiency seen in the United States, other countries were able to substantially increase their inventive efficiency across a wide range of technologies and economy sizes. Innovators in Japan, Germany, Great Britain, and Taiwan were able to achieve much increased efficiency across the diverse technologies covered by the Other Technologies category as indicated by their countries' sharply upwardly angled efficiency curves for at least some of the period of the study. The means that innovators used in these countries to achieve these desirable changes (as well as the reasons why the trends in the United States were uniformly in the opposite direction) deserve further analysis.

Third, several countries – most notably Japan and Germany – were able to keep their invention efficiency relatively constant across the diverse technologies in the Other Technology category despite vast changes in their economies and the steady drop in inventive efficiency among United States innovators in the same period. The techniques used by these countries to keep their production of patented advances apace with their GDP increases (while the United States was not able to do the same, thereby producing drops in invention production efficiency) deserve greater study.

IV. Conclusion

This article has assessed the efficiency of several countries as sources of new, patented technologies in the United States during the period of 1977 to 2001. Studies of technologies submitted from foreign sources for patenting in the United States are valuable in that they measure how innovators in diverse foreign settings respond to the common societal needs and commercial potential of United States consumers and businesses. Innovations patented in the United States have similar commercial importance and functional value regardless of the sources of the patented inventions. Hence, by focusing on the common target of United States patenting and the dissimilar circumstances of foreign and domestic innovators who have hit that common

target, we can assess how different characteristics and practices of innovators around the world influence the production of patented inventions.

The visualization analyses presented here illustrate how invention production per GDP dollar has varied across countries and over time. These analyses also portray how the same invention production efficiencies have varied over time for United States-based innovators. The results suggest that the United States may presently be producing too few patents given the size of its economy and its much higher production of patented advances per GDP dollar in earlier years. This conclusion stands in contrast to the criticisms of some commentators suggesting that we are suffering from too many patents. In addition, the country-to-country comparisons in this project suggest that United States innovators may be falling behind some of their foreign counterparts in certain technology fields, again a troubling implication in a period when new technology production provides economic power in world economies and when technological prowess may be one of the main areas of continuing American excellence and strength in competition with economic powerhouse countries in other parts of the world.