Canada's Patent Productivity Paradox: Recent Trends and Implications for Future Productivity Growth

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Abstract

Canada's slow productivity growth rate relative to peer countries has been the focus of considerable attention among academics and policymakers. In contrast to the relatively flat trajectory for total factor productivity, Canada's production of patents has grown considerably in the last three decades. In this article, we examine changes in Canadian patenting over the past 30 years, with a view to understanding this "patent productivity paradox": slower productivity growth than might be expected given significant increases in patenting. We draw on recent literature on patents as a measure of innovation as well as literature on the relationship between patents and productivity to study this paradox. We propose several explanations for the disconnect between TFP growth and patenting and examine the evidence. We find that the weaker relationship between productivity and patenting in Canada is not explained by the relative rate of invention in information and communications technology, nor by lower invention quality. However, we find suggestive evidence that foreign ownership of patents and inventor migration help to explain the weaker relationship between productivity and patenting in Canada.

Canada's slow productivity growth relative to peer countries has been the focus of considerable attention among academics and policymakers (Baldwin *et al.*, 2014 and Sharpe and Tsang, 2018). According to the Penn World Tables, Canada's total factor productivity (TFP) at constant national prices increased by 7 per cent between 1990 and 2018. By contrast, in the United States and Germany TFP grew by 20 per cent and 24 per cent respectively, while in South Korea it increased by 46 per cent. Be-

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cause technological innovation is associated with TFP growth, this has led to questions about how the rate of innovation in Canada compares to other countries, and numerous policy initiatives in recent decades have sought to increase the rate of innovation in Canada.

Although not without its limitations, patent data provide one of the most comparable measures of invention across countries, technological fields, and time. In contrast to its relatively flat trajectory for TFP, Canada's production of patents has grown considerably over the past three decades. In absolute terms, the total number of patents granted by the US Patent and Trademark Office (USPTO) with at least one inventor residing in Canada roughly tripled during this period, outpacing growth in the Canadian population and in real GDP. Using a different metric – the number of patents granted by the USPTO and also filed at the Japanese Patent Office, and the European Patent Office (known as "triadic" patents) – Canadian patents per capita increased by approximately 73 per cent during this period. Yet the trajectory of aggregate TFP growth in Canada over the same period has been relatively flat.

This presents a puzzle: if invention is alive and well in Canada, why is this not reflected in productivity growth? This apparent disconnect may simply be an artifact of measurement challenges. It has long been recognized that there need not be a tight, one-to-one relationship between patenting and TFP growth. Patents are an imperfect measure of the inventive output of an economy: not all inventions are patented, and not all inventions (patented or unpatented) are developed into new products or production processes that contribute to growth in TFP. There are, of course, potentially long and variable lags along the path from invention to innovation to productivity growth. Nor need the relationship between invention and productivity growth be geographically constrained: In an open economy, productivity-enhancing ideas and technology can be sourced externally and implemented domestically through licensing agreements, or by being embodied in imports, without leaving footprints in domestic patenting. Conversely, locally generated inventions may find their principal economic use in products or processes developed and sold abroad, with little impact on domestic productivity.

Not surprisingly, looking at the experience of the past 30 years in a sample of countries with high rates of R&D investment, we see that patenting and productivity are imperfectly correlated (with a 10 per cent increase in patents per capita associated with an approximately 1 per cent increase in TFP).[2] However, the relationship is unusually weak for Canada, whose recent history of strong growth in patenting but little improvement in TFP stands in sharp contrast to countries like Finland, South Korea or Sweden.

In cross-country regression analyses that compare the relationship between changes

2 A recent estimate from a long-run causal analysis of the relationship between patenting and productivity at the country-sector level (Berkes *et al.*, 2022) finds that a one standard deviation increase in patenting leads to a 1.1 per cent increase in growth of output per worker.

in patenting and changes in TFP, we show that the relationship between patenting and TFP growth is significantly weaker in Canada than in most other countries, so that a given increase in the number of patents filed by Canadians is associated with a smaller increase in productivity than is observed in other countries. It seems unlikely that there are sufficiently large Canada-specific idiosyncrasies in the relationship between patenting and inventive activity or in productivity measurement to account for this difference, and we are left with a "patent productivity paradox": if patents are an (albeit imperfect) measure of invention, and increases in invention lead to ultimately to increases in productivity, why has the growth in Canadian patenting not led to faster growth in TFP?

Prior research on Canadian patenting focused on several notable patterns. Trajtenberg (2000) highlighted the Canadian economy's deficiencies in innovation in information and communications technologies (ICT). In this article, we ask whether the share of ICT inventions among Canadian patents can help explain the patent productivity paradox. We find that Canada is no longer a laggard in ICT patenting: recent decades have seen a dramatic increase in the previously low share of Canadian-invented patents in ICT. However, it is possible that, due to challenges in the measurement of productivity growth in ICT-intensive sectors, the increasing number of ICT patents as a share of total patents may have led to a weaker correlation between patenting and TFP. As noted by Solow (1987), "you can see the computer age everywhere but in the productivity statistics."[3] We investigate this hypothesis in this article.

Trajtenberg (2000) also found that Canadian patents were on average of lower quality or importance than patents filed by U.S. inventors, using the best measures of patent quality available at the time. Attention has recently been drawn to the relationship between productivity and innovation quality by authors such as Akcigit and Ates (2021) and Bloom, Jones, Van Reenen, and Webb (2020). The latter asks whether radically productivity-enhancing technological innovations are becoming less common, replaced by more incremental innovations. One possibility, therefore, is that the Canadian inventions patented in recent years are less novel or important, and therefore have a smaller impact on firm productivity, than inventions produced in other countries. We evaluate the evidence in favor of this hypothesis by examining conventional as well as recently developed measures of patent importance or novelty.

Prior research has also documented a high and rising share of patents invented in Canada and owned by foreign firms. It has been suggested that this could be harmful for the Canadian innovation ecosystem (Gallini and Hollis, 2019). We examine data on Canadian patents held by foreign firms and consider the mechanisms through which this might affect productivity. In particular, we incorporate data on the mi-

3 Robert Solow, "We'd better watch out", New York Times Book Review, July 12 1987, page 36 (citation courtesy of https://standupeconomist.com/solows-computer-age-quote-a-definitive-citation/ accessed 12/14/2022).

gration of inventors based on a comparison of the nationality of inventors and their country of residence made available by the World Intellectual Property Organization (WIPO) (Miguelez and Fink, 2013, Ivus, 2016). We find that neither ICT patenting nor invention quality appear to explain the Canadian patent productivity paradox. In a regression that accounts for the share of patents in computing-related fields, we continue to find that increases in Canadian patenting are more weakly associated with increases in productivity than in comparable countries. We also continue to estimate a lower patent-productivity correlation for Canada in sector-level analyses that omit the ICT sector. Using both conventional and new measures of invention quality, we find that recent Canadian inventions are not on average less important or novel than inventions from other countries. Incorporating data on invention quality in the cross-country productivity regression fails to eliminate the estimated weaker correlation between patenting and productivity for Canada.

Another possible explanation is that, for whatever reason, new patented technologies generated by Canadian-resident inventors are less likely to be put into practice in Canadian production facilities. Canadian inventors may sell their ideas to foreign firms that implement them elsewhere, or even out-migrate i.e. take their patented ideas to other countries for implementation. Other inventions may come from Canadian employees of multinational enterprises that prioritize development and implementation of these technologies in other countries rather than in Canada. Consistent with this, we find that, after controlling for the share of patents held by assignee firms located in a country different from the inventor country, the Canadian patent-productivity gap is reduced, and it is completely eliminated after we control for the net migration of inventors (although the latter data is only available until 2012).[4] Moreover, foreign ownership of patented inventions may not be negatively associated with productivity when combined with net inflows of inventors. This suggests that productivity is positively associated with foreign ownership when it shifts foreign R&D workers into the country, and negatively associated with it when there is no associated inflow of R&D workers. Although there is likely to be endogeneity in the relationship between productivity and inventor migration, these findings suggest the importance of further inquiry into the relationship between inventor mobility, innovation, and productivity in Canada. The next section reviews prior literature and is followed by a description of our dataset. We then discuss the evidence for a Canadian patent productivity paradox, and evaluate several potential explations for this paradox using regression results. The final section concludes and discusses policy implications.

Prior Literature

4 In 2012, the America Invents Act removed the requirement that applications at the USPTO list inventors as applicants. This removed the requirement that inventors' nationality be listed on the application (Ivus;2016:3).

Interest in the relationship between patenting and productivity in Canada is not new. In the 1990s, Canada's relatively slow productivity growth led to an attempt to explain this lower growth rate, and since innovation is a source of productivity growth, several studies have focused on documenting rates of innovation in Canada and understanding its potential impact on productivity growth in Canada. Although an imperfect measure of innovation (Pavitt, 1988), data on patent filings and grants can provide highly detailed information on invention across countries, time and technological fields. Trajtenberg's (2000) survey of 30 years of Canadian patenting identified several ways in which Canada could be missing the "technology boat." Notably, Trajtenberg found that the technological composition of Canadian patents was out of step with the growth of information and communications technologies (ICT), the rate of unassigned and foreign-assigned patents was high, and the quality of Canadian patents was below average using the best measures of patent quality available at the time. Trajtenberg speculated that these disparities could be remedied by choosing appropriate innovation policies.

When Trajtenberg's analysis was conducted, the use of patent data by empirical economists studying innovation and growth was relatively new. The past two decades have seen an explosion of research on patents as well as the availability of more detailed patent datasets. Two surveys of patenting in Canada provide an excellent overview of recent trends, one by Greenspon and Rodrigues (2017) and the other by Gallini and Hollis (2019). Greenspon and Rodrigues (2017) study patenting by Canadian inventors at several patent offices[5], and found that the growth rate of patenting by Canadian inventors at the United States Patent and Trademark Office (USPTO) was the highest in the G7 between 2000 and 2014 (when the number of Canadian patents granted by the USPTO approximately doubled). Much of this increase can be explained by the growth of patenting in information and communications technologies (ICT). Greenspon and Rodrigues also document a divergence between R&D spending and patenting, with business expenditure on R&D falling slightly during the period in which patent grants doubled. They consider several potential explanations for this pattern and suggest that developments in ICT and other technologies may have increased the productivity of R&D spending, leading to greater research productivity, but conclude that more research is needed to understand this divergence between R&D and patenting. Other potential explanations include a rise in "strategic" patenting, an increase in the number of patents per innovation, and a shift away from business R&D toward R&D performed by the public sector.

While patenting by Canadian inventors at the USPTO has increased significantly in our sample period, Eckert*et al.* (2022)

5 The Canadian Intellectual Property Office (CIPO), the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO) and the European Patent Office (EPO)).

show that filings by Canadian inventors at CIPO have declined. Katz and Raffoul (2022) point to a sharp decline in the number of international patent filings by Canadian applicants via the Patent Cooperation Treaty (PCT) between 2014 and 2017, citing the report to the province of Ontario by the Expert Panel on Intellectual Property which shows that the decline in filings by Canada during this period is the largest of any PCT member state (Expert Panel on Intellectual Property, 2020) (Appendix A, p. 34). It is worth noting that PCT applications, which allow an application at the applicant or inventor's home country office to be used to obtain patents in foreign patent offices, are less commonly used by Canadian applicants/inventors to access the USPTO.

As shown by Greenspon and Rodrigues (2017), more Canadian-invented patents are filed at the USPTO than at the CIPO, and Eckert *et al.* (2022) show that only 8 per cent of USPTO patents issued to Canadians were via the PCT (implying that Canadian patents are much more likely to be filed directly at the USPTO).[6] This suggests that the number of PCT applications is not ideal as a single proxy for Canadian inventive output. However, it is worth noting that Eckert *et al.* (2022) find that Canadian-controlled firms are more likely to file patents via the PCT, which is relevant given trends in the percentage of Canadian-invented patents held by foreign firms.

Gallini and Hollis (2019) also provide an overview of recent patenting trends in Canada, with a focus on commercialization. They find that most patents with a Canadian inventor are assigned to a foreign firm or to a Canadian subsidiary of a firm with foreign headquarters (Gallini and Hollis; 2019:20-21) [7]. They argue that Canadian innovation is disproportionately focused on the early stages of research – Canada has strengths in academic science and researchers per capita, but lags in the application of research to commercialization (Gallini and Hollis 2019, :4). They emphasize the importance of encouraging Canadian small and medium-sized enterprises (SMEs) to use patents to "scale up" rather than selling to larger (mostly United States) acquirers of IP, and discuss policy interventions that may encourage this behavior. Plant (2017) shows that Canada ranks third (after Israel and Switzerland) in the number of inventions assigned to foreign firms (per million $ of GDP).

The high share of Canadian patents held by foreign firms has received attention among researchers as well as in the popular press (for example Gallini and Hollis, 2019 and Synder, 2021). The extent to which foreign ownership of patents invented in Canada may contribute to slow productivity growth is an open question. As suggested by Gallini and Hollis (2019), when Canadian-invented patents are assigned to

6 Eckert *et al.* (2022) argue that the PCT is primarily used by Canadian applicants to access patent offices other than the United States and Canada. Miguelez and Fink (2013) note that a rule change in 2004 required PCT applicants to automatically designate the USPTO.

7 Gallini and Hollis classify Canadian-invented patents as those patents with at least one Canadian resident listed as an inventor.

foreign firms, those firms are more likely to "scale up" the invention outside Canada, and as a result, any ensuing impacts on productivity growth would occur in other countries.

However, a substantial literature has documented the potential benefits of international collaboration in patenting. Ferucci and Lissoni (2019) draw on data from WIPO applications which lists the nationality of inventors and find that inventor teams with more diverse nationalities produce higher quality patents (as measured by forward citation counts). Equally, inward FDI can enhance technology spillovers: several papers have found that inward FDI and R&D collaborations are associated with knowledge diffusion as measured by patent citations (e.g. Branstetter 2006, MacGarvie 2006). Moreover, foreign-owned subsidiaries have been found to have higher productivity than domestically-owned competitors (Griffith *et al.* 2004). Thus, foreign ownership of Canadian patents may also confer benefits for innovation in Canada by allowing Canadian inventors to access information about advanced innovations abroad.

Although this article is primarily concerned with the relationship between patenting and productivity in Canada, concerns about changes in innovation and slowing productivity growth are not unique to Canada. For example, Bloom, Jones, Van Reenen, and Webb (2020) document a decline in the productivity of research across many sectors and technologies. Kalyani (2022) documents a decline in the use of novel word combinations in the text of patents and associates this with slower productivity growth. Akcigit and Ates (2021) link slower productivity growth to a decline in the diffusion of ideas from leader firms to follower firms, which may be explained by increases in industry concentration. There is some evidence that this rise in industry concentration may be explained by the growth of information technology (IT). Bessen (2020) finds a relationship between adoption of proprietary IT and increases in industry concentration.

Data on Patents and Productivity

One of the major developments in the field of innovation studies in the past two decades is the emergence of new patent datasets and indicators. We use several different data sources in this article. For our primary analyses, we use USPTO data (downloaded from Patentsview.org) for ease of use and interpretation as well as consistency with prior studies. One of the key advantages of USPTO data is that they record both the identity of the organization or individual that owns the patent (the assignee) as well as the name(s) and address(es) of the inventor(s).[8] This fact is important for understanding trends in the location of invention and ownership as studied by prior authors (e.g. Trajtenberg

8 Country coding of inventors and assignees was exhaustively checked to remove errors from sources such as: (a) apparent data entry or file format errors, e.g., city listed as "Chongqing, Canada"; or (b) potential confusion between, e.g., the US state of California, and the country of Canada – both of which have the code "CA" on USPTO documents.

1999, Greenspon and Rodrigues 2017, and Gallini and Hollis 2019). Screening out inventions that do not result in a US patent may also control for patent quality. Prior studies have suggested that Canadian firms are more likely to patent at the USPTO than at the Canadian Intellectual Property Office (CIPO) (Greenspon and Rodrigues 2017; Eckert, *et al.* 2022), and that patents filed by Canadian inventors in the USPTO and the CIPO are of higher quality than those filed in CIPO only (Eckert, *et al.* 2022).

Although we rely on the USPTO data for most of our analyses, we supplement it with additional data from other patent offices in several cases. We use data from WIPO on the total number of patent applications filed by applicants from a given country across all patent offices worldwide, which we call "worldwide" patents. This helps address potential "home bias" problems in USPTO data. US and Canadian inventors disproportionately file applications in the USPTO relative to other offices, and thus may be over-represented in USPTO data (de Rassenfosse *et al.* 2013).[9] Higher-quality inventions will be patented in more locations, and the worldwide application count will incorporate this fact. However, inventions filed in more than one location will be counted more than once. To address this, we use data on two patent family measures from OECD.Stat, described below. A "family" is the collection of patents filed in patent offices around the world which claim (approximately) the same invention.[10] Worldwide counts of patent families may thus be better measures of the number of inventions across countries, since multiple patent documents can relate to the same invention. Use of family counts can also minimize home bias problems. These variables have the advantage of not constraining attention to inventions patented in the United States alone, and allow us to obtain a broader picture of the full extent of Canadian patenting.[11]

Looking at the countries in which applications are filed for a given invention also permits some degree of screening on the quality of the invention. We use data on "triadic" patent families, families with patents granted by the USPTO that were also filed at the European Patent Office (EPO) and the Japanese Patent Office (JPO), from the OECD. Research has suggested that "triadic" patent families are a better measure of high-quality innovations (OECD 2009:71). We therefore include tri-

9 To be precise, we use indicator 1, "Total patent applications (direct and PCT national phase entries)", "Total count by applicant's origin" from the WIPO IP Statistics Data Center (https://www3.wipo.int/ipstats/ips-search/patent).

10 Technically speaking, a family is the set of patent documents (applications or granted patents) that share the same priority document. The OECD data on patent families draws on the DOCDB definition in the PATSTAT database (Dernis and Khan 2004:8).

11 The WIPO patent dataset classifies a patent as originating in a country based on the residence of the first-named applicant.

12 Plant (2017) argues that triadic patent counts are the "gold standard" patent indicators, and points out that Canada is at the bottom of a list of peer countries in counts of triadic patents. However, overall applications at the JPO have declined since 2000 (World Intellectual Property Indicators 2020, p.14), making triadic patents somewhat difficult to interpret because they show a decline for most countries after 2000, where other patent indicators have been rising.

adic patent family counts as a robustness check in some of our analyses.[12]

An alternative is to count only patent families protected in two or more patent offices and at least one of the world's top five patent offices (known as IP5 patent families). Note that the data on triadic and IP5 patent family counts (both produced by the OECD) are based on the priority year, and are fractional counts by inventor location (i.e. if half of a patent's inventors are located in one country and half in another, the patent is counted as half a patent in each country). OECD data on patent families are however only available starting in 1985.

We also make use of WIPO data on the country of citizenship of inventors. USPTO inventors can be identified by their addresses, but patents filed under the PCT list the nationality of inventors (until 2012). This allows us to measure how many Canadians invented patents outside of Canada, and how many citizens of other countries invented patents in Canada. Miguelez and Fink (2013) and Ivus (2014) provide in-depth analysis of this data and how it can be used to measure flows of inventors. We make use of data on the number of patent applications from a country which have immigrant or emigrant inventors (in other words, those whose citizenship does not match their country of residence) relative to the number of patent applications filed by nationals (inventors residing in their country of citizenship), in the first year the patent application was filed in any patent office (the priority year).

It is important to note that these data do not count the actual numbers of immigrant and emigrant inventors; rather, they count the number of patent applications by migrant inventors. Thus, a migrant inventor can be counted more than once if they are listed on multiple patent applications. If Canadian migrant inventors have substantially different rates of inventive productivity, this could cause us to under- or overstate Canadian migration. Moreover, if the listed nationality of an inventor changes after migration, the migration event will not be recorded in this data. The migration data also includes information on applications for patents that were never granted. Finally, we assume that the percentage of migrant inventors in PCT applications is similar to the percentage in applications filed directly with the USPTO.

USPTO patent data have been assigned to the following technological categories: chemical, computers and communications, drugs and medical, electrical and electronic, mechanical, and others (Hall *et al.* 2002). We compute the percentage of patents assigned in the "computers and communications" field by country and application year. USPTO patents have both assignees (the owner of the patent) and inventors, and locations of both are listed in the patent document. In our primary measures based on USPTO patents, we attribute patents to a country if it has at least one inventor with an address in that country. We compute the percentage of patents with any inventor from a particular country and an assignee from another country and call this the percentage of foreign-assigned patents.

To measure the value or importance of patents, we make use of a standard indicator – the number of forward patent citations – which have been shown to be positively correlated with market value at the firm level (Hall *et al.* 2005, Bloom *et al.* 2013). We also draw on new text-based novelty measures originally compiled by Arts *et al.* (2021). These metrics use text from the title, abstract, and claims of the corpus of US patents to these measures identify the "technical novelty" of a given patent. For instance, one such measure is *new_bigram* which captures the number of two-word combinations that the focal patent uses that had not previously been used. Arts *et al.* (2021) validates and makes available a suite of metrics to capture the technical novelty of a patent. Finally, we use data from Penn World Tables version 10.0 (Feenstra *et al.*, 2015) for country-level information on TFP, GDP per capita and per hour worked, and population.[13] Data on the ratio of gross domestic spending on R&D to GDP come from the OECD Science, Technology and R&D Statistics and are measured in purchasing power parity adjusted USD constant prices with 2015 as a base year.[14]

To construct data at the sector level we match counts of patents by 4-digit IPC codes to ISIC industries using the concordance described in Lybbert & Zolas (2014).[15] This procedure uses keywords from patent text and industry descriptions to create a probabilistic mapping.[16] We use this concordance to match patent data with labour productivity (per hour worked) statistics from the OECD Stan database and R&D statistics from the OECD ANBERD database. Our final sector-level dataset consists of the industries listed in Table 1.[17]

Although it should in principle allow a more fine-grained analysis of the relationship between patenting and productivity, the sector-level data has several limitations. It should be noted that, although the mapping between patents and industries is designed to identify the patent classes most related to technologies in a particular industry, this mapping is imperfect. Classes are assigned to patents based on the nature of the technology, not the industry of use, and the mapping between patents and industries is probabilistic rather than definitive (Lybbert and Zolas 2014).

Most importantly, some patents are "general purpose" inventions that may be used across multiple industries, and in-

13 The TFP variable is rtfpna, a TFP index normalized within each country to equal 1 in 2017. GDP per capita is output-side real GDP (rgdpo), at chained PPPs (in mil. 2017 US dollars), divided by population. GDP per hour is rgdpo divided by the product of average hours worked per worker (avh) and total employment (emp)."

14 Data come from https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htmindicator-chart (downloaded October 2021).

15 R&D and productivity data are not available for all industry groupings in all years. To improve the match with patent data, we often aggregate two-digit ISIC codes into wider industry ranges. We consider the first-listed IPC code for each patent at the time of issue. The final list of industries is found in Table 1.

16 The concordance maps IPC codes to ISIC sections pertaining to "Manufacturing," "Electricity, gas, steam and air conditioning supply," "Water supply; sewerage, waste management and remediation activities," and "Construction."

17 We exclude resource-based industries D01T03 (agriculture, forestry and fishing) and D05T09 (mining and quarrying) as well as D45 and above (wholesale and retail trade, transport, and service industries). The coke and refined petroleum products industry (D19) is a significant outlier in terms of labour productivity for Canada and Denmark relative to the rest of the world, and we exclude this industry in some specifications.

Table 1: Summary Statistics

Variable	Obs	Mean	S.D.	Min	Max
Country-level means for 1990-2018*					
Year	667	2004	8.38	1990	2018
TFP	667	0.95	0.08	0.661	1.149
GDP per capita	667	42230.30	13517.03	13819.28	94650.81
GDP per hour worked	667	51.09	16.54	12.18	129.03
Depreciated stock measures					
R&D /GDP(%)	588	11.759	4.107	4.299	24.449
USPTO patents per million pop	667	730.68	526.28	28.70	2634.91
Triadic patents per million pop	552	247.30	181.94	17.97	803.06
Worldwide applications per million pop	580	6551.00	6006.97	375.14	28747.05
IP5 patents per million pop	552	810.32	534.53	71.09	2796.63
% patents in computing/communications fields	666	0.22	0.127	0.000	0.55
Mean forward cites per patent	666	19.45	8.80	4.17	48.37
Mean new bigrams	666	1.46	0.71	0.17	4.58
% USPTO patents assigned to foreign entity	666	0.32	0.18	0.01	0.72
Immigrant/National patents*	529	0.19	0.28	0.00	3.26
Emigrant/National patents*	529	0.17	0.24	0.00	2.53

Country-sector-level data (mean values for all countries over the period 1990-2018)

Industry	Labor Productivity	R&D/GDP (%)	USPTO patents per capita**
Food products, beverages and tobacco	51.98	0.11	19.80
Textiles, wearing apparel, leather and related products	32.01	0.03	11.09
Wood, paper, printing and reproduction of recorded media	39.22	0.07	21.10
Coke and refined petroleum products	2503.71	0.04	3.16
Chemical and pharmaceutical products	101.07	0.75	101.82
Rubber and plastic products	48.04	0.09	17.03
Other non-metallic mineral products	50.05	0.05	22.42
Basic metals and fabricated metal products, except machinery and equipment	46.73	0.02	34.15
Computer, electronic and optical products	58.37	1.54	251.49
Electrical equipment	54.97	0.19	28.89
Machinery and equipment n.e.c.	54.27	0.43	44.21
Motor vehicles, trailers and semi-trailers	46.68	0.61	14.32
Other transport equipment	87.25	0.25	7.40
Furniture, other manufacturing and repair and installation of machinery and equipment	40.83	0.11	24.01
Electricity, gas and water supply; sewerage, waste management and remediation activities	133.81	0.05	30.47
Construction	41.25	0.06	18.96

Note: Countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Republic of Korea, Singapore, Sweden, Switzerland, United Kingdom, United States. Labour productivity is measured in US dollars per hour worked, R&D/GDP is industry R&D spending as a percentage of aggregate GDP, and USPTO patents are measured per million residents. R&D/GDP and USPTO patents are reported in percentages as stock variables.

ventions relating primarily to one industry may have productivity spillovers for other industries. For example, innovations in computing have the potential to increase productivity across all sectors, but this type of innovation will not be captured by the country-industry regressions displayed here. Moreover, the panel of industries and countries measures labour productivity rather than TFP, and is unbalanced, with varying availability of productivity and R&D data across country-industries and years.[18]

With these caveats in mind, we use the country-industry-year dataset to examine the roles of specific industries. A more thorough analysis of the relationship between patenting and productivity at the country-industry level can be found in Berkes *et al.* (2022), who analyze a sample of 36 countries between 2000 and 2014. In OLS regressions similar in spirit to ours, they find no significant relationship between patenting and productivity at the country-sector level, but a small positive and significant relationship after instrumenting patents with pre-existing knowledge spillovers across countries and industries combined with technological shocks to specific countries.

Each patent is assigned to a year based on the year of application of the patent (rather than the grant year). We do this because the year of application most closely relates to the development of the invention, while grants can arrive with a lag. The Triadic and IP5 measures based on patent families are based on the priority year.

In the analysis that follows, we construct a stock of each explanatory variable: for example, patents (and variables that capture novelty and foreign assignment), R&D, migration. This is to account for the fact that we expect these variables to take time to impact productivity and do so in a way that is dependent on past values of the variable. We construct these variables with a simple depreciation method using a standard δ =15 per cent discount rate (e.g., Hall 1990; Bessen 2009), such that within a country, the stock of a variable x in year t is constructed as a weighted sum of the previous 10 years.[19] Table 1 shows summary statistics for the 16 country and country-industry panels.[20]

18 Notably, for the 10,672 potential observations (23 countries X 16 industries X 29 years), R&D information is available for 6,052 observations, productivity data are available for 6,250 observations, and both are available for 4,103 observations in the raw data. We then interpolate missing values of R&D using a time trend within country-industry and present regressions with and without controls for R&D investment, but do not interpolate the productivity data since it is the dependent variable.

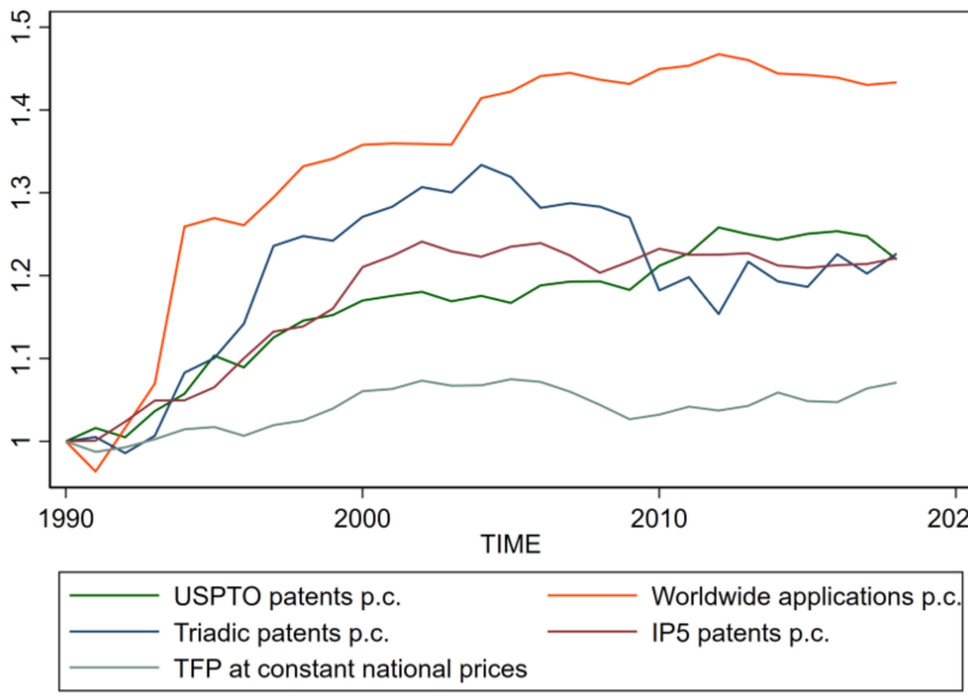
19 To be precise, we use the following formula:

$$\text{stock}(x_t) = \sum_{k=0}^{10} x_{t-k}(1-\delta)^k$$

This is our preferred method of calculating depreciated stocks as it relies on fewer assumptions and allows for simpler and more transparent calculations. In the Appendix Table A-1, we also confirm that our baseline results in Table 2 are robust to using contemporaneous flows or the stock calculation method proposed by Hall 1990. For industry level data, we use a 5-year depreciation, to minimize the number of observations that are excluded from the analysis in the presence of missing data.

20 There are no patents with an inventor for Iceland in 1990, so per patent measures are missing for this observation.

Chart 1: Canadian TFP and Patents per Capita, 1990-2018 (1990=1)



Note: USPTO patents are the count of patents filed by at least one inventor with a Canadian address with the US Patent and Trademark Office. "Triadic" patent families granted by the USPTO and also filed at the European Patent Office (EPO) and the Japanese Patent Office (JPO) (source: OECD 2022). Worldwide applications s count all applications filed in offices worldwide, direct and national PCT entries (source: WIPO IP Statistics Data Center). IP5 patents are patent families filed in two or more offices and at least one of the world's top five patent offices (source: OECD). All patent counts are by application year or priority date and normalized by population. TFP is a Total Factor Productivity index at constant national prices (source: rtfpna in Penn World Tables). All series are normalized by their value in 1990 and are shown as flows, rather than stocks.

Divergence between Patenting and TFP growth

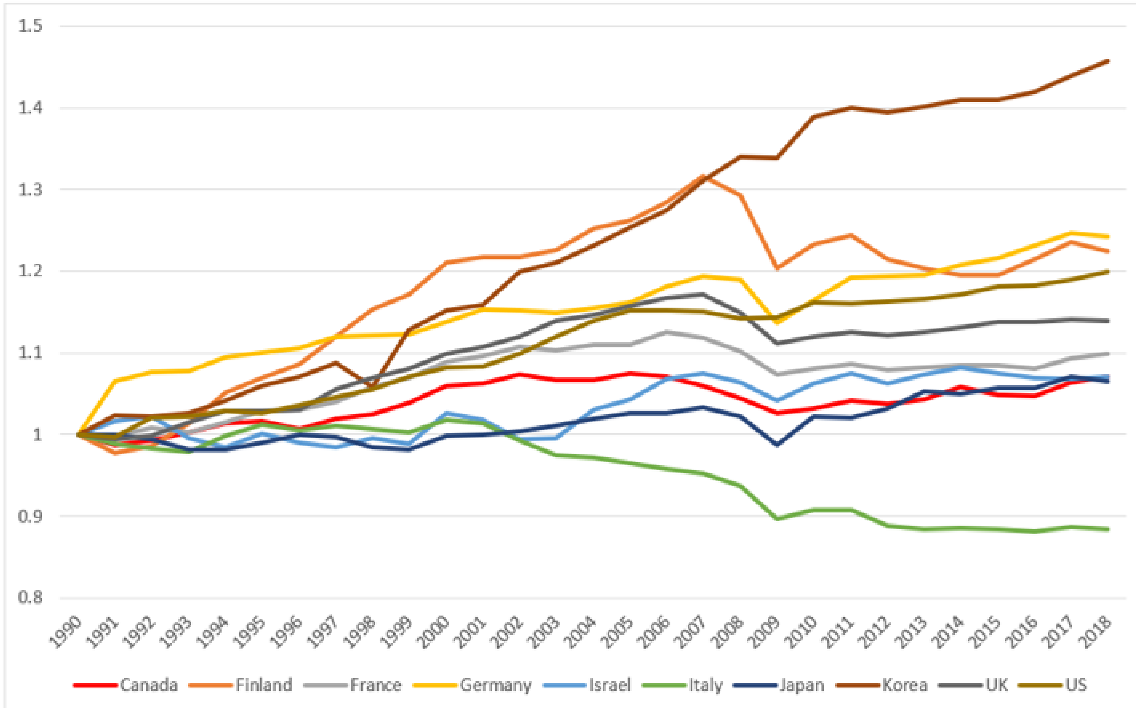
Chart 1 displays the growth in patent applications by Canadian residents (per million population), according to the USPTO, triadic and IP5 patent family counts, and worldwide patents.[21] These series show a dramatic increase in the propensity to patent by Canadians in the last three decades.[22] However, annual TFP at the national level has not kept pace. Similar to the relationship between business R&D expenditure and patenting identified by Greenspon and Rodrigues (2017), we see a divergence between patenting and productivity.

Chart 2 compares TFP growth across a sample of G7-plus countries over the period from 1990 to 2018, with each country's TFP normalized relative to its value in 1990. Among the selected group of coun-

21 Chart 1 shows yearly flows, rather than patent stocks.

22 The dip in triadic patents observed after the mid-2000s is also observed in the triadic patent counts of other countries and the OECD as a whole. Canadian triadic patents as a share of all OECD countries actually rose from 1.1 per cent of all OECD triadic patents in 2000 to 1.3 per cent in 2020.

Chart 2: Normalized TFP at Constant National Prices, G7-plus countries (1990 = 1)



Source: Data on TFP index (rtfpna) from Penn World Tables 10.0 (Feenstra *et al.*, 2015), indexed to 1990 values for each country.

tries, only Italy displays slower cumulative productivity growth than Canada.

To understand the relationship between patenting and productivity growth at the country level, we analyze panel data on countries and years from 1990-2018, with regression results in Table 2. Fixed effects for country and year are included in all regressions. This allows us to answer two questions: 1) what is the overall relationship between the growth of patenting and the growth of TFP during this period, after holding constant country-specific and aggregate temporal variation in TFP and patenting? and 2) Is the relationship between TFP and patenting growth weaker in Canada than in other countries? To answer the latter question, we incorporate an interaction between the (natural logarithm of) the stock of per capita number of patents filed by Canadian inventors and a dummy variable for Canada. If the coefficient on this interaction term is negative and statistically significant, this implies that the relationship between productivity and patenting is weaker in Canada than in the other countries in the sample.

Columns 1-3 of Table 2 include TFP regressions for the broad set of countries for which we were able to obtain data on TFP and R&D/GDP during our sample period. To identify a peer set of countries, we select countries that spend at least 1 per cent of GDP on R&D on average during our sample period. In order to restrict attention to countries with economies and innovation ecosystems more similar to Canada's, we exclude current or

Table 2: Regression Results - The Relationship between the Growth in Patenting and Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample, R&D only	+ Patents	+ Can X pats	+ Patents peer countries	Peer countries, no R&D	TFP yr>99
R&D/GDP	0.0931***	-0.0257	-0.0268	-0.00408		-0.0142
	(0.0224)	(0.0267)	(0.0267)	(0.0273)		(0.0468)
Patents		0.0989***	0.0980***	0.0985***	0.0466***	0.108***
		(0.0164)	(0.0164)	(0.0233)	(0.0178)	(0.0295)
Can X Patents			-0.0604***	-0.0538***	-0.0504***	-0.106***
			(0.0118)	(0.0105)	(0.00968)	(0.0357)
Sum of coefs:			0.038*	0.045*	-0.004	0.002
Observations	685	685	685	588	667	419
	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7+	GDPpc G7+	GDPph G7+	TFP (pop weights)
R&D/GDP	-0.309***	-0.255***	0.00151	-0.117	-0.0764	-0.0393
	(0.0729)	(0.0739)	(0.0447)	(0.0831)	(0.0565)	(0.0382)
Patents	0.388***	0.336***	0.164***	0.270***	0.215***	0.0823***
	(0.0696)	(0.0678)	(0.0326)	(0.0503)	(0.0598)	(0.0317)
Can X Patents	-0.131***	-0.188***	-0.0624***	-0.0584**	-0.139***	-0.0676***
	(0.0292)	(0.0236)	(0.0145)	(0.0256)	(0.0195)	(0.0160)
Sum of coefs:	0.257***	0.147**	0.101**	0.211***	0.076	0.015
Observations	588	588	260	260	260	588

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018. Fixed effects for country and year included in all regressions. Columns 1-3 include countries spending more than 1% of GDP on R&D on average during the sample period; columns 4-8 and 12 also exclude China, Russia, the Czech Republic, Estonia, Hungary, and Slovakia. Columns 9-11 include only the "G7 Plus" group of G7 countries plus Israel, Finland and South Korea. Column 12 weights by country population. The dependent variable in Columns 1-6, 9 and 12 is the natural logarithm of output-side real GDP per chained PPPs in mil 2017 USD. The dependent variable in Columns 7-10 and 11 is the logarithm per capita output-side real GDP per chained PPPs, rounded (source: TFP data per PPP 2017 USD, Penn World Tables). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the country's patent stock per capita, and a dummy variable for Canada interacted with the patent variable. The patent stock is based on counts of USPTO patents with inventors located in the country. The "sum of coef's" is the linear combination of the coefficient on "Patents" + the coefficient on "Can X Patents". (***/**/*): significant at the (1/5/10)% level.

former planned economies China, Russia, the Czech Republic, Estonia, Hungary and Slovenia in remaining analyses. Columns 9-11 further restrict attention to the "G7 plus" group of G7 countries plus Israel, Finland and South Korea (following Trajtenberg 1999).[23] Column 12 reproduces the specification in Column 4 after weighting by country population.

The measures of normalized income and productivity that serve as dependent variables in these regressions are taken from the Penn World Tables. The dependent variable in Columns 1-6, 9, and 12 is the

23 Although Trajtenberg includes Taiwan, we do not because data on Taiwan was not available in all our data sources. The main results are however robust to including Taiwan.

natural logarithm of TFP at constant national prices (2017=1). The dependent variable in columns 7 and 10 is the natural logarithm of per capita output-side real GDP at chained PPPs in mil. 2017 USD. The dependent variable in columns 8 and 11 is the natural logarithm of output-side real GDP per hour worked. The independent variables are the natural logarithm of R&D as a share of GDP, the natural logarithm of the country's patents per capita, and a dummy variable for Canada interacted with the patent variable. To account for heteroskedasticity and potential autocorrelation, in all regressions we calculate Newey-West standard errors with a lag of 2 years.

These regressions show that, although increases in patenting are associated with increases in productivity during this period, the elasticity of productivity with respect to patenting is low (around 0.1 per cent), and significantly lower for Canada than for other countries in the sample (in Column 4, the implied patent elasticity for Canada is 0.045 compared to compared to 0.099 for the rest of the sample). [24] The patent elasticity is higher for GDP per capita and GDP per hour worked (0.39 per cent and 0.34 per cent, respectively, for countries other than Canada), but once again, the elasticity of normalized GDP with respect to patents per capita is significantly lower for Canada. Table 3 shows that this negative and significant interaction effect is similar whether we use USPTO patents per capita, Triadic patent families per capita, worldwide applications per capita, or IP5 patent families per capita. In general, using USPTO patents as our measure, we find a positive relationship between changes in patenting and changes in the output measures, but a significantly smaller relationship for Canada than for other countries in the sample, and the estimated relationship between patenting and output for Canada is not statistically distinguishable from zero at the 5 per cent level in most specifications).[25]

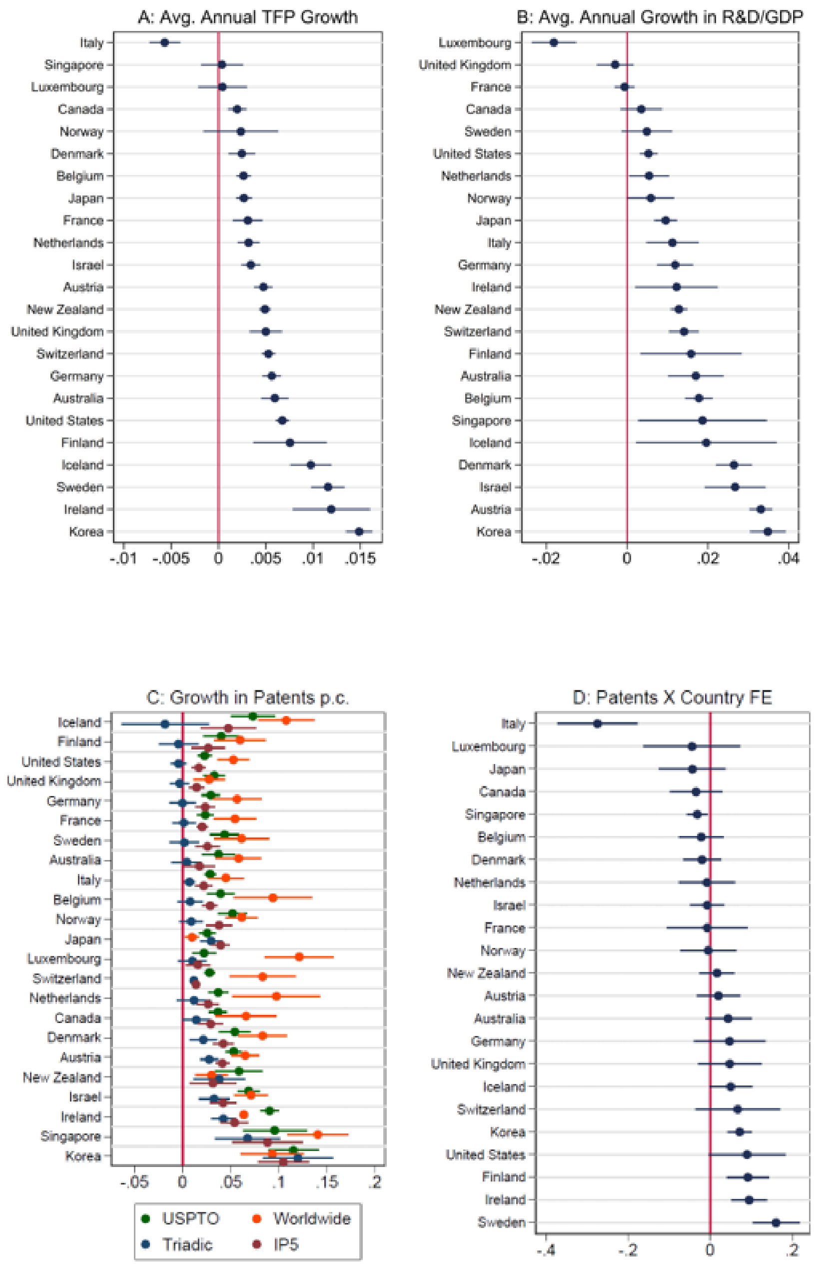
Chart 3 displays the patents interaction effect for Canada in comparison to other countries (without controlling for R&D/GDP). Looking at panel D, only Italy, Luxembourg, and Japan have patent interaction coefficients below Canada's, implying that the correlation between productivity and patenting is higher in all but a few countries.

The coefficient on the number of patents in Table 2 implies an elasticity of approximately 0.1 per cent, implying a relatively small increase in productivity growth when the rate of patenting increases. This may partly reflect the fact that analysis at the sectoral or national level will average firm-specific effects of patenting, which makes it difficult to trace the relationship between patenting and productivity. However, it does not explain why the relationship between patenting and productivity would be

24 We calculate the Canada-specific elasticity of TFP with respect to patents by summing the coefficient on patents (0.0985) with the Canada X patents interaction (-0.0538).

25 The sum of the Patents and the Patents X Canada coefficients is significantly negative at the 5 per cent level in Table 3, Column 1, panel A and panel B, when controlling for R&D/GDP. This may reflect the difficulty of separately estimating the effects of R&D investment from patenting when these two variables are highly correlated.

Chart 3: Regression Results by Country



Note: Regression coefficients and Newey-west standard errors (lag of 2 years). The chart displays the coefficients and 95 per cent confidence intervals for regressions on panel data on countries and years from 1990-2018. Panel A: coefficients on Country X year interactions when dependent variable is the natural logarithm of TFP. Panel B: coefficients on Country X year interactions when dependent variable is the natural logarithm of R&D/GDP. Panel C: coefficients on Country X year interactions when dependent variable is the natural logarithm of annual patents per capita (USPTO, WIPO or Triadic definition) by application year. Panel D: coefficients on stock of USPTO patents per capita interacted with the country fixed effects, controlling for year and country effects.

Table 3: Regression Results by Patent Family

	(1) TFP	(2) TFP	(3) GDP pc	(4) GDP pw	(5) TFP G7	(6) TFP pop wt
Panel A: Triadic patent families (OECD)						
R&D/GDP	0.0806***		-0.0814	-0.0406	0.117***	0.0473
	(0.0269)		(0.0625)	(0.0616)	(0.0418)	(0.0463)
Patents	-0.00653	0.0363*	0.134**	0.128***	0.0583***	0.0113
	(0.0288)	(0.0213)	(0.0541)	(0.0554)	(0.0215)	(0.0314)
Can X Patents	-0.0707***	-0.0651***	-0.167***	-0.246***	-0.0912***	-0.0735**
	(0.0229)	(0.0243)	(0.0776)	(0.0739)	(0.0368)	(0.0342)
Sum of coefs.	-0.077***	-0.029	-0.033	-0.118	-0.033	-0.062
Observations	514	552	514	514	228	514
Panel B: Worldwide applications (WIPO)						
R&D/GDP	0.0500**		-0.0612	-0.0474	0.131***	0.0541*
	(0.0203)		(0.0430)	(0.0421)	(0.0272)	(0.0305)
Patents	0.0112	0.0238*	0.0785***	0.0742***	0.0413**	0.0305**
	(0.0120)	(0.0123)	(0.0253)	(0.0197)	(0.0195)	(0.0134)
Can X Patents	-0.0389***	-0.0433***	-0.0805***	-0.110***	-0.0613***	-0.0520***
	(0.00564)	(0.00598)	(0.0130)	(0.0122)	(0.00687)	(0.00698)
Sum of coefs.	-0.028***	-0.019*	-0.002	-0.036*	-0.020	-0.022*
Observations	530	580	530	530	230	530
Panel C: IP5 patent families (OECD)						
R&D/GDP	0.0392		-0.161*	-0.136	0.0396	0.0250
	(0.0332)		(0.0849)	(0.0826)	(0.0605)	(0.0551)
Patents	0.0492	0.0584*	0.240***	0.252***	0.114***	0.0300
	(0.0306)	(0.0307)	(0.0862)	(0.0801)	(0.0371)	(0.0420)
Can X Patents	-0.0682***	-0.0658***	-0.194***	-0.253***	-0.0695***	-0.0773***
	(0.0182)	(0.0191)	(0.0484)	(0.0460)	(0.0251)	(0.0247)
Sum of coefs.	-0.019	-0.007	0.046	-0.001	0.045	-0.047
Observations	514	552	514	514	228	514

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018. Fixed effects for country and year included in all regressions. Columns 1-4 in each panel include all countries listed in note on Table 1. Column 5 in each panel includes the "G7 plus" group of G7 countries plus Israel, Finland and South Korea. Column 6 in each panel weights by population. In each panel, the dependent variable in Columns 1-2 and 5-6 is the natural logarithm of TFP at constant national prices (2017=1). The dependent variable in column 3 is the natural logarithm of per capita output-side real GDP at chained PPPs in mil. 2017 USD. The dependent variable in column 4 is the natural logarithm of output-side real GDP per hour worked (source for TFP and GDP data: Penn World Tables). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the country's patent stock per capita, and a dummy variable for Canada interacted with the patent variable. Panel A uses "Triadic patent families," the number of patent families per capita from a country granted by the United States and also filed in Japan and the European patent offices. Panel B uses all patent applications filed worldwide, by applicant's origin (source: WIPO IP Statistics Data Center). Panel C uses "IP5 patent families," patent families filed at two or more offices and at least one of the five largest patent offices, by priority year (source for IP5 and triadic patents: OECD.Stat). (***/**/*): significant at the (1/5/10)% level.

substantially weaker for Canada than for other countries.

Potential Explanations for the Patenting-productivity Divergence

ICT patenting and industry mix

We investigate whether the Canada gap in the relationship between patenting and productivity can be explained by Trajtenberg's (1999) observations that Canadian patenting was not keeping pace with the growth of ICT. Has this phenomenon persisted, and can it explain the gap? ICT patents as a share of all patents invented in Canada have increased substantially in the last two decades. Much of the total growth in patenting at the USPTO since 1990 can be explained by a growth in ICT patenting spurred partly by changes in the USPTO's treatment of software patents. Computing and communication inventions as a share of total patents have risen from less than 10 per cent of total to nearly half of all patents granted to Canadians.

Chart 4 shows disaggregated technology counts of patents by Canadian applicants, from the WIPO IP statistics database, and displays the top 10 technologies by total patents as of 2020. The rise in computer technology and digital communication from very low levels in the 1980s and 1990s is striking, as is the decline in this sector after 2014. This corresponds to the fortunes of Research In Motion/Blackberry, which filed thousands of patents in the early 2000s before declining after 2010.[26] A plateau in pharmaceutical patent counts after 2000 is apparent, however this is tempered by strong growth in medical technology, which from quite low levels in the 1980s and 1990s became one of the top sectors by the end of the sample period.

The exclusivity represented by patents can both stimulate innovation, by creating incentives to invest in R&D, and stifle it, if thickets of patents create barriers to entry and raise the cost of cumulative innovation. Many ICT patents could represent strategic patenting by competitors, which can be a drag on firm resources rather than a spur to productivity growth.[27] Moreover, productivity growth in ICT-intensive sectors is notoriously difficult to measure. As described above, recent research has suggested a link between the growth of ICT, rising industry concentration, and declining innovation diffusion. To determine whether the gap between the growth of patenting and of productivity could be explained by trends in ICT patenting by Canadian inventors, we first examine the relationship between productivity and the share of ICT patents at the country level.

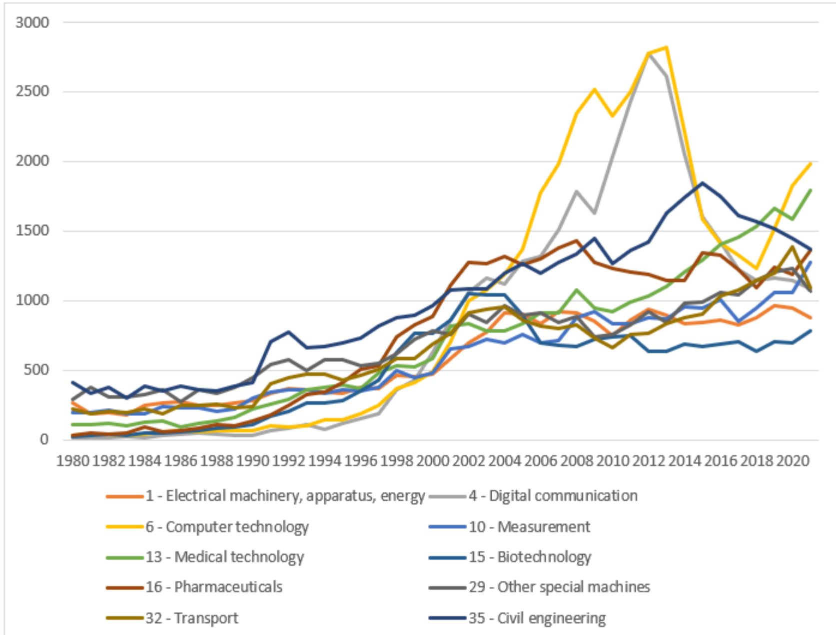
Column 1 of Table 4 contains the result of a panel regression at the country level of ln(TFP) on ln(Patents per capita), the R&D to GDP ratio, and Canada X ln(patents per capita), as well as a control for the percentage of patent stock at the country level that are in ICT-related fields (the "computers and communications" field according to the NBER categorization). The Canada X patents interaction remains negative and statistically significant. This shows that adding a variable capturing the percentage of patents assigned to a country's inventors that are in ICT fields does not reduce the magnitude of the coefficient on Canada X ln(patents per capita). Column 2 drops the control for the natural logarithm of the R&D/GDP, and the coefficient on the Canada X patents interaction remains unchanged.

However, these aggregate measures may mask heterogeneity in the impacts of patents across industries. We thus turn to

26 The rise and fall of Nortel Networks is also apparent in patent application data in an earlier period (with applications peaking around 2000).

27 Hall and MacGarvie (2010) find that software patents themselves are not independently associated with firm market value after controlling for invention quality.

Chart 4: Patent Publications by Canadian Applicants by Technologies, 1980-2020



Note: This chart displays patent publications (equivalent count) filed by Canadian applicants worldwide by year and technological field, for the top ten technologies as of 2020.
Source: WIPO IP statistics database.

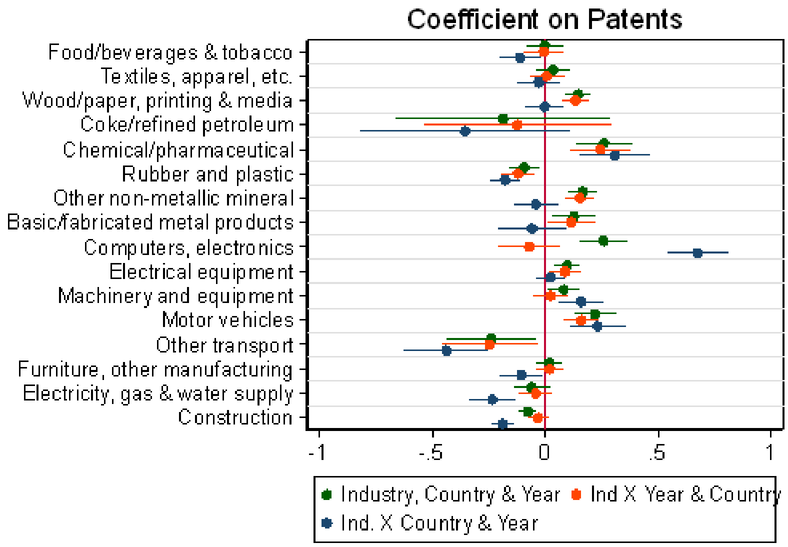
data at the sector level. The right panel of Table 4 and Chart 5 present information on regressions in which a unit of observation is a country-industry-year. Columns 6 and 7 of Table 4 present the industry-level regression of log labour productivity on ln(patent stock) and Canada X ln(patent stock), with and without controls for ln(R&D/GDP). The latter variable is missing for much of the sample, and we chose to omit this variable from the remaining regressions after confirming that its inclusion did not substantially change the main results. Column 8 drops oil refining and column 9 drops oil and ICT, with the significantly negative coefficient on Canada X patent stock persisting.[28]

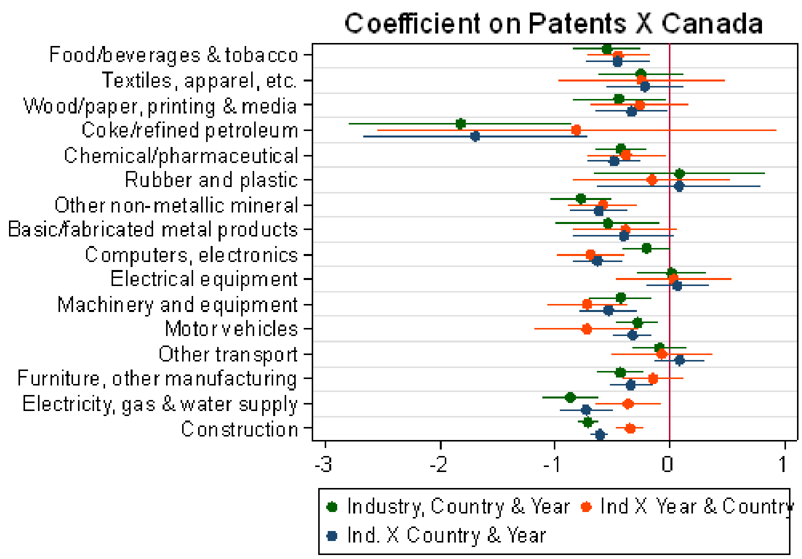
Chart 5 presents results from a regression of log labour productivity on both the patent stock and the Canada X patents variable interacted with industry fixed effects. [29] The chart displays three different specifications with fixed effects that control for different sources of variation. The first specification controls for industry, country and year fixed effects. The second controls for global technological trends/shocks in a given industry by adding industry X year effects (and keeping the country fixed effect). The third specification controls for permanent differences across country-industry pairs as well as global trends over

28 We drop the coke and refined petroleum products industry (D19) since it is a significant outlier in terms of labour productivity for Canada and Denmark relative to the rest of the world.

29 In contrast to the country-level TFP data which are normalized within each country, the labour productivity data is measured in US dollars per hour worked. Our fixed effects for country implicitly normalize the labour productivity data relative to other observations within a country.

Chart 5: Industry-specific Relationships between Patenting and Productivity





Note: The top panel displays coefficients and 95 per cent confidence intervals on the patent variable interacted with industry fixed effects, and the bottom panel displays the coefficient on the triple interaction Industry X Patents X Canada. "Industry, Country & Year" refers to a specification with ln(labour productivity) as the dependent variable and industry, country and year fixed effects (as well as a fixed effects for Canada X industry). "Ind. X Year & Country" is the same specification, only with industry interacted with year dummies. "Ind. X Country & Year" controls for industry X country interactions and year fixed effects.

Table 4: Regression Results - Industry-specific Effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Country: TFP					Country-industry: Labour Prod.			
	TFP	TFP	TFP	TFP	TFP	W/ R&D	W/o R&D	Drop Oil refining	Drop ICT & Oil
R&D/GDP	-0.00557		-0.00382	0.0125	-0.00422	0.0990***			
	(0.0266)		(0.0274)	(0.0280)	(0.0275)	(0.0122)			
Patents	0.0941***	0.0453**	0.0981***	0.0902***	0.0921***	0.0247	0.0354	0.0461**	-0.00366
	(0.0246)	(0.0180)	(0.0235)	(0.0223)	(0.0235)	(0.0244)	(0.0235)	(0.0202)	(0.0187)
Can X Patents	-0.0635***	-0.0660***	-0.0530***	-0.0573***	-0.0555***	-0.203***	-0.224***	-0.0769***	-0.0899**
	(0.0166)	(0.0160)	(0.0111)	(0.0105)	(0.0107)	(0.0396)	(0.0491)	(0.0268)	(0.0366)
% in ICT	0.0659	0.114							
	(0.0885)	(0.0870)							
Natural resources			0.000778						
			(0.00274)						
Forward citations				-0.00126					
				(0.00112)					
New Bigrams					-0.0178				
					(0.0136)				
Observations	588	666	588	588	588	3158	5670	5328	4994
Country fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry fixed effects	NA	NA	NA	NA	NA	Y	Y	Y	Y

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Countries included: see note on Table 1. Columns 6-9 are at the country-sector-year level, for the industries listed in Table 1. Column 8 excludes coke and refined petroleum industry (ISIC D19). Column 9 also excludes computer, electronic and optical products (ISIC D26). The dependent variable in Columns 1-5 is the natural logarithm of TFP at constant national prices (2017=1) and in columns 6-9 it is the natural logarithm of labour productivity at the country-industry level. The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the stock of the country's USPTO patents per capita, a dummy variable for Canada interacted with the patent variable, the percentage of patent stock that is in the "computers and communications" technological field, the share of natural resources rents as a share of GDP, the mean stock of forward citations per patents, and the mean stock of number of new bigrams per patent. Because the NBER category classification is available through grant year 2014, we extrapolate forward using the proportion of each IPC code that falls into the "computers and communications" technological field historically. (***/**/*): significant at the (1/5/10)% level.

time by including country X industry and year fixed effects.

The top panel of Chart 5 displays the coefficients on the industry dummies interacted with the patent variable (which informs us about the relationship between patenting and productivity within an industry). We see that the relationship tends to be positive in the industries known to be reliant on intellectual property as a source of growth. For example, the coefficient on patents is positive, large and significant in the chemical/pharmaceutical industry across all specifications. However, in several industries there is an insignificant or even negative relationship between patenting and productivity. These industries tend to be resource-intensive (e.g. coke and petroleum, electricity/gas/water) or industries not typically associated with strong use of intellectual property (e.g. construction). We suspect that our probabilistic mapping between patent classes and economic activity may be less reliable for industries in which intellectual property plays a less central role. This source of measurement error may explain the insignificant or negative coefficients in those industries.

It is also worth noting that the choice of fixed effects has an impact on the results. Estimates from regressions with controls for Country, Industry, and Year or Country and Industry X Year effects generally suggest a more positive correlation between patents and productivity, while specifications that control for fixed effects at the country-industry level suggest a weaker correlation between patenting and productivity.

This suggests that cross-sectional variation in patenting and productivity across country-industry pairs is an important source of variation for identifying the relationship between patenting and productivity, while the variation within country-industry pairs over time provides less identifying variation. Because productivity in most industries is fairly stable over time, we do not observe strong effects of increases in patenting over time within country-industry groups (except in some with rapid changes in productivity and patenting, like computing and electronics, which we discuss further below). The weaker within-country-industry results may also relate to the difficulty of linking patents to productivity in a specific time and different depreciation rates across industries.

One notable difference across specifications is in the computing and electronics sector. When we control for country and industry or country X industry effects, we estimate a significant positive relationship between patenting and productivity in computing and electronics. In the specification with Industry X year effects, we estimate a positive relationship between patenting and productivity for most manufacturing-related industries, but not computing and electronics. This suggests that the positive coefficient for computing and electronics in the first two specifications was driven by global trends in this sector rather than variation in patenting and productivity across country-industry pairs.

To estimate the effect of patenting in Canada relative to other countries, we include a triple interaction of the industry effects with the Canada dummy and the patent stock variable.[30] These results are displayed in the bottom panel of Chart 5. Although not significantly negative in every industry, the general pattern of coefficients suggests a weaker relationship between patenting and productivity in several sectors. The weaker relationship between patenting and productivity in Canada does not appear to be driven purely by the ICT sector.[31] This, together with the results in Table 4, suggests that the Canadian patent productivity paradox is not fully explained by differences in the rate of ICT patenting in Canada.

Another possibility is that Canada's high share of GDP in natural resources explains the disconnect between patenting and productivity. As seen in Chart 5, the gap between Canada and other countries in the estimated relationship between patenting and productivity tends to be large in re-

30 In the specification with country and industry or country X year and industry X year effects, we also control for the Canada dummy interacted with the industry dummies (which is automatically included in the specification with country-industry fixed effects).

31 We also ran regressions separately for each industry and confirmed a negative and significant coefficient on the Patents X Canada interaction in most industries.

source sectors such as coke and refined petroleum. In Table 4, Column 3, we control for the total natural resources rents (the sum of oil, natural gas, coal, mineral, and forest rents) as a percentage of GDP, by country and year.[32] Including this control variable does not materially change the coefficients on patents or Canada X patents, and the variable itself is insignificantly associated with TFP.

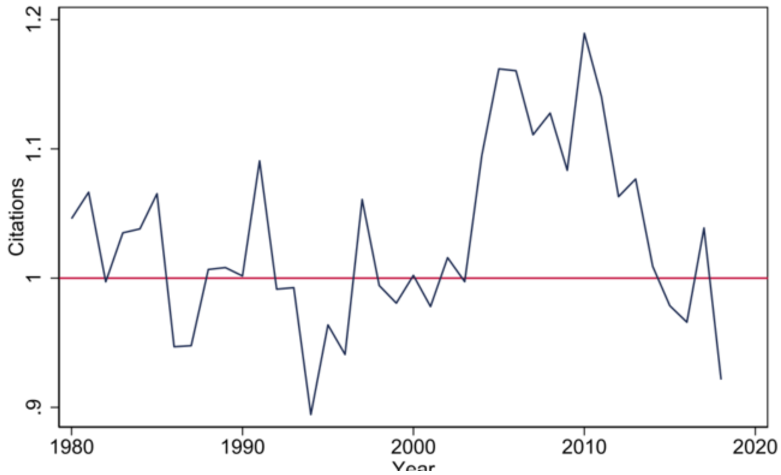
Invention Quality

A second potential explanation for the discrepancy between the growth of patenting and the growth of productivity in Canada is lower invention quality. Trajtenberg (2000) found that Canadian-invented patents were approximately 20 per cent less important than US-invented patents, as measured by the number of forward citations. There is a divergence apparent in Chart 3 between relatively strong growth in Canadian patenting and relatively stagnant R&D spending as a fraction of GDP. This divergence raises the question of whether the increase in Canadian patenting since 1990 reflects a larger number of less important or more derivative inventions.

When inventors file patents, they must cite the preexisting prior art upon which their invention builds (and which is not covered by the application in question). The number of forward citations (or citations received by a patent) have been widely used in the innovation literature as an indicator (albeit an imperfect one) of patent quality or importance. More recently, alternative measures of novelty have emerged based on text analysis of the words in patents (e.g. Arts *et al.* 2021). These measures count the number of patents with novel word combinations (combinations not observed in previously granted patents) and it has been suggested that a decline in patent novelty can explain slowing productivity growth (Kalyani 2022). We begin by comparing the number of forward citations per patent to Canadian patents with the number of forward citations per patent to non-Canadian patents by year of application, in Chart 6. This chart displays the ratio of the mean forward citations per Canadian-invented patent to the mean forward citations per patent to non-Canadian patents. Consistent with Trajtenberg (2000), we find that Canadian patents received fewer forward citations per patent in the 1980s and early 1990s. However, in mid-nineties, the number of citations received by Canadian patents rose considerably to match those received by patents in other countries, and exceed them after 2000 before declining again in recent years. It is difficult to interpret data on forward citations to recently granted patents. The application years in the chart correspond to grant lags approximately 2-4 years later (Hall *et al.* 2002 and Popp *et al.* 2003), and recently granted patents take several years to accumulate citations. For this reason, one should be cautious about interpreting the relative decline in the ratio of Canadian to other citations after 2010. However, it does warrant further investigation in future research. Overall, however,

32 World Bank, see https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS for more information.

Chart 6: Average Forward Citations to Patents, Canada/Non-Canada



Note:This chart displays the average total forward citations for patents with a Canadian inventor ("Canadian" patents) compared to non-Canadian patents filed at the USPTO, by application year.

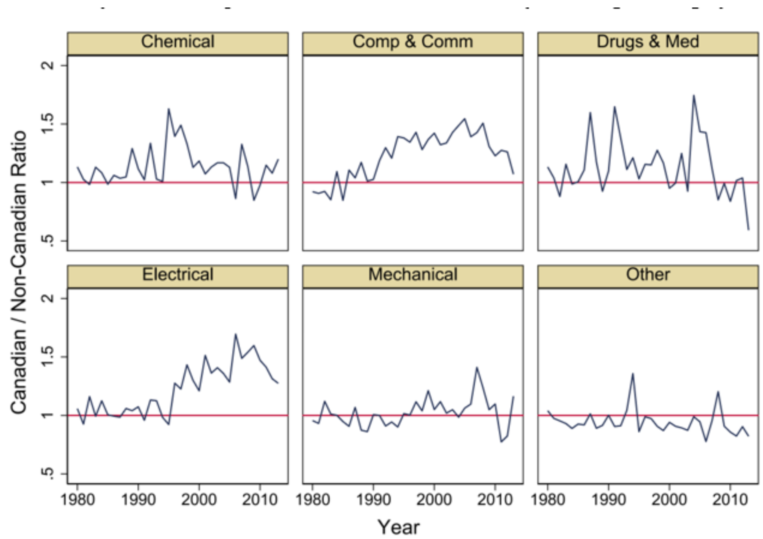
this chart does not suggest that Canadian patents are of lower quality on average during our sample period.

Text-based novelty measures based on Arts *et al.* (2021) show a slightly different picture (Chart 7). Across several technological fields (in particular, computers and communications and electrical), Canadian patents appear to use more novel word combinations (bigrams) than patents from other countries. In no field do Canadian patents appear to be consistently less novel than patents from other countries. In the computing and electrical categories, Canadian patents are substantially more novel than patents from other countries after 1990 (according to this measure).

Perhaps not surprisingly, adding measures of invention quality to the TFP regressions does little to enlighten us about the Canadian patent-productivity gap. Results from regressions similar to those in Table 2, but with patent quality measures included as controls, are found in Columns 4 and 5 of Table 4. The coefficients on the mean of forward citations per patent in a country are not statistically significant, and their inclusion in the regression does not materially affect the coefficient on Canada X Patents. The same is true when we include the mean of the number of novel word combinations (new bigrams) in a country's patents.

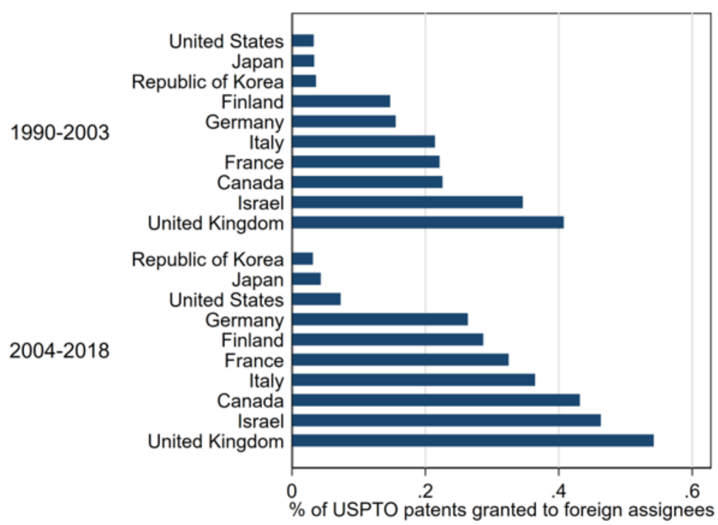
It must be noted that both citation-based and text-based measures of novelty and importance have their limitations. The fact that they appear to be uncorrelated with aggregate productivity after accounting for covariates suggests that they are nuanced measures of invention importance or quality that deserve further study. Alternatively, it could be that although these measures have been found to be correlated with market value or productivity in firm-level data (Hall *et al.*, 2009 on citations; Kalyani 2022 on bigrams), the correlation in the cross section across individual firms between measures of patent quality and economic value and impact may be driven by differences that are smoothed away once data are aggregated to the sector or country level. For example, Berkes *et al.* (2022)

Chart 7 : Novelty of Canadian Patents Relative to Other Countries by Technological Category



Note: This chart displays the ratio of Canadian to non-Canadian new bigrams (novel two-word combinations) in patent flows by year and technological category. NBER technology categories are available for patents granted in 2014 and earlier. Source: Arts *et al.* (2021) and authors' calculations.

Chart 8: Foreign Assignment of Patents (G7 plus countries)



Note: Mean percentage of USPTO patents assigned to a foreign entity, by inventor country.

argue that the relationship between innovation and productivity is affected by attenuation bias due to measurement error or increases in industry concentration, and find a larger impact of innovation on output per worker at the sector level in a two-stage least squares model. Our preliminary analysis of the most readily available and commonly used measures of patent quality thus finds no obvious indication that Canada's slow productivity growth is explained by lower-quality inventions.

Foreign assignment

Because Canadian firms are a small share of the world economy, many Canadian-invented patents will inevitably be assigned to foreign firms. Although the share of patents with a Canadian inventor assigned to Canadian firms has stayed roughly the same, the share of Canada-invented patents assigned to foreign firms has risen (as the share of unassigned patents has fallen). This increase, seen in Chart 8, has been documented by Gallini and Hollis (2019) as well as Greenspon and Rodrigues (2017), the latter of whom stated, "Although increasing the level of innovative activity that takes place in Canada is a crucial policy goal, it is also important for Canadian firms to commercialize these inventions. This inventor-assignee patent gap merits further research and attention because it suggests that Canada may be unable to profit from increases in innovative activity." (p. 66).

While we do not explicitly analyze data on patent filings by Canadian residents at the CIPO, it is worth describing trends in this variable. According to the WIPO IP Statistics Data Center, CIPO patent applications filed by Canadian resident applicants averaged 2,986.9 per year from 1990 to 1999, and rose to 4,710.0 per year from 2000-2009, before declining slightly to 4,377.3 per year from 2010 to 2019. This rate of increase is slower than the rapid increase in patenting by Canadian residents at the USPTO. This may reflect greater innovation among export-oriented firms (Eckert *et al.* 2022), or a greater representation of Canadian residents among inventors on patents held by multinationals (consistent with trends described above in the share of foreign-assigned patents).

Does the rise in foreign-assigned patenting explain Canada's TFP gap? Column 1 of Table 5 shows that the percentage of the stock of patents with foreign assignees is negatively associated with productivity and controlling for this variable partially mitigates the weaker correlation between patenting and productivity in Canada, as the Canada X Patents coefficient falls to -0.028 (significant at the 10 per cent level with a standard error of 0.014). Controlling for this variable has a bigger impact on the Canada-patents interaction in columns 7 (the G7 plus sample) and 9 (the population-weighted regression), where the interaction is no longer significant after controlling for foreign assignment.

There may nonetheless be mixed effects of foreign ownership on productivity. Subsidiaries of foreign firms in the UK have been found to be more productive (Griffith *et al.* 2004) and inward FDI has been found to increase the productivity of domestic firms (Aitken and Harrison, 1999). Foreign-owned R&D-intensive firms often have access to cutting-edge technol-

Table 5: Regression Results - Foreign Ownership and Migration

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Full sample	Full sample, Year<2013					G7 plus	G7 plus, Year<2013	Full sample, pop wt	Year<2013, pop wt
R&D/GDP	-0.00610	0.0256	0.0414	0.0258	0.0400	0.0408	-0.100	-0.0553	-0.0726	-0.0837*
	(0.0262)	(0.0310)	(0.0317)	(0.0314)	(0.0322)	(0.0316)	(0.0642)	(0.0438)	(0.0475)	(0.0464)
Patents	0.102***	0.0690***	0.0827***	0.0697***	0.0783***	0.0820***	0.182***	0.158***	0.0938***	0.105***
	(0.0227)	(0.0247)	(0.0254)	(0.0247)	(0.0249)	(0.0235)	(0.0347)	(0.0279)	(0.0313)	(0.0269)
Can X Patents	-0.0276*	-0.0570***	-0.0317	-0.0576***	-0.0236	-0.0226	-0.00211	0.0251	-0.0274	0.0180
	(0.0141)	(0.0140)	(0.0211)	(0.0150)	(0.0207)	(0.0202)	(0.0298)	(0.0450)	(0.0237)	(0.0402)
% foreign assignees	-0.172***					-0.0879*	-0.408***		-0.219**	
	(0.0506)					(0.0485)	(0.153)		(0.103)	
Immigrant/National patents			0.0250**		0.0276**	0.0208*		0.0574**		0.0305
			(0.0123)		(0.0118)	(0.0123)		(0.0230)		(0.0260)
Emigrant/National patents				0.00132	-0.0120	-0.00855		-0.0182		-0.0416***
				(0.0107)	(0.00891)	(0.00868)		(0.0154)		(0.00866)
Observations	588	452	444	452	444	444	260	200	588	444

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018 in columns 1, 7, and 9, and 1990-2012 in columns 2-6, 8, and 10 (which exclude later years due to missing data on inventor flows). Fixed effects for country and year included in all regressions. Columns 1-6 and 9-10 include the full sample of countries listed in the notes on Table 1. Columns 7-8 include the "G7 plus" group of G7 countries plus Israel, Finland and South Korea. The dependent variable in all columns is the natural logarithm of TFP at constant national prices (2017=1). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of USPTO patent stock with inventors located in the country, a dummy variable for Canada interacted with the patent variable, the percentage of the stock of patents assigned to foreign assignees, the natural logarithm of the stock of the number of immigrant and emigrant invented patents per patent invented by nationals. (***/**/*): significant at the (1/5/10)% level

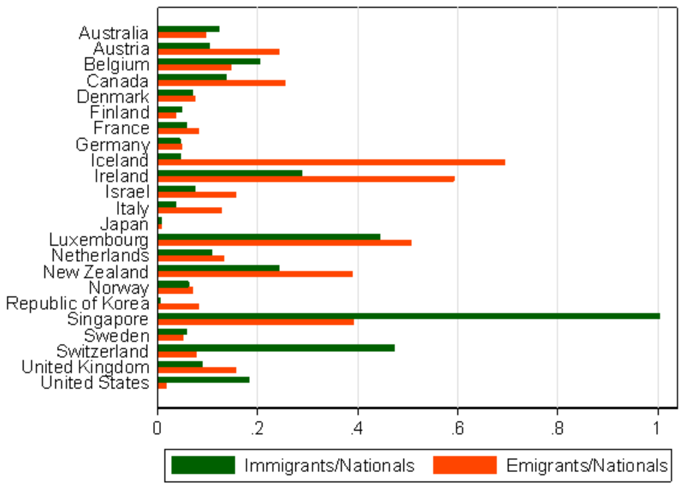
ogy developed abroad, and may generate spillovers from R&D activities located in Canada (Javorcik 2004). This may incur benefits including international knowledge diffusion among inventor teams and subsequent spillovers to domestic firms. Patents with inventor teams that are more diverse in terms of nationality may be higher quality (Ferrucci and Lissoni, 2019). On the other hand, there may be few benefits if foreign ownership leads to R&D being shifted out of Canada, for example if inventors of patents owned by foreign parents are transferred to other parts of the company overseas, leading to emigration of highly skilled employees.[33]

Fons-Rosen *et al.* (2018) find that inward FDI increases the productivity of host-country firms when foreign and domestic firms are technologically similar, and that inventor mobility is one of the mechanisms that explains this.

A factor not identified by Trajtenberg (to whom the relevant data were not avail-

33 We tried including a control for a five-year moving average of the percentage of inventors located in country among patents with an inventor from a given country, by year. We found that this was positively but insignificantly related to productivity in the main specification, and the coefficient fell substantially after controlling for the percentage of domestically invented patents assigned to foreign firms. These control variables have a correlation of -0.86. This suggests that our preferred control – the percentage of domestic patents assigned to foreign firms – is capturing most of the effect of the percentage of inventors located in a country. Of course, this is largely explained by the sizes of these countries. In our sample, Iceland, Canada, Ireland, and Italy have the highest average rates of net emigration per national over the whole sample period (computed as the ratio of emigrant to national patents minus the ratio of immigrant to national patents). The lowest rates of net emigration (or highest rates of net immigration) are in Singapore, Switzerland, the United States, and Luxembourg. Miguelez and Fink (2013) note that the coverage of nationality information in PCT patents has increased over time. There are some outlier values for the migration data for very small countries (e.g. Iceland, Ireland, Luxembourg, New Zealand and Singapore) in the earliest years of our sample. Results are robust to dropping these early sample years, as well as to restricting the sample to years after 2003, the period for which Miguelez and Fink report that the data have "excellent" coverage (p. 9).

Chart 9 : Ratio of Patents with Immigrant or Emigrant Inventors to Patents Invented by Nationals



Note: Authors' calculations based on data described in Miguelez and Fink (2013). Average ratio of depreciated stock of patents with Immigrant or Emigrant inventors to patents invented by Nationals (inventors residing in their country of citizenship), 1990-2012.

able), but subsequently flagged by Ivus (2016), is the high rate of net emigration of Canadian inventors (Chart 9). China and India are the only countries with higher rates of total net inventor emigration than Canada (Miguelez and Fink 2013; Ivus, 2016). To attempt to disentangle some of the positive and negative aspects of foreign ownership, we include controls for the natural logarithm of the stock of the number of immigrant inventors per national, and the log of stock of the number of emigrant inventors per national.

As noted previously, this data is only available until 2012. Table 5 displays results based on the full sample period in Column 1 and 9, and sample years restricted to 1990-2012 in all other columns. We find that the log of the stock of immigrant inventors per national is significantly positively correlated with TFP and including it makes the negative coefficient on the Canada X patents interaction small and insignificantly different from zero (Column 3). This suggests that foreign-owned patents may indeed reduce productivity IF they are not accompanied by shifting of inventors to locations inside the country. However, a high rate of foreign-owned patents will not necessarily be harmful if combined with a high rate of inventor immigration.[34]

One interpretation of this result is that it is capturing the extent to which MNCs are establishing R&D labs in the country as opposed to Canadian inventors selling

34 This data is also available by type of applicant: corporate, individual or public/university. We estimated regressions using migration data based on each of these three types of patents and found that the results in Table 5 appear to be primarily driven by immigrant corporate patents, with a small effect of immigrant individual inventors and relatively little relationship between productivity and emigrant or public-sector migrant inventors of both types.

their IP to foreign firms that develop it outside the country. This highlights the importance of distinguishing between foreign-owned patents that could potentially lead to productivity spillovers in Canada versus "extractive" foreign-owned patents that primarily benefit firms in other countries.

Caution is warranted in interpreting these panel regressions, which are conditional correlations rather than causal estimates. For example, there is likely to be reverse causality in the relationship between inventor migration and productivity growth, with rapid growth causing immigration to some extent. However, other research has highlighted the importance of retaining and attracting skilled human capital for productivity growth and prosperity (e.g. Kerr 2018). Indeed, Sharpe (2003;28) notes that due to Canada's small size relative to the rest of the world, "what matters for productivity growth is the importation of best-practice technologies from other countries and the wide diffusion and adoption of these technologies by Canadian business." To the extent that mobile inventors bring knowledge about best-practice technologies to their destination countries, Canada's low rate of inventor immigration relative to inventor emigration combined with a high rate of foreign-owned patents suggests that it is a net exporter of embodied technological knowledge. More research is needed to disentangle the causal relationships between foreign ownership, inventor migration, innovation and productivity.

Conclusion

In this article, we document a "patent productivity paradox" in Canada: slower growth in productivity than would be predicted by the growth of patenting by Canadian inventors. Guided by prior literature, we investigate three potential explanations. The first of these is that the gap is driven by changing sectoral composition, i.e. acceleration in the rate of ICT patenting that has yet to show up in productivity growth. The second is the possibility that Canadian inventions are of systematically lower quality or economic importance, which is difficult to reconcile with Canada's prominence in academic science. The third is that a combination of high rates of net out-migration by Canadian inventors and the high degree of foreign ownership of Canadian patents limits local implementation of productivity-enhancing new technologies, and associated knowledge spillovers in Canada. We find no evidence in favor of the first two explanations, but some evidence consistent with the third.

Our results raise questions for future research. For example, how do policies affecting the location of ownership of IP (as distinct from the location of invention) affect productivity and growth? What is the causal relationship between inventor migration and productivity?

It is easy to see how net out-migration of inventors can generate "patents without growth". A patent per se has little impact on productivity and growth. What counts is prompt and effective implementation of the underlying invention in the form of new products and production processes. And without the continued engagement of the inventor this implementation step may be slow, may be ineffective, or may not take place at all. Departing inventors take this deep understanding of their inventions and the challenges and opportunities of implementation of these ideas with them, along with their human capital. If they are not replaced by inflows of immigrant inventors, productivity is bound to stagnate.

The impact of foreign ownership of Canadian inventions on the degree to which they affect productivity growth is less clear. While the scientific and technical employees of foreign-based companies may generate economically significant inventions and ideas while working in Canada, it is their employers who control where, and when, subsequent development and implementation efforts take place, and which markets they will be directed towards. A substantial fraction of inventions with inventors based in Canada may therefore be contributing primarily to productivity growth elsewhere. More research is needed to distinguish between inventions with a domestic development and production footprint, those connected to foreign development through a multinational's internal processes, and those with little continued involvement of the Canada-based inventor.

As a small open economy highly integrated with its trading partners, many patents invented in Canada will inevitably be owned by foreign companies. Rather than seeking to limit the extent of ownership of IP by foreign companies, policymakers could consider the conditions under which foreign ownership is associated with increases in productivity. Our results suggest that the foreign ownership of patents is mainly a problem if it is not accompanied by inventor immigration, which is positively associated with productivity. Confirming prior findings, we show that the growth of patenting has outpaced the growth of R&D, as the percentage of patents assigned to foreign firms has increased (Greenspon and Rodrigues , 2017).

Policy could seek to encourage the location of R&D workers within Canada. For example, Hall (2019) has highlighted the Netherlands' use of lower social charges on science and engineering employment as a way of reducing firms' costs of performing R&D. Research has suggested that Canada's points-based immigration system may have limitations relative to the US employer-sponsored system when it comes to promoting innovation (Blit *et al.* 2020). Recent changes to immigration policy that make it easier for firms to fast-track work visas for skilled workers may represent a step in the right direction.[35] Recognizing the impacts of migration and foreign ownership also suggests close attention by policy makers to the economic incentives for inventors to locate in Canada and "scale up" their inventions (Gallini and Hollis, 2019).

Canada has disproportionately strong academic science. In the most recent WIPO Global Innovation Index (2022),

35 According to Silcoff and O'Kane (2023), "The program to fast-track visa applications by skilled foreign workers to work for companies in Canada has brought more than 9,000 people here and is widely considered a success."

36 The top two filers of international patents (via the PCT) in 2021 were the National Research Council of Canada and the University of British Columbia, while the University Health Network and the University of Toronto ranked fourth and fifth in terms of patents filed through the PCT).

Canada ranked 15th overall but 6th for university quality and 9th for university-industry collaboration.[36] Although world-class universities are a source of well-deserved pride for Canadians, research has documented a "Canadian commercialization discount" in which Canadian universities are less likely to commercialize research than similar counterparts in the United States (Agrawal, 2006). Although efforts to change this have made progress (e.g. via University of Toronto's Creative Destruction Lab), a recent report (Intellectual Property in Ontario's Innovation Ecosystem) identified gaps in expertise in resources at technology transfer offices, and called for clarity on the mandates of these offices and other entities involved in commercialization of university research.

The findings described here also raise questions for future research on the role of tax policy for innovation in the context of global tax competition. Recent policy discussion in Canada has focused on the potential of "patent boxes," or privileged tax rates for IP-related income (Lester, 2022). Research has suggested that IP boxes do not stimulate innovation but rather encourage profit shifting (Hall, 2019; Gaessler *et al.* 2021), and other research has highlighted the impact of tax havens on profit shifting on aggregate productivity (Guvenen et al. 2022). To what extent can tax differences across countries explain the patterns of foreign ownership observed in patent data, and what implications does this have for productivity growth?

Perhaps most importantly, our results raise questions about how policy should target innovation outcomes. Simply increasing the number of patents filed by Canadian inventors may not lead to improvements in economic growth and well-being. Policies should be focused on making sure innovation outputs translate into economic activity in Canada that leads to economic growth.

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Appendix Table A1: Robustness to Alternative Patent Flow/Stock Calculations

Panel A: Annual flows of R&D/GDP and Patents

	(1) Full sample R&D only	(2) + Patents	(3) + Can X pats	(4) + Patents peer countries	(5) Peers, no R&D	(6) TFP yr>99
R&D/GDP	0.0608***	-0.0584**	-0.0613***	-0.0583**		-0.0355
	(0.0207)	(0.0230)	(0.0230)	(0.0254)		(0.0348)
Patents		0.0811***	0.0806***	0.0817***	0.0484***	0.0883***
		(0.0102)	(0.0102)	(0.0167)	(0.0173)	(0.0206)
Can X Patents			-0.0806***	-0.0634***	-0.0537***	-0.129***
			(0.0184)	(0.0135)	(0.0116)	(0.0467)
Observations	800	800	800	649	667	435
	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7	GDPpc G7	GDPph G7	TFP (pop weights)
R&D/GDP	-0.221***	-0.195***	-0.00562	-0.0804	-0.0948	-0.0546
	(0.0640)	(0.0616)	(0.0485)	(0.0735)	(0.0847)	(0.0378)
Patents	0.271***	0.247***	0.108***	0.182***	0.190***	0.0968***
	(0.0462)	(0.0412)	(0.0207)	(0.0318)	(0.0372)	(0.0177)
Can X Patents	-0.163***	-0.214***	-0.0532***	-0.0590**	-0.149***	-0.0826***
	(0.0383)	(0.0347)	(0.0172)	(0.0239)	(0.0219)	(0.0197)
Observations	649	649	288	288	288	649

Panel B: Stock of Patents (Hall 1990 method)

	(1) Full sample R&D only	(2) + Patents	(3) + Can X pats	(4) + Patents peer countries	(5) Peers, no R&D	(6) TFP yr>99
R&D/GDP	0.0412	-0.0813*	-0.0852*	0.00292		0.00619
	(0.0365)	(0.0447)	(0.0446)	(0.0270)		(0.0429)
Patents		0.0953***	0.0958***	0.0712***	0.0345**	0.0913***
		(0.0175)	(0.0175)	(0.0221)	(0.0145)	(0.0278)
Can X Patents			-0.0649***	-0.0540***	-0.0479***	-0.0755***
			(0.0104)	(0.00848)	(0.00785)	(0.0229)
Observations	685	685	685	588	666	419
	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7	GDPpc G7	GDPph G7	TFP (pop weights)
R&D/GDP	-0.214***	-0.142*	-0.0367	-0.0708	-0.0477	-0.116***
	(0.0727)	(0.0735)	(0.0425)	(0.0803)	(0.0585)	(0.0443)
Patents	0.224***	0.184***	0.166***	0.196***	0.156**	0.116***
	(0.0714)	(0.0653)	(0.0315)	(0.0512)	(0.0670)	(0.0273)
Can X Patents	-0.144***	-0.183***	-0.0742***	-0.0719***	-0.130***	-0.0734***
	(0.0232)	(0.0198)	(0.0106)	(0.0234)	(0.0246)	(0.0128)
Observations	588	588	260	260	260	588

Note: See note on Table 2. Panel A uses the annual flow of patents and RD; Panel B uses the stock of RD and patents calculated according to the methodology in Hall 1990. (***/**/*): significant at the (1/5/10) percent level