Canadian Productivity Growth, Secular Stagnation, and Technological Change

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Abstract

In this article, we show first that the recent slowdown in productivity growth in Canada, similar to that in the United States, can be attributed at least in part to the fall-off in the commercialization of new technologies. Using our book-based indicators of technological change, we are able to show that this is true for both aggregate measures of technology and, at the disaggregate level, for mechanical/manufacturing and electrical technologies. Our results also indicate that the productivity impact of the slowdown in Canada is much greater on goods-producing industries than it is on services. Second, our latest results suggest that, contrary to the concerns of some that we are entering a new period of secular stagnation characterized by low productivity and economic growth, we are actually on the threshold of significant new technological breakthroughs, associated largely, but not only, with advances in artificial intelligence (AI) and robotics. Provided that Canadian firms adopt these innovations, we can anticipate not a continuation of slow productivity growth but an acceleration.

Since the early 2000s Canada's productivity growth has been poor relative to historical and international performance. While there is no general agreement about the causes of this slowdown, there is concern among a number of prominent economists that it may presage the beginning of an extended period of secular stagnation.[2] Many contend, moreover, that technological change, which, for the last 150 or so years, through good times and bad, had been a main source of productivity advances and output growth is no longer up to the task. Gordon (2015), among others, maintains that the great inventions and innovations of the second industrial revolution — electricity,

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2 See, e.g., Gordon (2012, 2015), Summers (2015), Fernald (2016, 2018).

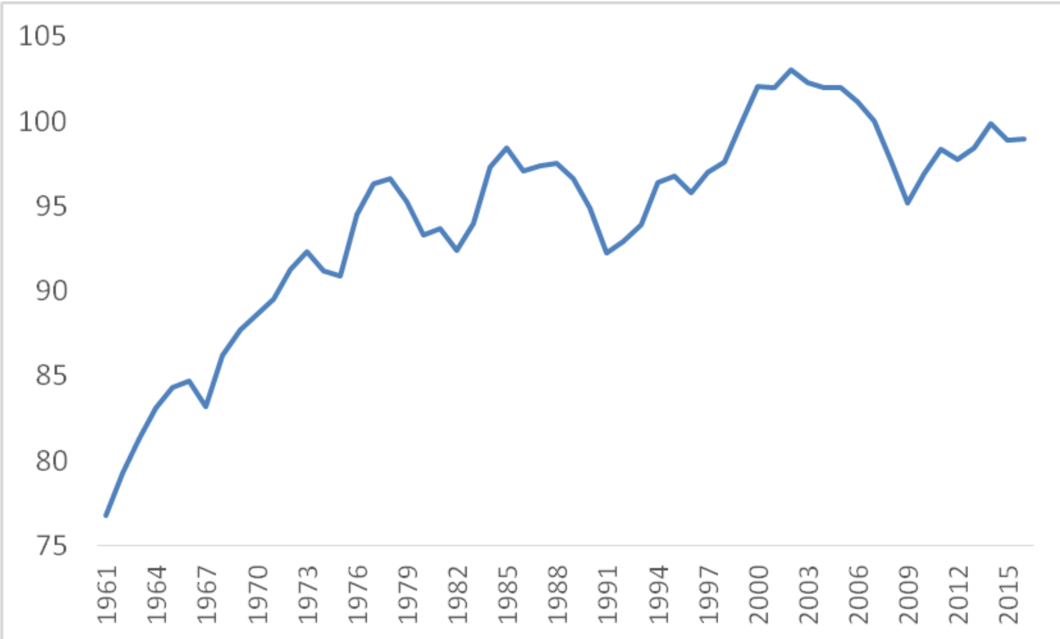
the internal combustion engine, organic chemicals — are spent forces and nothing evenly remotely comparable to their transformative impact, with the possible exception of the ICT revolution, also over, is conceivable for the foreseeable future. From this point of view, then, lackluster technical change has been a major contributor to the recent fall-off in productivity growth and there is little reason to believe that a turnaround is imminent.

This argument raises two fundamental questions about growth and productivity in Canada. First, can the post-2000 slowdown in Canadian productivity growth be attributed, at least in part, to a fall-off in the pace of technical change? The answer, as we show, is, by and large, yes. The second, which flows directly from the first, is the following. Can we infer from the marked drop in innovative activity in the first decade or so of the new century that Canada, along with other developed economies, faces a dismal future of modest (at best) technological advances and, therefore, very low rates of productivity and economic growth?

Although the answer to this question is less definitive for Canada than it is for the United States, we are able to show that even here the pace of technological change has begun to rebound and is likely to accelerate, not moderate further in the next few years. If the trend continues, the issues that Canada must deal with are not those linked to slow productivity growth and secular stagnation but are, instead, those related to the changing nature of employment opportunities, skills requirements, educational demands, and, most probably, income distribution.

We proceed as follows. In the first section, we review the evidence on the recent slump in productivity growth in Canada and display recent trends in the multifactor productivity (MFP) of the goods and service producing sectors. In the following section, building on our past work, we present measures of innovative activity derived from books held in Canadian libraries in the different fields of technology (based on an analysis of OCLC holdings and WorldCat data). These book-based measures indicate that the fall-off in innovative activity in the early 2000s closely parallels the productivity growth decline in terms of both timing and areas of economic activity. In short, the data show a drop in technological advances beginning around 2002-3, centered primarily (but not exclusively) in electronics and goods-producing technologies. In section four, we estimate a series of vector autoregressive (VARs) equations to determine the relationship between our technology indicators and measures of MFP, and then estimate how much of the slowdown can be attributed to the slowdown in technical change. We find, first, that there is a positive relationship between our aggregate technology measures and business sector MFP. Second, our results indicate that innovations related to electrical goods (including computer networks and telecommunications) as well as those linked to mechanical machinery have a significant positive impact on productivity, and

Chart 1: Business Sector Multifactor Productivity in Canada, 1961-2016 (2007 = 100)



Source: Statistics Canada, Productivity Measures, Table: 36-10-0208-01.

have been the most important drivers of Canadian MFP. In section five, we review evidence on the current pace of technical change. We, first, present indicators based on computer and technical titles available for sale at Amazon.com and Amazon.ca. These data show that there are tentative signs of a rebound in technical change (more marked at present in the United States than in Canada). Next, through textual analysis of book data and other printed sources, we pinpoint the specific areas — artificial intelligence (AI), robotics, etc. — where the resurgence is occurring. Given that these innovations are, for the most part, located in areas that are likely to be the main drivers of Canadian productivity in the near future (if adopted), we foresee a recovery in productivity and a substantial improvement in the economy's growth prospects. Section six offers some concluding remarks.

The Recent Slowdown in MFP Growth in Canada

While Canada, like other countries, has witnessed a number of productivity slowdowns in the past, we focus here on the most recent one which, according to Statistics Canada data reported in Chart 1, dates from the early 2000s.[3]

As in past instances of productivity slowdowns (e.g. the mid-1970s and the 1930s when, it is worth noting, similar concerns about secular stagnation were raised), Canada's recent productivity fall-off is mirrored in a number of other countries. In particular, as can be seen in Table 1, both total factor produc-

3 MFP data was retrieved from http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=3830021.

Table 1: U.S. Output and TFP Growth in the U.S. Business Sector (average annual rate of change)

	TFP growth	Utilization adjusted TFP growth	Output growth
1947:2-2018:2	1.24	1.27	3.31
1974:2-2000:4	1.40	1.45	3.69
1995:4-2018:2	0.99	1.03	2.78
1995:4-2000:4	1.85	2.02	4.88
2001:1-2018:2	0.73	0.73	2.15
2001:1-2016:2	0.67	0.70	2.05
2016:3-2018:2	1.21	1.03	2.94

Source: Data from Fernald (2014) updated Sept 7, 2018 available from Federal Reserve Bank of San Francisco.

tivity (TFP)[4] corrected for utilization, and output growth in the United States fell sharply after 2001.[5] In short, then, whatever forces are dragging down productivity and economic growth rates in Canada are doing the same thing elsewhere, most significantly in our large neighbor to the south.

The Canadian data shown in Chart 2 indicate that MFP growth fell off much more in the goods sector than in the service sector.[6] The disaggregated numbers reveal, for example, that the largest contributors to the decline in business sector MFP were the goods producing industries such as mining and quarrying, utilities, manufacturing, construction, agriculture, fishing and forestry where, after 2002, MFP actually fell in absolute terms.[7] In contrast, as can be seen in Chart 2, MFP in the service sectors — wholesale and retail trade, transportation, information, finance and insurance, real estate, education, health care, arts and entertainment, recreation and tourism, public administration and other services — suffered an absolute drop in MFP in the 1980s but has, since then, experienced modest year over year increases.

The key question raised by these descriptive statistics: can the recent drop in productivity growth in Canada (and in the United States) be attributed, as Gordon contends (2015), to the fall-off in the pace of innovative activity? We attempt to answer this question in the following section.

Was There a Slowdown in the Pace of Technological Change

A little background is useful. Most would agree that the Second Industrial Revolution (beginning more or less in the third quarter of the 19th century) ushered in a stunning array of new technologies, including electricity, the internal combustion engine, synthetic dyes,

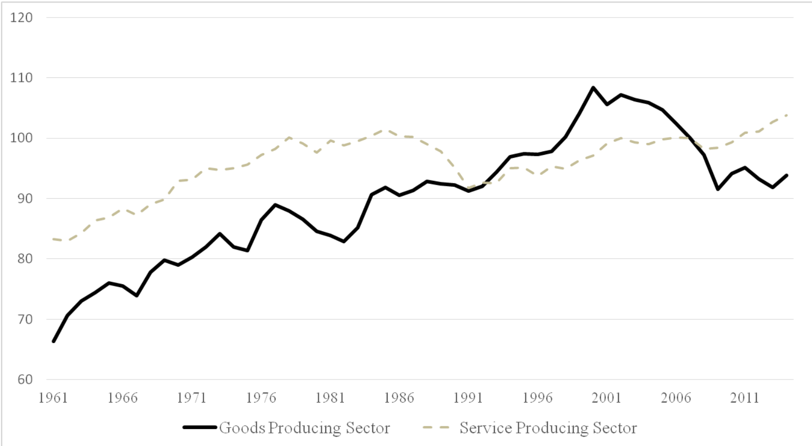
4 Note that the term multifactor productivity (MFP) and total factor productivity (TFP) are synonymous. The former term is used primarily by statistical offices such as Statistics Canada and the U.S. Bureau of Labour Statistics while the latter term is used largely by academic researchers.

5 For additional US-Canada productivity comparisons, see Baldwin and Gu (2013, Table 3) and Gu and Willox (2018). As expected, the data reveal a slowdown at the end of the 20th century in both countries.

6 See Gu and Lee (2013) for additional evidence on the variation in sectoral MFP growth rates.

7 The definition of goods producing industries in Canada can be found in Statistics Canada's North American Industry Classification System (NAICS) Version 3.0, 2017

Chart 2: Business Sector Multifactor Productivity in Canada: Goods vs Service Sectors, 1961-2016 (2007=100)



Sources: Statistics Canada, Productivity Measures Table: 36-10-0208-01.

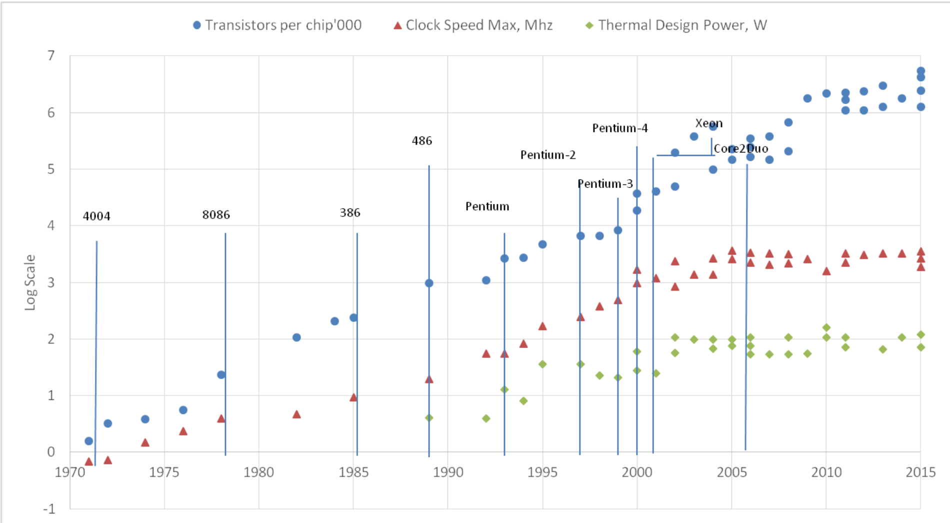
clean water and effective sewer systems. Together they dramatically altered the way most people in the West lived and worked.[8] According to the technological pessimists such as Gordon (2015), however, by the 1960s the economic growth generated by these advances was, for the most part, over and those that followed lacked the transformative force of the earlier breakthroughs. The one exception may have been computer and information technologies (the so-called "Third Industrial Revolution") but, as Gordon and others point out, while their impact on output and productivity may have been substantial it was also relatively short-lived (1996 to 2004 in the United States).

There may be some merit to this argument. It is, after all, true that while the innovations in information technology (IT) were largely responsible for productivity growth in the last years of the 20th century, advances in a number of IT areas has slowed and, computers, once the *wunderkinder* of the modern age, are now more properly thought of as commodities. Moreover, Moore's Law (i.e. the doubling of transistors and related computing power per circuit every two years) may be less of a law than was once thought (Chart 3). Despite these observations, given that Industrial Revolutions 1 and 2 each took over 100 years to play out, with ebbs and flows in the pace of innovations, it would seem that it is too early in the process to warrant writing the obituary of the Third Industrial Revolution.[9] Indeed, as we show below, while there clearly was a slowdown in innovative activity in the early years of this century, our metrics suggest

8 It is worth pointing out that these urban public health initiatives were not in themselves technological advances. The real advances were associated with the germ theory of disease and other breakthroughs in medicine and biology

9 For example, recent articles stemming from statements and research from the computer industry suggest that Moore's Law may still hold; it just needs to be altered to reflect current advances in the industry. See, for example, McGoogan (2017).

Chart 3: Changes in Processors Over Time



Notes: Vertical lines represent introduction dates for various processors. Thermal design power is based on the maximum safe poser consumption levels.
Sources: The Economist (2016), Intel, Linley group, IB consulting and Bob Colwell.

that AI and robotic technologies, direct progeny of the IT revolution, are at the initial stages of their development and diffusion.

Quantifying Technical Change

We use in this article, as we have done elsewhere, book-based measures of technical change (Alexopoulos, 2011; Alexopoulos and Cohen, 2011). The idea behind this approach is simple and intuitive. Books are written and published on new technologies because authors earn royalties by spreading the word and publishers profit by selling the titles. Timing, of course, matters: too early to market and there is no demand, too late, and demand is already satisfied by competitors. It is not surprising, then, that the first appearance of books on a new innovation coincides with its commercialization date, which, in turn, means that changes in the number of new technology titles over time provides a compelling measure of technological advances.

These measures have other attractive properties. They are available at least on an annual basis over a very long time horizon; they are objective in that their classification is determined by specialists in the field (librarians, publishers and/or booksellers); and they weight technologies according to their importance because the number of titles tend to vary with the significance of the innovation and thus with the size of the market.[10] As a final bonus, they are more likely than other indicators to cover the full range of both product and process innovations because both types of ad-

10 The weighting occurs because publishers make well-informed forecasts about the size of market for a technology and thus the potential demand for related titles. The larger and more important the technology, *ceteris paribus*, the greater the number of titles.

vances appeal to readers and potential adopters.

These measures also overcome many of the shortcomings associated with more traditional indicators of technical change such as cleansed residuals,[11] patent counts, and R&D expenditures when attempting to track commercialized technologies. The problem with the cleansed residual is that while they may pick up technology-induced changes in productivity (MFP or labour), they can also be driven by factors totally unrelated to new production techniques.[12] While patent counts and/or citations do provide some indication of potential advances, many do not result in commercially viable innovations and, even for those that do, the lag between the patent date and the diffusion of the technology varies widely and unpredictably. As a result, even in the best case scenario, the link between them, commercialized innovations, and changes in aggregate productivity is difficult to uncover (e.g. Shea, 1998). Finally, R&D expenditures, which typically pre-date patents, are similarly plagued by problems of timing and realization and thus make it difficult to use them as proxies for the commercialization of new technologies.

To employ our book based approach for Canada, we need first to identify an appropriate data source. Unlike in the United States, where the Library of Congress is essentially the literary depository of record for all published materials, no one such institution exists in Canada. Therefore, as we did in our previous work on IT innovation in Canada (Alexopoulos and Cohen, 2012), we employ book data collected from the catalogues of over 1,000 Canadian libraries covered in the WorldCat database of the Online Computer Library Centre (OCLC). Although not all Canadian libraries belong to OCLC, membership includes most of the major collections in the country, including the National Library of Canada, the largest public libraries (e.g. those in Toronto, Montreal and Vancouver), and every major university library. As such, data associated with the technology and computer Library of Congress (LOC) Classifications (i.e., the T class and QA75-77 classes) should provide a comprehensive list of the major technology titles available in Canada.[13] To avoid double counting, we de-duplicated the data using information in the **MA**chine **R**eadable **C**atalogue **R**ecords (MARC) for each of the titles.[14]

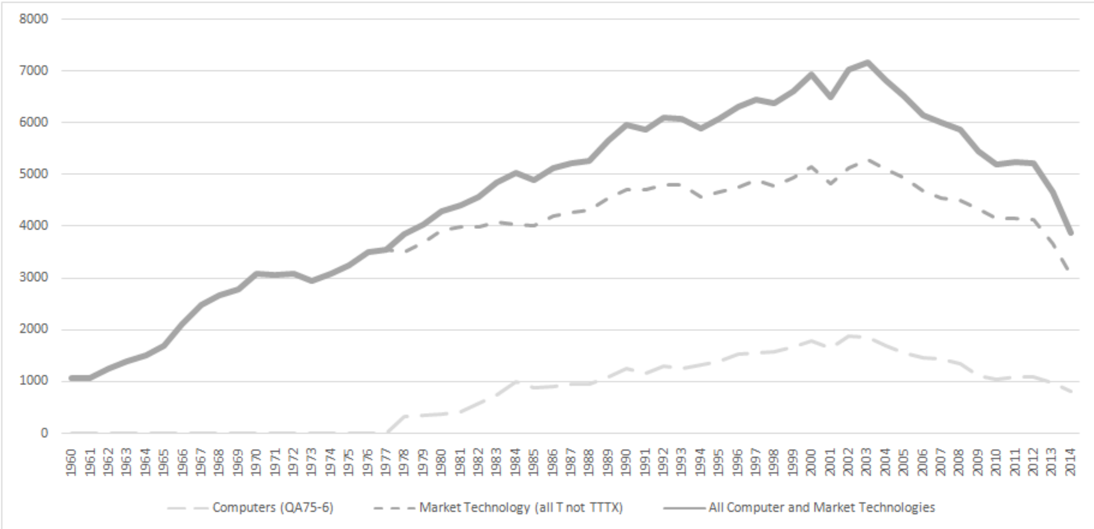
11 Cleansed residuals are Solow-type TFP measures that attempt to control for factors such as increasing returns, imperfect competition, cyclical utilization of capital and labour, and reallocation effects.

12 See, for example, Basu, Fernald, and Kimball (2006) and Christiano, Eichenbaum and Vigfusson (2004).

13 While some libraries use the Dewey decimal system, the MARC records, for the most part, record both the Dewey and LOC classifications. We make use of the later largely because the major university and research libraries, the principal location for much of the technology literature, uses the LOC classification.

14 MARC records contain identifiers such as the Library of Congress Id number, and ISBN numbers which can be used to remove duplicates.

Chart 4: Unique LOC Classed Technology and Computer Titles Held in Canada by Copyright Date, 1960-2014



Source: Authors' calculations from OCLC Worldcat Data.

What Do the Data Tell Us?

Our indices for Canada, presented in Chart 4, cover the years 1960-2014 and show the unique titles held by copyright date.[15] The most notable finding is that we do indeed see a downturn in innovative activity as proxied by technology and computer titles held in Canadian libraries, in the early 2000s, more or less in line with the fall-off in productivity. As can be seen in the chart, this drop occurred in the T class (all marketable technologies, excluding those related to home production in the TT and TX groups), in QA 75-76 (computer science titles) and in the sum of the two.

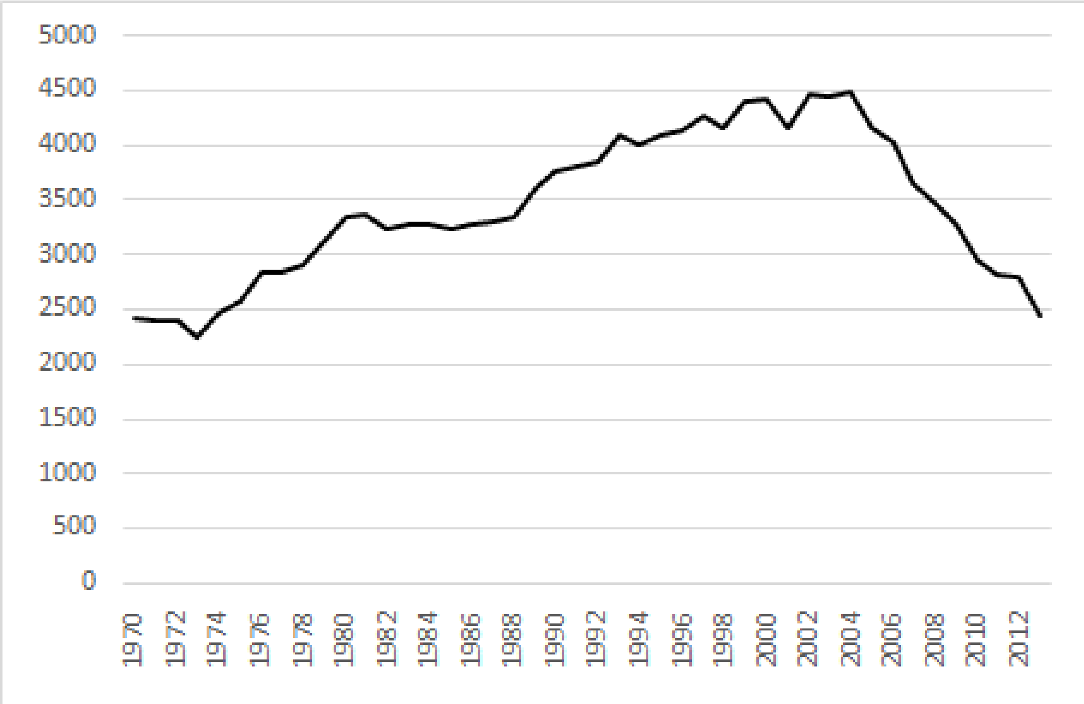
One possible concern about these findings is that the decrease represents not a fall-off in innovative activity but a general decline, for some reason, in the number of all published titles. The data, however, do not support this. On the contrary, they indicate that the number of new titles in other fields (such as literature) rose, not fell, in the early 2000s. Similarly, there is no evidence that acquisitions fell due to budget contractions at Canadian libraries. Indeed, library budgets, for the most part, were unusually robust during these years, bolstered, among other things, by a strong Canadian dollar for much of the period.[16]

Additional support for a technological slowdown comes from south of the border where the well-known decline in innovative activity in the United States (Chart 5) is matched by a drop in the number of new titles in the T class. In short then, the Canadian data, consistent with those in the United States,

15 The decision to omit the last few years of the sample removes biases associated with backlogs in cataloguing activities by libraries.

16 The US-Canadian and UK-Canadian exchange rates matter because the largest number of imported titles come from these two countries.

Chart 5: Technical Change in the United States: New Titles in LOC T CLass by Copyright Date



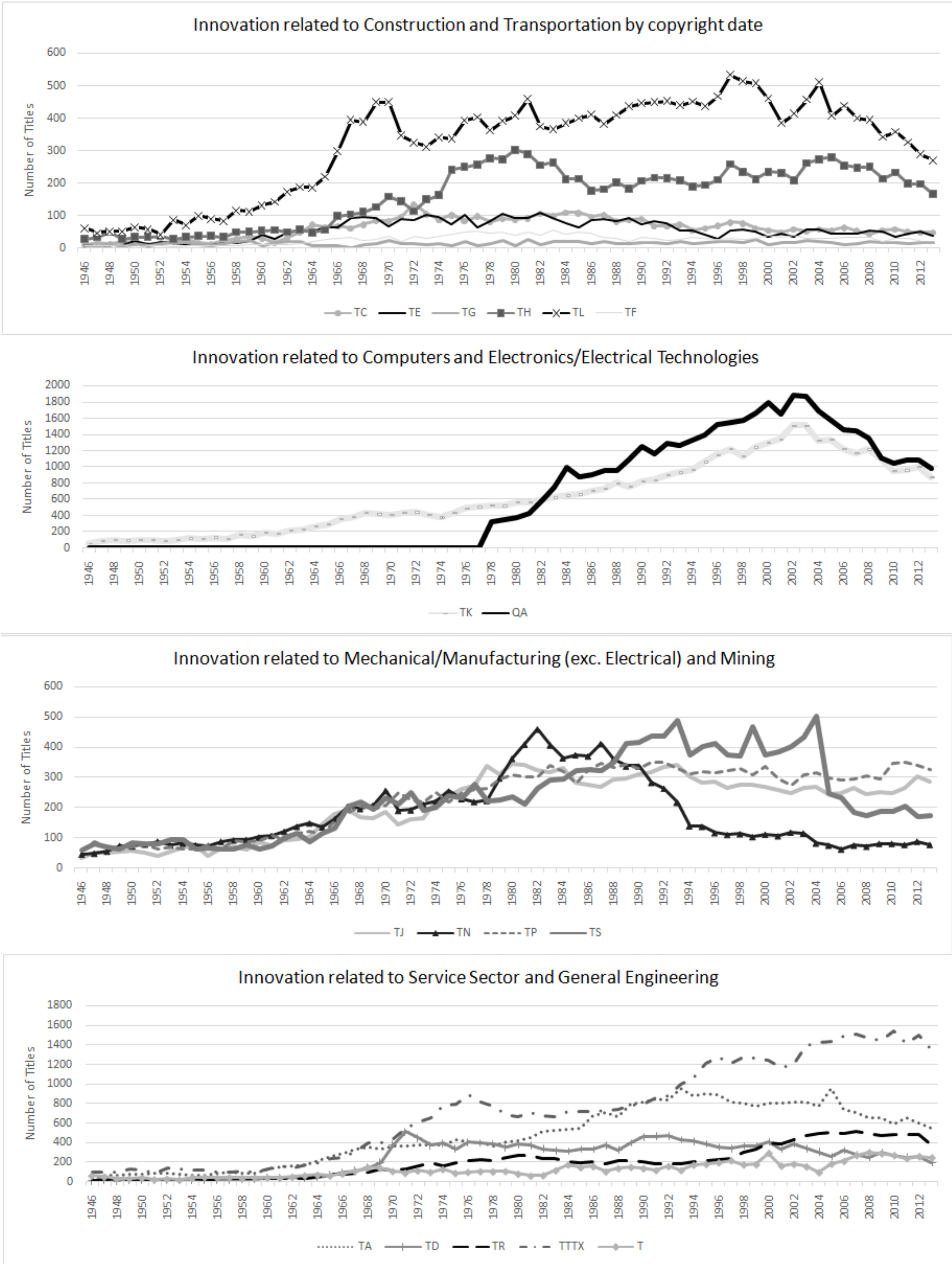
Source: Authors' calculations from OCLC Worldcat Data.

confirm that the fall-off in technical change as captured by library holdings parallels the slowdown in productivity growth.

In an effort to pinpoint the exact sectoral breakdown of these trends, we undertake a more fine-grained analysis. Chart 6 plots the number of titles by copyright date for general technology (T subclass), general engineering (TA), hydraulic and ocean engineering, including the building of dams (TC), environmental and sanitary engineering (TD), highways and roads (TE), railroads (TF), bridge engineering (TG), building construction (TH), mechanical engineering and machinery (TJ), electrical engineering and electronics (TK), transportation technologies (TL), mining and metallurgy (TN), chemical engineering and technologies (TP), photography including uses for digital cameras and medical radiology (TR), manufacturing (TS), home economics/food preparation, handicrafts, cloth manufacturing and design, and management of services such as hotels and restaurants (TTTX), and books in the QA75-77 class (QA) related to computer science.

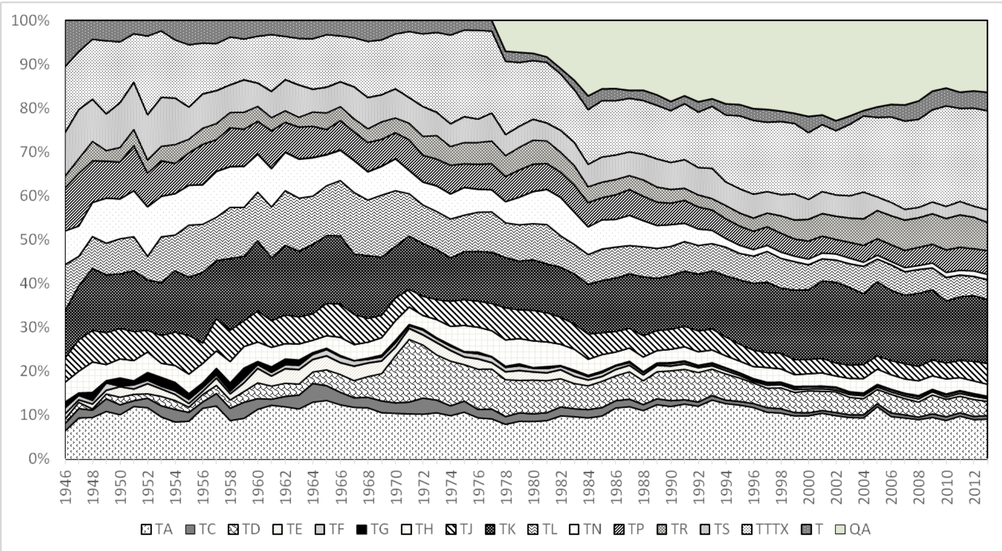
They show that the largest decreases were centered in the QA (computer science and software) and TK (electrical, including telecom, computer hardware, and computer networks). TA (general engineering) and TS (manufacturing technology) display a similar if less dramatic pattern beginning in the 1990s while technical change in mining and natural resources (TN) began its descent, again less pronounced, even earlier. Some sub-sectors, on the other

Chart 6: Waves of Innovation by Copyright Date – Breakdown of Titles in Technology Classes



Source: Authors' calculations from OCLC Worldcat Data.

Chart 7: Distribution of Waves of Innovation in Technology Classes by Copyright Date, 1946 - 2012



Source: Authors' calculations from OCLC Worldcat Data.

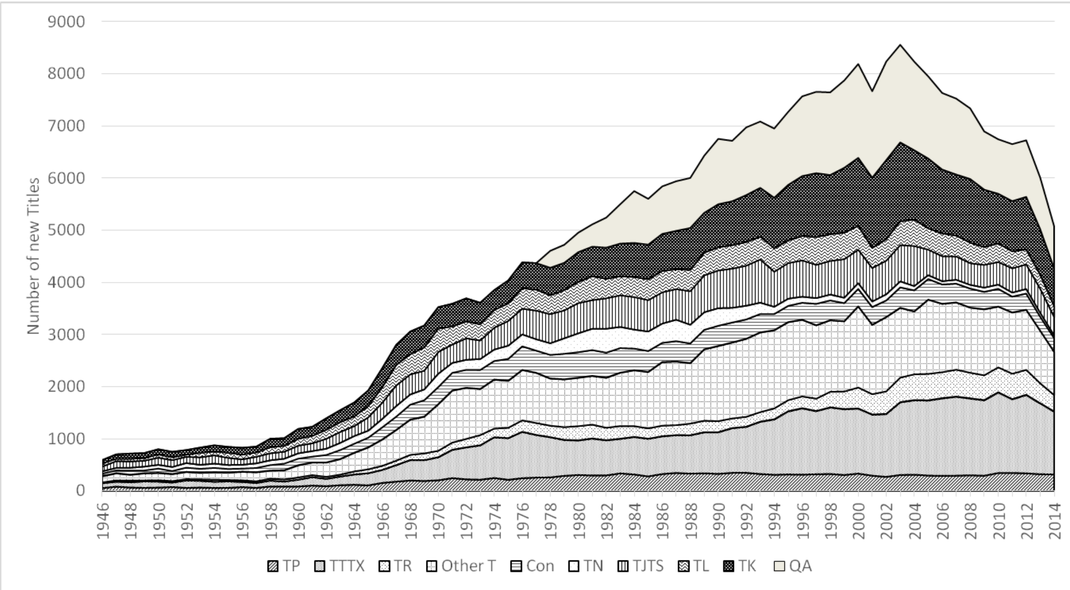
hand, as can be seen in the chart, particularly those linked to services such as TTTX (hotel and restaurants, food prep and related services) and TR (cinematography, photography, radiography) experienced modest growth post 2003. As can be seen by comparing these data with the productivity numbers presented in Chart 2, there is a striking coincidence between the divergent productivity patterns traced by MFP in the service sector and in the goods sectors and innovations in the two sectors.

An examination of the percentage distribution of titles in each of the T categories each year (i.e., the number of new titles in the technology/computer subclass in year j divided by all new titles in the technology and computer subclasses in the same year) provides additional insights into the changing significance of the various technology sub-groups in the country's technological profile. This breakdown is shown in Chart 7.

While TN (mining) was a non-trivial area of innovation in the early post-war period, it now appears to account for a relatively small share of new innovations. On the other hand, TL (automotive), which was approximately the same as mining in terms of its innovative importance in the late 1940s, has declined much less in the ensuing 60 or so years.

The largest changes in shares have been in the Information Technology (IT) related areas. Specifically, the computer class (QA) clearly rose to prominence in the 1980s and 1990s, but has lost ground recently. In contrast, TK (electrical/electronics), a main contributor to innovative activity throughout the period, has, following the introduction of personal computers and the internet, boosted slightly its share in the total. Finally, near the end of the sample period, the share of innovations related to TP (chemical technologies including some biotech innovations), TR,

Chart 8: Technical Change Over Time by Copyright Date



Source: Authors' calculations from OCLC Worldcat Data.

and TTTX are all on the rise.[17]

In an effort to synthesize the information contained in the previous area figures, we present in Chart 8 a stacked area graph. To do this we created ten groups out of the initial sixteen and ordered them from bottom to top by average growth rate post-2003. It is clear that if we focus sharply on the period after 2003 the largest decline in the number of new technological titles occurred in construction ("Con defined as TC +TE+TH+TG), mining (TN), mechanical/manufacturing ("TJTS defined as TJ +TS), transportation (TL), electrical/electronics (TK), and computers (QA). Moreover, within this larger grouping, areas linked to computer technologies and electronics were the largest contributors to the fall-off with a lesser but still not insignificant part played by transportation and manufacturing. In contrast, changes in the number of new titles in TP (chemicals), TTTX (hotel and restaurants, food prep and related services) and TR (cinematography, photography, radiography) seem to have played no role in the decline while environmental technologies, general engineering, and railroads (i.e., "Other T" defined as subclass T + TA + TD +TF) experienced at most a minor reduction in new titles. While the coincidence between the sectoral pattern of the slowdown in innovations and the drop in productivity growth would seem to suggest that the former were largely responsible for the latter, we undertake a formal statistical analysis in the next section before presenting concrete conclusions.

17 Interestingly, Gu and Lee (2013) point out that the information and culture sector's labour productivity and multi-factor productivity grew during the 2000-2010 period. This would be consistent with an increase in innovation captured by the TR class.

A Statistical Analysis of Technical Change's Contribution to the Productivity Slowdown

To determine the impact of variations in technical change on Canadian MFP, we ran a series of bivariate VARs[18] on annual data from 1961 to 2014 of the form:

$$Y_t = \alpha + \sum_{j=i}^{k} \rho_j Y_{t-j} + f(t) + \epsilon_t \qquad (1)$$

where the starting date was determined by the availability of MFP data from Statistics Canada and the end date by the availability of the book holdings data. We estimated cases with $k = 2, 3$ where $Y_t = [\ln(\text{Productivity}_t), \ln(\text{tech index}_t)]$, with and without time trends included,[19] as well as a case with both productivity and the technological indices in first differences.[20] We include more than one year of lags because, in our previous work, we found that many of the titles (and innovations) coming from south of the border begin to diffuse with a 1-3 year lag in Canada.

Technology shocks are identified using a Cholesky decomposition. Specifically, our identifying assumption, similar to the one we used in our previous work (and in keeping with Christiansen (2008) and Shea (1998)), is that a technology shock only affects MFP with a lag. Since the different specifications make very similar predictions, we focus on the cases of VARs in levels with 2 lags and a trend and VARs in first differences. Due to space constraints, we limit our discussion to areas where the effects of the technology shocks are significant.

Aggregate Technology Shocks

Overall, we find that business sector productivity (MFPagg) is Granger-caused by the aggregate technology measures (i.e., "T Class" is defined as all new T titles per year and "T class +QA75-6" are all T class and computer titles) at the 5 per cent and 10 per cent levels with no evidence of reverse causality. When we looked at the relationship between the indicators and MFP in the goods and service sectors, we found the technology measures signif-

18 A vector autoregression (VAR) is a useful time-series application to capture the linear interdependencies among economic variables. The model consists of a system of equations where a linear multivariate relationship is defined for each variable. VARs are a-theoretical as they contain little or no economic theory. They do not have any implication for causality. Thus, researchers often impose a structure or restriction (i.e. determining contemporaneous casual relationships between variables) on VARs to isolate estimates of policy or economic agents' behaviour and its effects on the system or the economy. With this assumption, economic shocks occur from different sources of uncertainty and interact with each other only through their effect on the decisions of the economic agents. Hence, it is clear how the causalities work in the economy.

19 Time trends are included in the base case to account for the rise over time in the number of unique technology titles driven by: (1) increases in potential readership as a result of population growth and a rise in general educational levels, and (2) decreases in publishing and market costs caused by technological advances in the publishing.

20 In the Appendix we run two alternative sets of regressions, one where we substitute labour productivity for MFP the other where we replace ln(tech index) with ln(stock of technology titles). The results illustrate that the main findings reported in the paper are robust to these sensitivity checks. The Appendix is posted at http://www.csls.ca/ipm/35/Alexopoulos_Cohen_Appendix.pdf.

icantly Granger-caused MFP in goods but not MFP in services, again indicating that the slowdown in innovation appears to have had its greatest effect on manufacturing, mining and construction.

The impulse response functions confirm that positive technology shocks during this period increased both aggregate and goods sector productivity significantly over the 10-15 years following the shock with the peak impact occurring after 5 years.[21] In contrast, there was no significant impact on service sector MFP. As the responses displayed in Chart 9 (along with 90 per cent confidence bands)[22] show, while the effects of the shocks are long lasting, the results become significant only after a few years, in keeping with the conventional wisdom that Canada adopts U.S. innovations with a lag.

Table 2 displays the associated variance decompositions for the cases of VAR in levels and VARs in growth rates for both business sector MFP and MFP for the goods sector. The results for the aggregate and goods sectors suggest that technology shocks account for a significant fraction of the fluctuations in Canadian MFP (and its growth rates). The fraction of the variation goes up modestly over time, similar to magnitudes seen for the United States.[23]

Disaggregated Technology Shocks

As innovations are likely to vary in terms of their impact on productivity, it is useful to break down technical change into a number of sub-categories to determine with greater precision the technology-productivity link for Canada. To do this, we examine separately the effects of technology shocks associated with manufacturing/mechanical (i.e., TJ+TS), Chemical (TP), transportation (TL), mining (TN), construction (TC+TE+TH+TG), and electrical (TK) in a series of bivariate VARs. We find that only the first of these Granger-cause business sector MFP at the 5 per cent level while all the other do so at the 10 per cent level. None of the other shocks were significant at conventional levels. For the goods sector, we find that electrical (TK) and mechanical/manufacturing technologies (TJTS) Granger-cause goods sector MFP at just under a 1 per cent level. None of the technology indicators consistently Granger-cause service sector MFP at conventional levels of significance.

In Panel B of Chart 10 we present cases where we find significant responses to the various technology shocks. Overall, the trajectories are similar to those seen for aggregate technology. In most cases, peak impact occurs 4-5 years following the shock with a limited initial impact. The one exception is mechani-

21 In what follows, only significant responses to shocks are displayed in the charts.

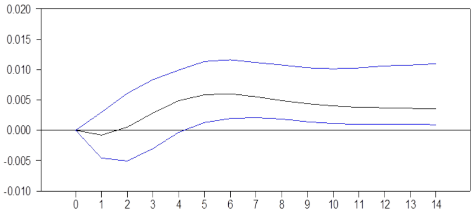
22 All confidence bands are computed using a Monte Carlo procedure.

23 See Alexopoulos and Cohen (2018) and Alexopoulos (2011) for US values.

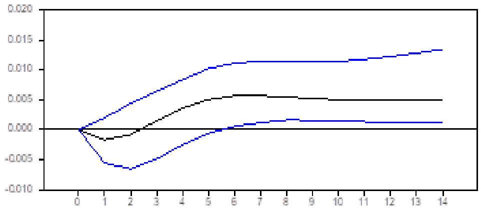
Chart 9: Responses of Canadian MFP to a Positive One-Standard Deviation Aggregate Technology Shocks.

Panel A. Business Sector MFP responses (VARs in levels)

T Class

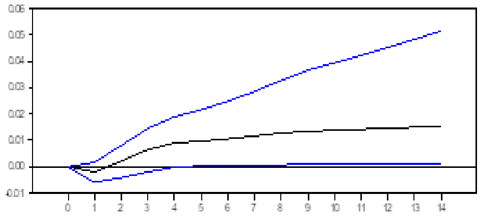


T Class + QA75-6

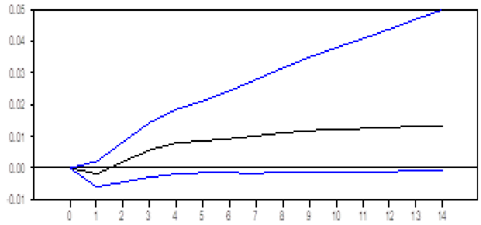


Panel B. Implied Business Sector MFP responses (VARs in first differences)

T Class

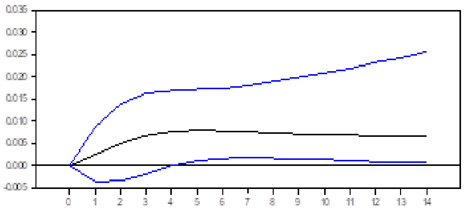


T Class + QA75-6

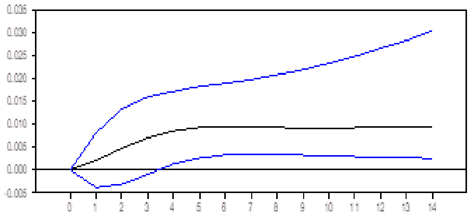


Panel C. Goods sector MFP responses (VARs in levels)

T Class

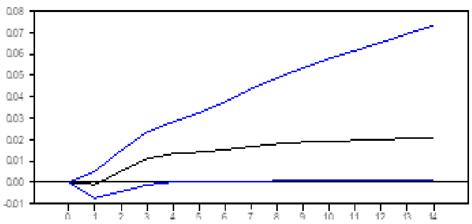


T Class + QA75-6

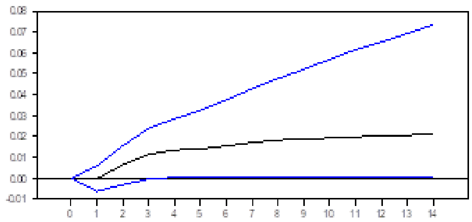


Panel D. Implied Goods sector MFP responses (VARs in first differences)

T Class

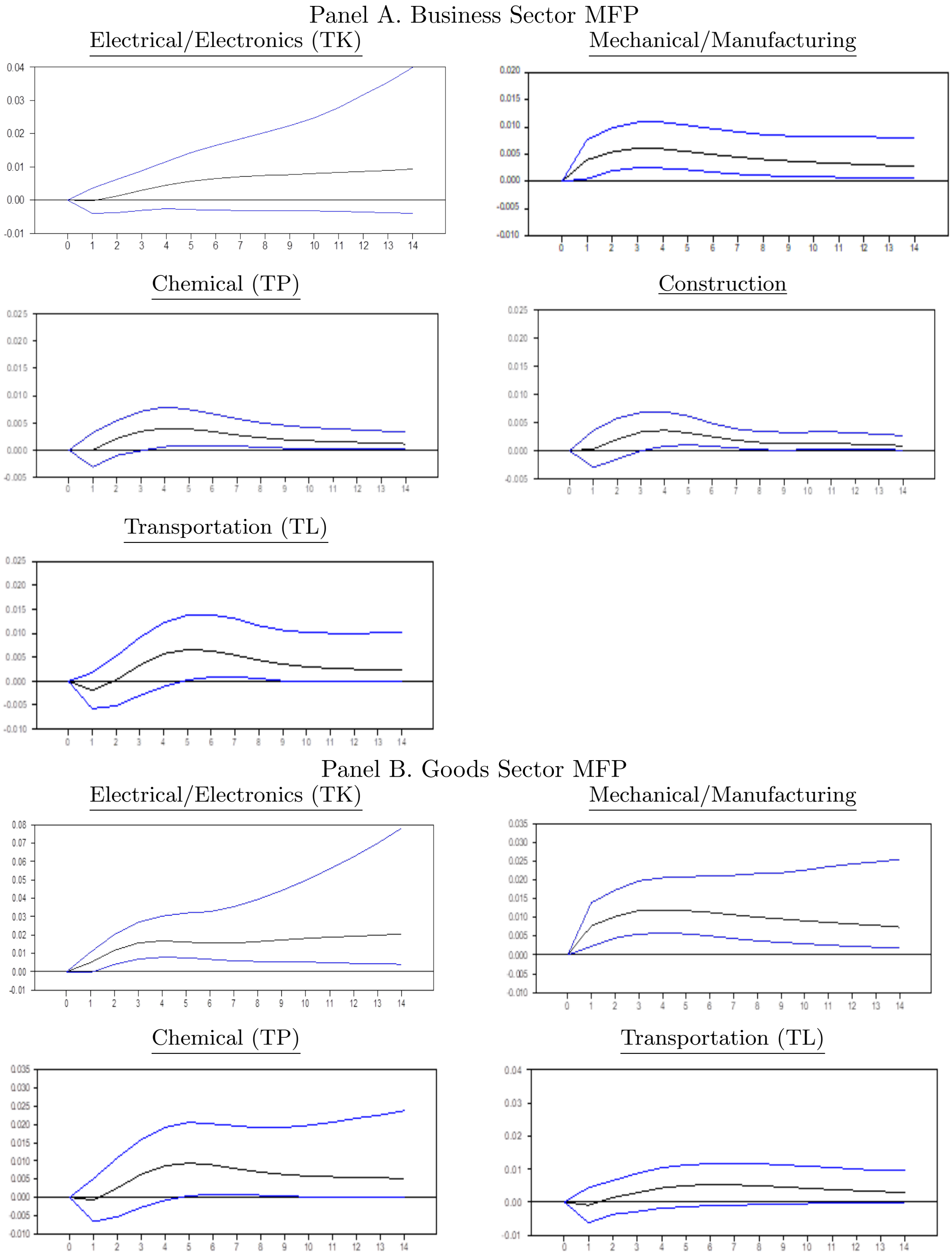


T Class + QA75-6



Note: The responses measure percentage deviations of MFP in response to positive one standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags. Our indicators are ordered last and shocks are identified using a Cholesky decomposition. Implied MFP responses are the *cumulated* growth responses from the VAR in estimated with differences.

Chart 10: Selected Responses of Business Sector MFP, and Goods Sector MFP to Positive One Standard Deviation Technology Shocks



Note: The responses are percentage deviations of MFP in response to positive one standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags and a trend. Indicators are ordered last and shocks are identified using a Cholesky decomposition.

Table 2: Variance Decompositions of VARs for Business Sector and Goods Sector MFP Levels and Growth Rates

Horizon (years)	Level (ln) MFPagg	Level (ln) MFPgoods	Growth MFPagg	Growth MFPgoods
	T class technologies			
3	1.5	2.2	9.8	8.2
	(0.1, 11.2)	(0.1, 14.2)	(2.3, 23.9)	(1.2, 21.4)
6	13.8	9.0	18.1	13.6
	(2.1, 37.4)	(0.6, 32.9)	(4.4, 38.8)	(2.1, 32.6)
9	25.2	14.6	19.5	14.5
	(5.1, 52.7)	(1.3, 41.5)	(4.6, 42.1)	(2.1, 37.4)
12	29.4	17.6	20.1	14.8
	(7.1, 61.5)	(1.8, 47.7)	(4.7, 44.8)	(2.1, 40.3)
	T class and QA75-77 technologies			
3	1.7	2.2	8.4	7.9
	(0.1, 12.2)	(0.1, 13.4)	(1.6, 21.6)	(1.0, 21.6)
6	10.4	12.3	14.7	12.2
	(1.7, 30.2)	(1.2, 36.6)	(2.7, 34.9)	(1.6, 30.9)
9	22.1	21.5	15.8	13.3
	(4.2, 49.5)	(2.6, 50.3)	(2.8, 39.0)	(1.6, 36.5)
12	29.4	26.8	16.2	13.6
	(6.1, 60.9)	(3.9, 59.1)	(2.8, 41.6)	(1.7, 38.8)

Note: Numbers in brackets represent the 90% confidence bands.

cal/manufacturing, where both MFP in the business sector and in the goods sector increase significantly within the first few years.

To summarize briefly, it appears that innovations influencing manufacturing/mechanical (TJTS) technologies, and the electrical/electronic (TK) technologies play among the largest roles in explaining the variance in productivity.[24] By the 6-year horizon, approximately 21 per cent of the variation in business sector MFP was attributable to the TJTS innovations, with the share growing to over 30 per cent. When examining the case of electrical technologies, the estimated share at the 6-year horizon was about 10 per cent rising to over 35 per cent by year 12. The effects of the transportation technologies (TL) also appear to be in the 15-25 per cent range for the 6-12 year horizon. In contrast, construction (Con) and chemical technologies (TP) account for only about 10 per cent.

We obtain similar results for the relationships with MFP in the goods sector. In these cases, variations attributable to TJTS and TK were about 11 per cent by the 3 year horizon with the shares growing to 41 per cent and 51 per cent respectively by year 12. The fluctuation in goods sector MFP linked to chemical and transportation technologies remain in the range of 8 per cent-15 per cent. For the service sector MFP, TK (electrical, including networks, and telecommunications technologies) and TR (photographic/digital linked to areas such as advertising, medical services, arts and entertainment sectors, surveying services etc.) are, not surprisingly, the

24 The reported results are from the bivariate regressions. To the extent that the disaggregated series capture common underlying technological changes, it is important to note that these shocks will pick up some of the same variation in MFP.

largest contributors to fluctuations in productivity. However, the results are generally found to be insignificant at standard levels.

Predicting the future path of technical change in Canada (as elsewhere) is extremely difficult. However, given that many of our new technologies come from our southern neighbor, it is possible to glean some information about the probable course of new innovations by looking at current advances in the United States in conjunction with other available evidence. We present some of this below, and, for the most part, it would appear to support the notion that there is a quickening pace of innovative activity there, and, given the revolutionary nature of many of the new technologies, *if* Canadian firms embrace them, the future path for productivity here looks promising.

Is the Productivity Slowdown Over?

Evidence to support our optimism comes from, among other sources, technical titles distributed by Amazon. We make use of Amazon data to examine the most recent trends because cataloguing backlogs at libraries render numbers incomplete and thus severely bias downwards results.[25]

Because Amazon is in the business of selling books, it makes every effort to keep its listings up to date. For this reason, Amazon turns out to be a remarkably valuable source of information on the latest book titles.

This said, there are a number of features of the Amazon data that should be noted. First, because Amazon titles contain significantly less metadata on each book than do library catalogues, our ability to allocate the titles to the Library of Congress classifications is constrained. Second, Amazon data include more e-book and titles published by authors or conference organizers than do the catalogues of most libraries. Third, while library holdings, by definition, represent books that *have been* purchased, those listed on Amazon represent books that *can be* (but may not have been) purchased.

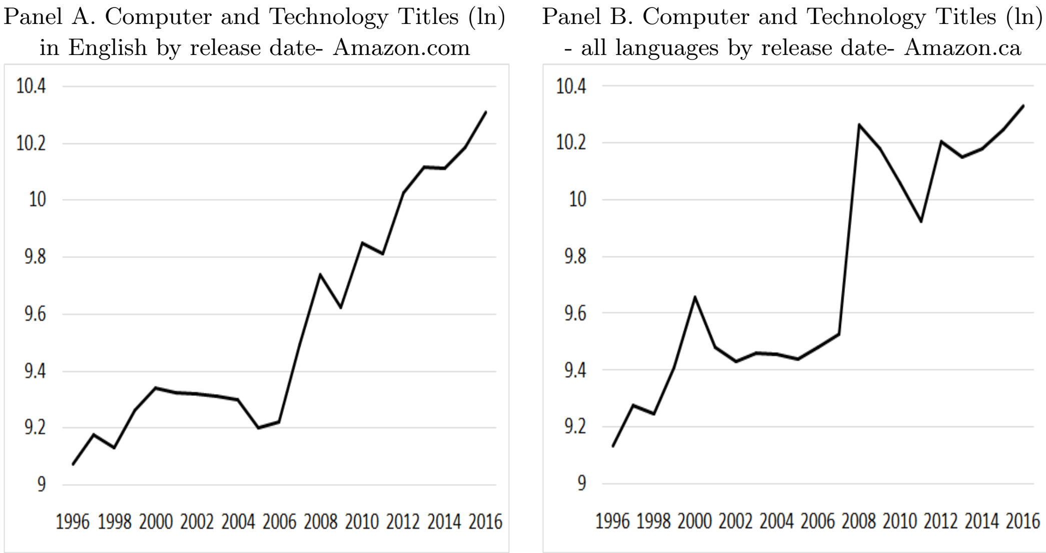
While the first factor limits our ability to use Amazon data for fine grained sectoral analyses and hinders direct comparisons with the holdings-based indices, the two other factors work to extend the time between when increases in the number of technology titles on Amazon are seen and the impact on productivity but does not compromise the value of the indicator.[26]

Chart 11 displays the data from Amazon's websites in Canada and the United States. First, we see that the number of US English language computer and

25 It is useful to note that our previous work would suggest that once backlogs are cleared, there is a high correlation between the Amazon.com data and titles listed in the Library of Congress' catalogue.

26 Items more akin to journal publications have previously shown longer lags since they tend to capture advances earlier on in the development process. Moreover, the appearance of a listing does not guarantee sales of the title in much the same way that filing a patent application offers no guarantee that technology will be commercialized.

Chart 11: Book Titles for Amazon



Source: Panel A is based on the authors calculations from data on Amazon.com on English language titles. Panel B is based on the authors calculations from book listings (all languages) on the Canadian site Amazon.ca.

technology titles listed on Amazon.com, after roughly flat-lining for a decade following 1996, began to grow rapidly again after 2005 (Panel A of Chart 11). Second, as can be seen in Panel B, computer and technology titles in all languages for sale on Amazon.ca trace a similar pattern, with recovery starting in 2007-08. In short, there is reason to be optimistic.[27]

To uncover the sources of the increase, we look at the break-down in the number of Computer and Technology titles by sub-class. In Panel A of Chart 12, the major categories are represented in the form of word clouds, where font size varies directly with the frequency of titles in each of the categories. In Panel B, change over the five-year period in the relative importance of the top 25 subcategories is presented. Together, these charts indicate that the growth in new titles has occurred mostly in areas related to artificial intelligence, computer security, cloud computing, big data and CAD (related to advanced manufacturing). In particular, 47 per cent of the recent computer science titles are linked to AI and 42 per cent of these relate to robotics.

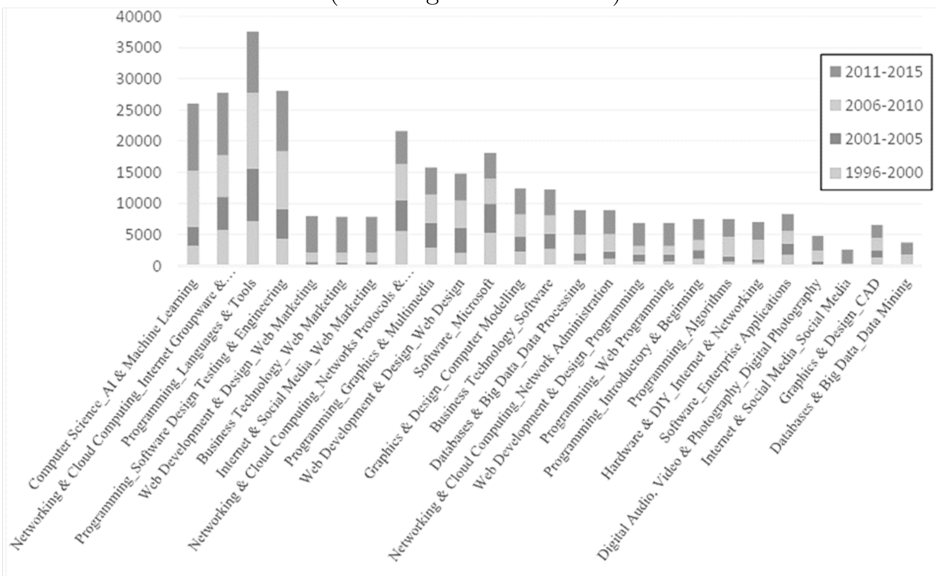
Chart 13 provides additional evidence of a dramatic innovative upswing in these areas. Patents granted by the United States Patent and Trademark Office (USPTO), reported in Panel A, show a jump in both robots and AI. Panel B reveals that the number of newspaper articles published on robots and AI in both America and Canada has soared over the last five or so years while, in Panel C, it can be seen that the number Canadian media articles on AI re-

27 Some of the increase is due to the availability of self-published and e-titles. However, even without these, there is a noticeable increase in the most recent years.

Chart 12: Top Technology Subgroups in Amazon Data

Panel A) Word Cloud of Top 10 Technology Subgroups in Last 5 Years

Panel B) Evolution of 5 Year Totals for Top 25 Subgroups for the 2010-15 Period (ranked greatest to least)



Source: Authors' calculations from Amazon.com.

lated employment issues jumped sharply after 2014. Overall, these data would seem to indicate a marked renewal of innovative activity in both the United States and Canada, with the promise that a vast new array of products and processes is likely to hit the market in the near future.

Will these advances reinvigorate productivity growth in Canada? The answer depends largely on how quickly and deeply they spread across the economy. The recent rebound in U.S. productivity growth (Table 1), may be at least partly attributable to gains associated with the adoption of the new technology. The evidence for Canada is, at present, mixed. On the one hand, Canada lags countries such as Japan, Germany and the United States (Chart 14) in the adoption of robots.[28]

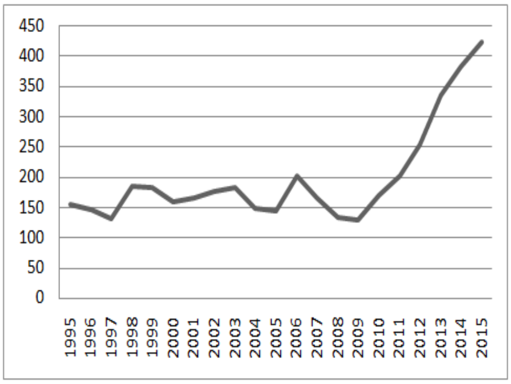
Moreover, while there is some willing-

28 A new survey from Accenture, Intel, Forbes Insight and SAS conducted in the summer of 2018 finds that while Canadian businesses are adopting AI, they lag behind many countries, including the United States, in terms of adoption and full deployment rates. See https://www.accenture.com/ca-en/company-news-release-artificial-intelligence-finds-study.

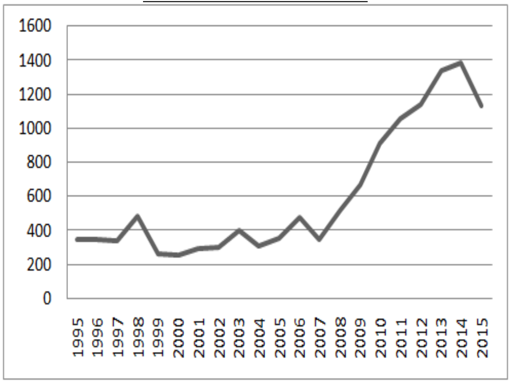
Chart 13: Indicators of Technical Change

Panel A. Patents Granted by the US Patent and Trademark Office

Robots

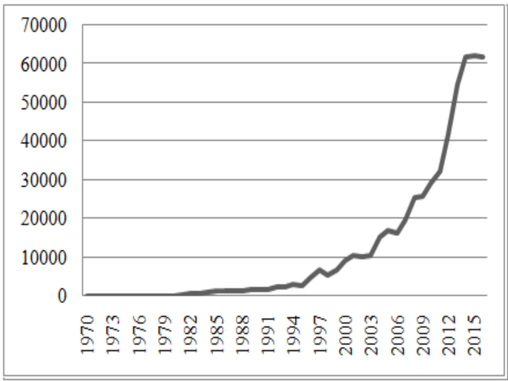


Artificial Intelligence

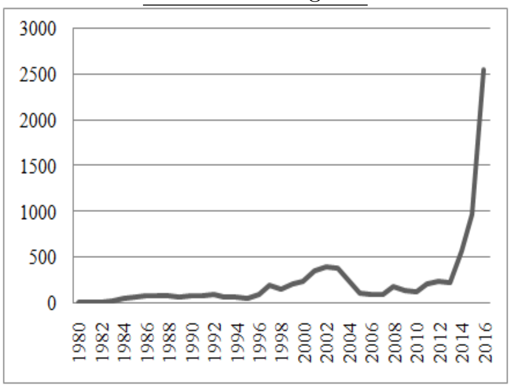


Panel B. Factiva Articles

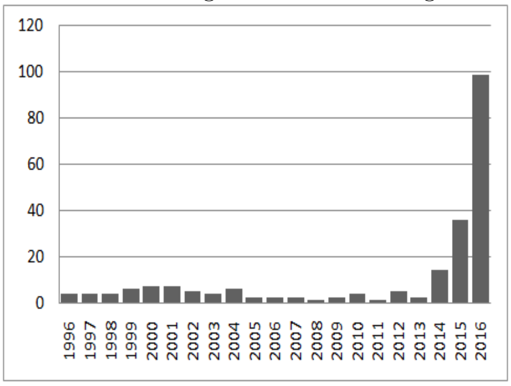
Robots



Artificial Intelligence

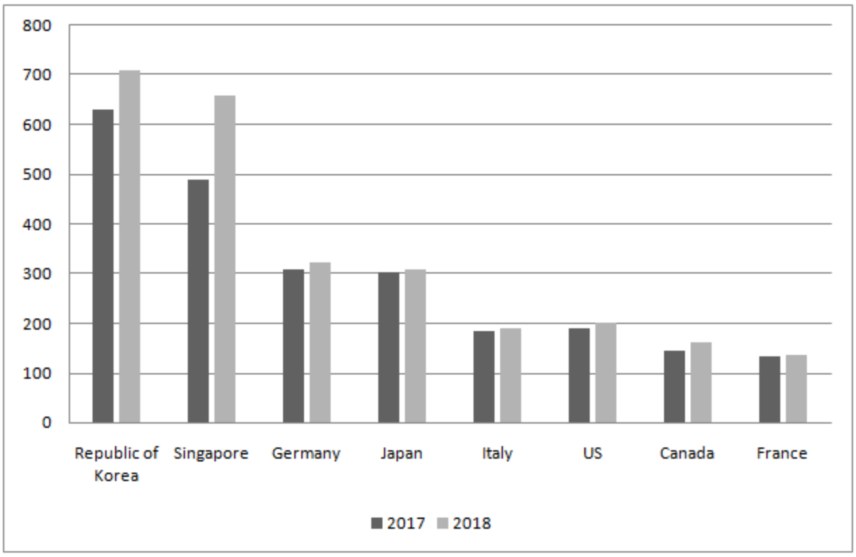


Panel C. Canadian Media Coverage of AI Mentioning Labour Market Issues



Source: Panel A is from the U.S. Patent and Trademark office. The patent counts by classes are based on original and cross-referenced classification with duplicate patents eliminated with classes. Panel B is based on authors calculations of the number of articles in the Factiva database on Robots and Artificial Intelligence. Panel C is based on authors calculation on the number of articles from Canadian sources in Factiva that are related to AI and the labour market.

Chart 14: Number of Installed Industrial Robots per 10,000 Employees in Manufacturing in Selected Countries, 2017 and 2018



Source: World Robotics, 2017.

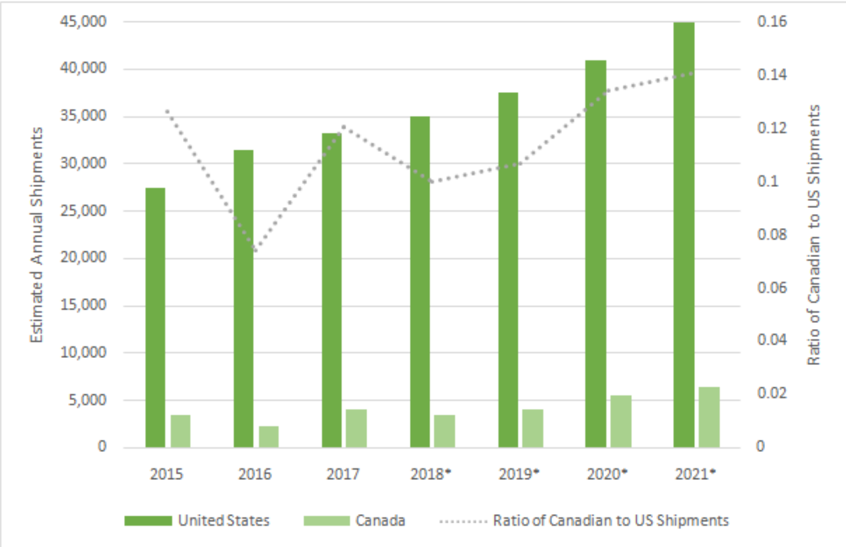
ness in Canada to invest in robotic technology (Chart 15) and AI, a large gap still exists between the pace of adoption in the United States and Canada.

On the other hand, if adopted, the productivity (and profit) payoff to "robotization is substantial. It has been estimated, for example, that the labour productivity gains in 1993-2007 associated with the adoption of industrial robots exceeds that attributable to the use in the United States of the steam engine between 1850 and 1910 (Crafts, 2004; Graetz and Michaels, 2015).

Our results support these findings since both AI and robotics are tied to innovations in electrical engineering and electronics and mechanical/manufacturing – the main drivers of MFP in the 1961-2014 period. Moreover, an analysis of the industry tags associated with articles from Factiva related to Artificial Intelligence and Canada suggests that many industries will benefit from advances in these areas. This is illustrated in the word cloud reported in Chart 16, where once again the size of the font indicates the relative frequency of mention of particular industries in the relevant articles. Major players, not surprisingly, include computers and electronics, telecommunications, machinery, pharmaceuticals, retail, finance, agriculture and biotechnology.[29] In short, then, while Canada currently lags its international competitors in the adoption of these new advances, the pay-off to catching up is large and there is at least some evidence to suggest Canadian entrepreneurs and firms

29 See Alexopoulos and Cohen (2018) for additional evidence on the potential for the use and spread of AI and robotics in the United States, and a comparison of these technologies to major GPT technologies in the past. See, also, Eichengreen (2015) for a discussion of the importance adaptability and adoption in determining the impact of new technologies.

Chart 15: Shipments of Multipurpose Industrial Robots



Source: Statistics are from the 2017 IFR World Report, where * represents the IFR's estimates of shipments.

are beginning to seize the opportunity.

Summary and Conclusion

Our results indicate, first, that there was a slowdown in productivity growth in Canada in the first decade or so of the 21th century, very similar to the one observed in the United States. Second, our VAR analysis reveals that technology shocks both in aggregate and in the areas of manufacturing/mechanical and electrical played an important role in driving the fall-off in productivity growth. We also find that the decline in productivity growth was more sector specific in Canada than is usually realized with the drop most marked among goods producers and least in services. As it happens, these results were echoed in the technical change numbers where the poorest performers were linked to mining and manufacturing.

The concern among a number of prominent economists is that this recent slowdown is just the start of a long period of secular stagnation, powered at least in part by lackluster technological advances. We would maintain that this preoccupation is unjustified. We have seen productivity slowdowns and speed-ups in the past – our previous work indicates that technical change comes in waves of lesser and greater intensity which suggests that this time is probably not different. As confirmation of this, we note that there are tentative signs, especially, but not only, in the United States, that a technological rebound is already underway. (The last row in Chart 2 provides compelling support for this observation.) Based on our textual analysis and confirmed by Linked-In, Factiva and other sources, the major new areas include, among others, AI, and robotics. As we report in the final section of the article, the recent turnaround in innovative activity in the United States bodes well for the future of productivity and economic growth there. Can the same be said for Canada? Given the usual

Chart 16: Factiva Industry Tags Associated with AI in Canada

Source: Authors calculation based on volumes of industry tags associated with AI articles in Canadian sources on Factiva.

adoption lags that typify the uptake of new technologies in Canada, it is difficult to be sure that we will take advantage of the new opportunities presented by these advances but we can, with confidence, make two observations. First, the new technologies are (almost) as accessible in Canada as they are in the United States and, second, there is no reason to believe that this time is different. That is, while we tend to adopt with a lag, we do, on the whole, seize the day. If we are correct, then the issues that Canadian policy makers will have to confront in the near future are not those associated with stagnation but, quite the contrary, are the ones, such employment opportunities, training requirements, and income distribution that the new disruptive technologies are likely to present.

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