# The Effects of Computer Technologies on the Canadian Economy: Evidence from New Direct Measures

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ABSTRACT

New indicators of technical change in the field of computers based on new titles held by Canadian libraries are presented, and are used to demonstrate that a positive computer technology shock in Canada increases hours worked, output, and productivity in the short run. These measures indicate, first, that advances in the implementation of computer technology in Canada are largely influenced by innovations in the United States; and second, when compared to a United States-based indicator, that a gap emerged between United States and Canadian-held titles around the time that the productivity gap emerged between the two countries. Given that a strong, causal relationship is found to exist between the new indicators and total factor productivity, this evidence provides additional support for the hypothesis that crosss-border differences in the development and use of new computer technologies play a key role in explaining Canada's productivity gap with the United States.

RÉSUMÉ

De nouveaux indicateurs du changement technique dans le domaine de l'informatique, basés sur les nouveaux titres des bibliothèques canadiennes, sont présentés et montrent qu'un choc technologique positif dans le domaine de l'informatique au Canada accroît à court terme le nombre d'heures travaillées, les résultats et la productivité. Ces mesures indiquent, premièrement, que les progrès de l'application de la technologie informatique au Canada sont en grande partie influencés par les innovations aux États-Unis et, deuxièmement, que lorsqu'elles sont comparées à un indicateur américaine, un écart apparaît entre les titres dans les bibliothèques canadiennes et américaines à peu près au moment où l'écart entre la productivité des deux pays se fait jour. Compte tenu de l'existence d'une forte relation de cause à effet entre les nouveaux indicateurs et la productivité totale des facteurs, ces observations renforcent l'hypothèse selon laquelle les différences entre le développement et l'utilisation des nouvelles technologies informatiques dans les deux pays jouent un rôle essentiel pour expliquer l'écart de productivité du Canada.

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COMPUTER TECHNOLOGIES ARE OFTEN viewed as a key contributor to productivity growth in advanced industrial countries such as the United States and Canada.[2] It follows that cross-country differences in the development and use of these technologies may at least partially account for cross-country productivity differentials. This is particularly relevant for Canada and the United States because it is frequently argued that the growth in the productivity gap between these two countries is attributable to the more rapid adoption of information technologies in the latter than in former.[3] As compelling as this argument may appear, the lack of direct measures of technical change in this area has made it difficult to provide a quantitative assessment of either the impact of computers on economic activity in the two countries or the causal link between differences in their adoption rates and productivity differentials. In short, if we want to quantify the impact on these economies of innovations in this area, we must be able to measure them.

As it happens, that is precisely what we propose to do in this article. We first present new direct measures of technological change in the field of computers in Canada for the 1950-2005 period, based on the number of new computer-related titles held by Canadian libraries[4] and then use them to show that: (1) the United States is the principal source of advances in computer technology in Canada; (2) the rate of adoption of new computer technologies in the United States began to surpass that of Canada in the 1970s; and (3) a strong relationship exists between computer innovations and productivity, GDP, and hours worked.[5] Together, these findings provide empirical support for the hypothesis that cross-border differences in the commercialization and rate of adoption of new computer technologies have played a key role in the widening of the Canada-U.S. productivity gap.

The article is divided into four sections. The first section discusses the indicators and their properties. Section two reports the results of our regressions. Section three discusses the potential link to the Canadian and U.S. productivity gap. The fourth and final section concludes.

## The Indicators

Most would agree that a good direct measure of technical change should, at a minimum: (1) be available at least on an annual basis over a long time horizon; (2) be objectively determined; (3) weight different technologies according to their importance; and (4) tap into the full range of new advances. Moreover, for many purposes we would add a fifth requirement – that the indicator capture innovations at the moment of their commercialization. This is important for two reasons. First, much of the impact on output, productivity and employment occurs through the adoption of new technologies. Second, unanticipated technology shocks, an important feature of many economic models, are generally identified not by the timing of the invention or even the patenting of a new technique but by its use.

Our new book-based indicators possess all of these features. They are: (1) objective because they are determined by cataloguing criteria established and followed consistently by librarians; (2) quantifiable because they are based on the number of new titles; (3) weighted because

2 See, for example, Alexopoulos (2011), Alexopoulos and Cohen (2011), Oliner *et al.* (2007), Khan and Santos (2002), Stiroh (2002), Van Ark *et al.* (2003), and Sharpe (2006), and the citations within.

3 See Basu *et al.* (2003) for an interesting study of differences in productivity growth between the United States and the United Kingdom and the relationship to IT technologies.

4 The approach, developed by Alexopoulos (2011), was applied initially to the United States.

5 In what follows we use the terms book-based and publication-based interchangeably. The indicators are primarily based on new manuscripts. However, pamphlets that are catalogued are included. Serial publications and continuing resources are, by and large, excluded from the counts.

more titles are published on important advances than on lesser ones; and (4) broad-based because new titles appear on all innovations of any significance.[6] Finally, new publications, for good economic reasons, are timed to coincide with the commercialization of new products or processes. The innovating companies want to spread the word about their new devices – what they are, how to use and maintain them, – while publishers and their writers want to profit from the market demand for information about these new technologies. In all cases timing is critical – too early and there is no market, too late, and the market is fully served. Although there are clearly other means aside from print to convey information about new technologies, our findings (Alexopoulos (2011) and Alexopoulos and Cohen (2009, 2011)) suggest that these book-based indicators provide a compelling way to quantify technical change and to evaluate its impact on the economy.[7]

### Description of the Indicators

Although we focused in our previous work on the United States, it is possible to use a similar methodology (developed in Alexopoulos (2011)) to create comparable technology indicators for Canada. This is because Canadian libraries also use **MA**chine **R**eadable **C**ataloging (MARC) records to run their online catalogues.[8] As is well-known, computer-related innovations in Canada are an amalgam of home-grown and imported advances, much more so than, for example, in the United States. Moreover, Canada does not have a library of the size and scope of the Library of Congress in the United States. For these reasons, we reshaped our approach to ensure that we capture the full range of foreign and domestic developed computer technologies commercialized in Canada. In particular, we used information from the catalogues of 1,062 Canadian libraries covered in the WorldCat database of the Online Computer Library Centre (OCLC) on the number of new computer titles published between 1950 and 2005, without regard for country of publication.[9] While not all Canadian libraries are members of OCLC, the membership includes the National Library of Canada, the country's largest public libraries (e.g. those in Toronto, Montreal and Vancouver), and all major university libraries. As such, the combined MARC records of the member libraries provide a comprehensive list of all major new computer-related titles available to the Canadian public.

Even though the MARC records were designed to serve the online cataloguing needs of librarians, it turns out , because of the large amounts of data buried in them, that they are also a potentially powerful research device for, among others, economists. For example, each MARC record contains information on the type of book (for example, a new title, a new edition of an existing one, a reprint, or a translation), the country and language of the publication, the publisher, the Library of Congress and/or the Dewey Decimal Classification Code, and a list of major subjects treated in the book. These data enable us to com-

6 Alexopoulos (2011), and Alexopoulos and Cohen (2009, 2011) also present evidence that the book publication measures are related to traditional measures of technical change such as R&D, patents, major innovations, and journal article counts in the United States.

7 Although some may be concerned that changes in the number of titles is driven by ups and downs in the publishing industry, our findings in the papers cited indicate that the patterns, on the whole, appear to be dictated by changes in innovations. Finally, although cataloguing and keyword assignment are potentially subject to error, there is no reason to believe that misclassification is a problem.

8 See Appendix A for an example of a MARC record.

9 The data used for this research were based on a snapshot of the OCLC's WorldCat database as of the middle of 2010. We took 2005 as our cut-off date to avoid any biases created by the backlog of uncatalogued titles.

**Chart 1**
**Indicators of Computer-Related Titles by Copyright Date**

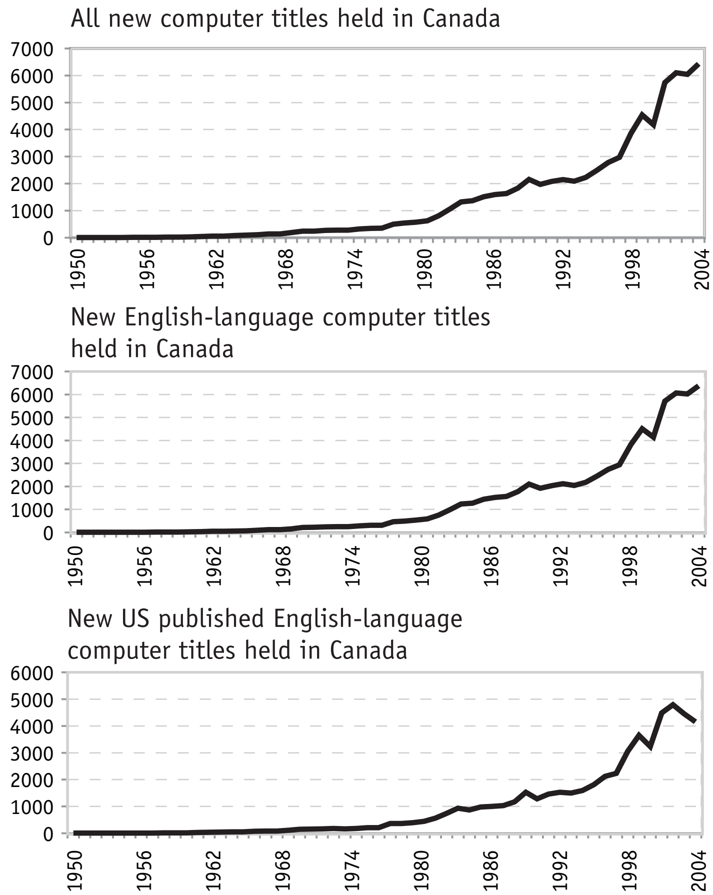
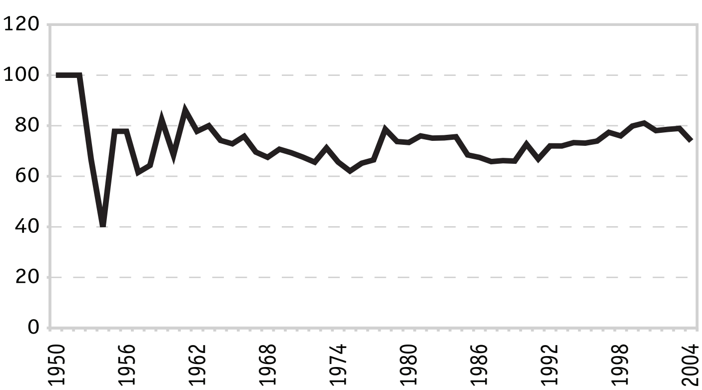



**Chart 2**
**Fraction of English-Language Held Computer Books in Canada Published in the United States (per cent)**




pile a list of new titles published each year on computers and computer science that are held by Canadian libraries in the sample between 1950 and 2005.[10] To ensure that our titles actually represent the appearance of new technologies, we eliminate from the sample all books that include history as a descriptor since they, almost by definition, focus on the past not the present. Thanks to the richness of the MARC records, we are able to create, as can be seen in Chart 1, three slightly different indicators for the purposes of this analysis: the first includes all books held in the field by the Canadian libraries regardless of the language or country of publication; the second excludes non-English language titles; while the third is limited to English language titles published in the United States.

In all cases, the indicator includes manuals and books that deal with new computer technologies that describe their nature and function, how they work, and how to use or repair them. Some of the titles are published or sponsored by the innovator or the company that developed it, while others are written by third parties who hope to profit from sales of the book. As noted earlier, all groups have an economic incentive to ensure that the publications appear as close as possible to the commercialization date of the new technologies. At the same time, libraries, seeking to serve their market, will then purchase the books they believe will be demanded and used by their patrons. For this reason we would expect to observe a close chronological coincidence between the copyright date of the first book on a new technology that appears in a library (as captured by the WorldCat database) and its commercialization date as reported in other source material. The results in Table 1, based on the dates for a sample of computer innovations commercialized in Canada and the United States, confirms this timing.

10 See Appendix B for a description of the Dewey Decimal Classifications and Library of Congress Classifications associated with the computer and computer science classifications included in the counts.

**Table 1**
**Comparison of Dates for Selected Computer Innovations**

| Innovation | Date of innovation | Country of Invention | Commercialization Date in the United States | First American Book Date | Commercialization Date in Canada | First Canadian Book Date |
|---|---|---|---|---|---|---|
| Windows | Nov. 1983 | US | Nov. 1985 | 1985 | Nov 1985[1] | 1986 |
| Lotus | Nov. 1982 | US | Jan. 1983 | 1983 | Feb 1983[2] | 1983 |
| Apple II+ | 1978 | US | June 1979 | 1979 | 1979[3] | 1979 |
| Macintosh | Jan. 1984 | US | First Quarter 1984 | 1983 | Jan 1984[4] | 1984 |
| Lisa | 1978 | US | Jan. 1983 | 1983 | April 1983[5] | 1984 |
| IBM PC | July 1980 | US | Aug. 1981 | 1982[6] | Aug 1981[7] | 1982 |
| IBM PC/AT | Aug. 1984 | US | Fall 1984 | 1985[8] | Fall 1984[9] | 1985 |
| Commodore 64 | Jan. 1982 | US | Nov. 1982 | 1982 | Sept 1982[10] | 1982 |
| PAT (OpenText)[11] | 1989 | Canada | 1992 | 1993 | by 1991 | 1992 |
| Corel Draw[12] | 1987-1989 | Canada | 1989 | 1988 | Jan 1989 | 1988 |
| Sinclair ZX80[13] | 1980 | UK | Fall 1980 | 1981 | Late 1980 | 1980 |

1. http://www.guidebookgallery.org/ads/magazines/windows/win10-powerwindows-8
2. Michael Kieran, "Programs for micros enter new generation," *The Globe and Mail*, pp. R.12-R.12, Feb 28, 1983
3. See comment on http://www.facebook.com/torontostar/posts/227813607276004 by J. Lyng, a resident of Toronto, and blog post on http://taoofnews.com/2011/01/25/thirty-years-in-new-media/
4. Jonathan Chevreau, "Xerox Canada will carry Lisa, Macintosh machines," *The Globe and Mail*, B.14, May 11, 1984
5. Michael Kieran, "Programs for micros enter new generation," *The Globe and Mail*, pp. R.12-R.12, Feb 28, 1983
6. WorldCat points to a scanned book captured by Google that is entitled Technical specifications under the series: IBM Personal Computer. Hardware reference library published by IBM.
7. Jonathan Chevreau, "Computerland chief expects IBM entry to add credibility to personal market," *The Globe and Mail*, pp. B.9-B.9, Aug 27, 1981
8. While not physically held in a library, OCLC records point to a technical publication by IBM for this computer with a copyright date 1984.
9. Jonathan Chevreau, "IBM launches new 20-megabyte PC unit," *The Globe and Mail*, pp. B.1-B.1, Aug 15, 1984
10. Jonathan Chevreau."Price war is expected in personal computers" *The Globe and Mail*, pp. B 15, Sept. 8, 1982
11. http://www.opentext.com/2/global/company/company-history.htm#ecml
12. http://www.fundinguniverse.com/company-histories/Corel-Corporation-Company-History.html and American review of the technology by S. Rosenberg, "Corel Draw shows great promise" Byte Magazine, June 1, p. 213.
13. http://en.wikipedia.org/wiki/Sinclair_ZX80 and http://maben.homeip.net/static/S100/sinclair/brochure/Sinclair%20ZX80%20Jan%2081%20Byte%20review.pdf

Notes: First book dates correspond to the copyright date of the first book held by a library in the OCLC WorldCat database. See Alexopoulos and Cohen (2011) for sources of the US innovation and commercialization dates for Windows, Lotus, Apple II+, Macintosh, Lisa, IBM PC, IBM PC/AT and Commodore 64, and the footnotes for information used for the Canadian commercialization dates and the dating of PAT, Corel Draw and the Sinclair ZX80.

Table 1 also demonstrates the fluidity with which computer technologies flow across borders. It appears that the technologies developed in the United States and the United Kingdom were quickly embraced in Canada. For example, the commercialization dates in Canada for computer software programs such as Lotus 1-2-3, and Windows were virtually identical to those in the United States. The same is true for computer hardware such as the Apple II+, Commodore 64, IBM PCs, Sinclair, and the Macintosh all of which appear almost simultaneously in the two countries. As it happens, the flow was not uni-directional. Canadian innovations like CorelDraw, developed by Corel, and PAT, developed by Open Text Corporation, were adopted by American firms soon after their Canadian release dates.

A close relationship can also be observed in Table 1 between first commercialization dates and copyright dates (book dates in the table), independent of the location of the innovations. For all of these cases, there is never more than a year's difference between the copyright date and the year of its adoption in either the United States or Canada. In other words, the appearance of a computer-related book in a Canadian library provides a good indicator of the initial arrival (commercialization) of the new technology in the country. Moreover, as we have shown elsewhere (Alexopoulos (2011), and Alexopoulos and Cohen (2011)), new titles are associated with the introduction of new processes or products and not their diffusion. Our indicators, in short, should provide a good measure of computer innovations in Canada. We turn now to the central question of this article – what impact did these new technologies have on economic activity in Canada?

## Output, Productivity, and Technical Change

We have used similar indicators in other papers (Alexopoulos (2008, 2011), and Alexopoulos and Cohen (2009 and 2011)) to explore the relationship between innovative activity in a variety of fields, output, productivity, and employment in the United States, drawing on the MARC records of the Library of Congress, Amazon.com's booklists, and R.R. Bowker's publishers' lists. In particular, we have found, first, that new computer technologies have been an important determinant of productivity growth in the United States during the post WWII period, and second, that computer-driven technology shocks have led to short run increases in productivity, employment, and output. We repeat the analysis using the new Canadian indicators and ask: do we observe the same relationships in Canada?

To answer this question, we estimate the following bi-variate VARs:[11]

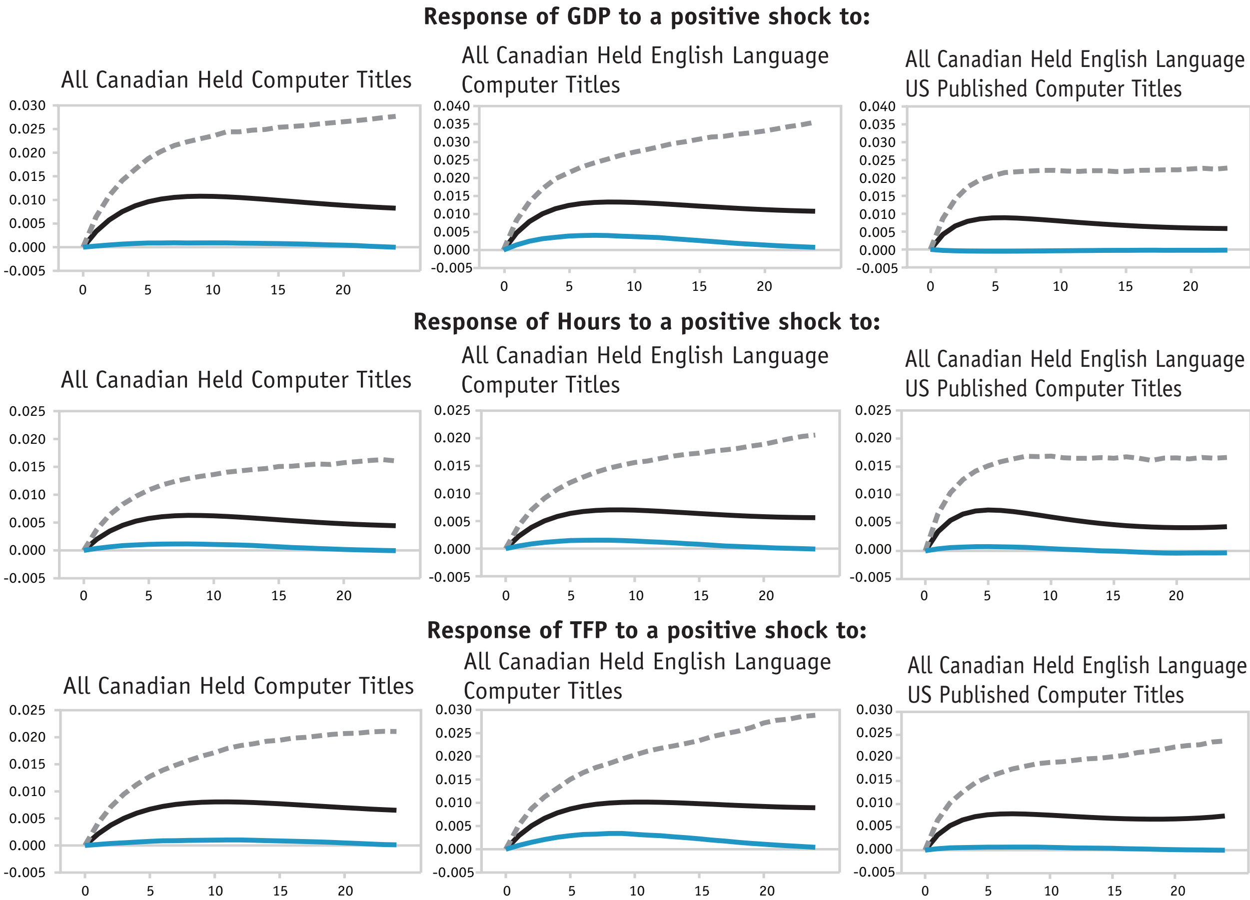
$$Y_t = \alpha + \gamma t + \rho Y_{t-1} + \varepsilon_t \quad (1)$$

where $Y_t = [\ln(Z_t), \ln(X_t)]'$, with $Z_t$ being our measure of aggregate output or total factor productivity (TFP), and $X_t$ being the number of new computer titles.[12] As in Alexopoulos (2011) and Shea (1998), our computer indicator is ordered last in the VAR and a computer technology shock is identified by assuming that it affects the Z variables with a one year time lag. Our measure of aggregate TFP is from Madsen (2007) while hours worked and real GDP are based on data from Maddison (2010), the Historical Statistics of Canada, and CANSIM. Chart 3 displays the impulse responses to a one standard deviation computer technology shock (as identified by our indicator), and 90 per cent confidence intervals. Table 2 reports the Granger-causality

11 A vector autoregression (VAR) is a popular statistical model used to capture the linear interdependencies among multiple time series. As above, each of the variables in the model is represented by an equation linking the variable's current value to lags of its own values, the lags of all the other variables in the model and other deterministic series such as a time trend.

12 Our choice of this specification is driven by two main considerations. First, it is comparable to the specification used in our earlier work focusing on the United States. Second, Gospodinov, Maynard and Pesavento (2011) highlight problems associated with choosing a specification based on univariate unit root tests and demonstrate that severe biases can be introduced by removing low frequency movements by estimating VARs in first differences.

## Chart 3
## Impulse Response Functions- Bi-Variate VAR




## Table 2
## P-values of Granger Causality Tests

| Technology Indicator | Do Computer Technologies Granger-Cause GDP? | Does GDP Granger-Cause Computer Technologies? | Do Computer Technologies Granger-Cause TFP? | Does TFP Granger-Cause Computer Technologies? | Do Computer Technologies Granger-Cause Hours? | Do Hours Grange-Cause Computer Technologies? |
|---|---|---|---|---|---|---|
| All Canadian held computer books (COMPALL) | 0.071 | 0.795 | 0.059 | 0.914 | 0.046 | 0.789 |
| All Canadian held computer books in English (COMPENG) | 0.019 | 0.518 | 0.018 | 0.856 | 0.040 | 0.757 |
| All Canadian held computer books in English published in the United States(COMPUS) | 0.111 | 0.168 | 0.064 | 0.315 | 0.061 | 0.850 |

Notes: For all cases $Y_t = \alpha + \gamma t + \rho Y_{t-1} + \varepsilon_t$, where $Y_t = [\ln(GDP_t), \ln(X_t)]'$, $Y_t = [\ln(TFP_t), \ln(X_t)]'$ or $Y_t = [\ln(Hours_t), \ln(X_t)]'$ and $X_t$ is the value of the indicator at time t.

tests, and Table 3 reports the variance decompositions for the bi-variate cases.

The results echo those for the United States reported in Alexopoulos (2011) and Alexopoulos

**Table 3**
**Per cent of Variation Due to Technology in Two Variable VARs**

| | Years | ln(GDP) | ln(TFP) | ln(Hours) |
|---|---|---|---|---|
| All Canadian held computer books (COMPALL) | 3 | 3.379 | 2.821 | 2.158 |
| | 6 | 12.593 | 11.791 | 9.124 |
| | 9 | 21.117 | 21.433 | 16.531 |
| | 12 | 27.353 | 29.247 | 22.293 |
| All Canadian held computer books in English (COMPENG) | 3 | 6.888 | 5.528 | 2.732 |
| | 6 | 22.359 | 21.275 | 11.474 |
| | 9 | 33.719 | 35.360 | 20.510 |
| | 12 | 40.779 | 45.048 | 27.339 |
| All Canadian held computer books in English published in the US (COMPUS) | 3 | 3.803 | 5.193 | 5.121 |
| | 6 | 8.987 | 13.650 | 14.785 |
| | 9 | 11.715 | 18.697 | 20.775 |
| | 12 | 13.135 | 21.506 | 23.788 |

Notes: These decompositions are based on bi-variate VARs where ln(GDP), ln(TFP) and ln(L) are ordered first. For the cases of using the new book measures and patents the VAR takes the form $Y_t = \alpha + \gamma t + \rho Y_{t-1} + \varepsilon_t$ where $Y_t = [\ln(GDP_t), \ln(X_t)]'$, $Y_t = [\ln(TFP_t), \ln(X_t)]'$ or $Y_t = [\ln(L_t), \ln(X_t)]'$ and $X_t$ is the value of the indicator at time t.

and Cohen (2011). We find, first, that computer-related technical change, as measured by our indicators, had a significant impact on output, hours worked, and TFP in post-WWII Canada. Second, our Granger-causality tests indicate that causality runs from computer-based innovations to output, hours, and TFP and not the other way round. And, third, of the three series (all computer-related books, all English language titles, and English language, U.S.- based publications), it is the second that has the strongest influence on output, hours, and TFP.

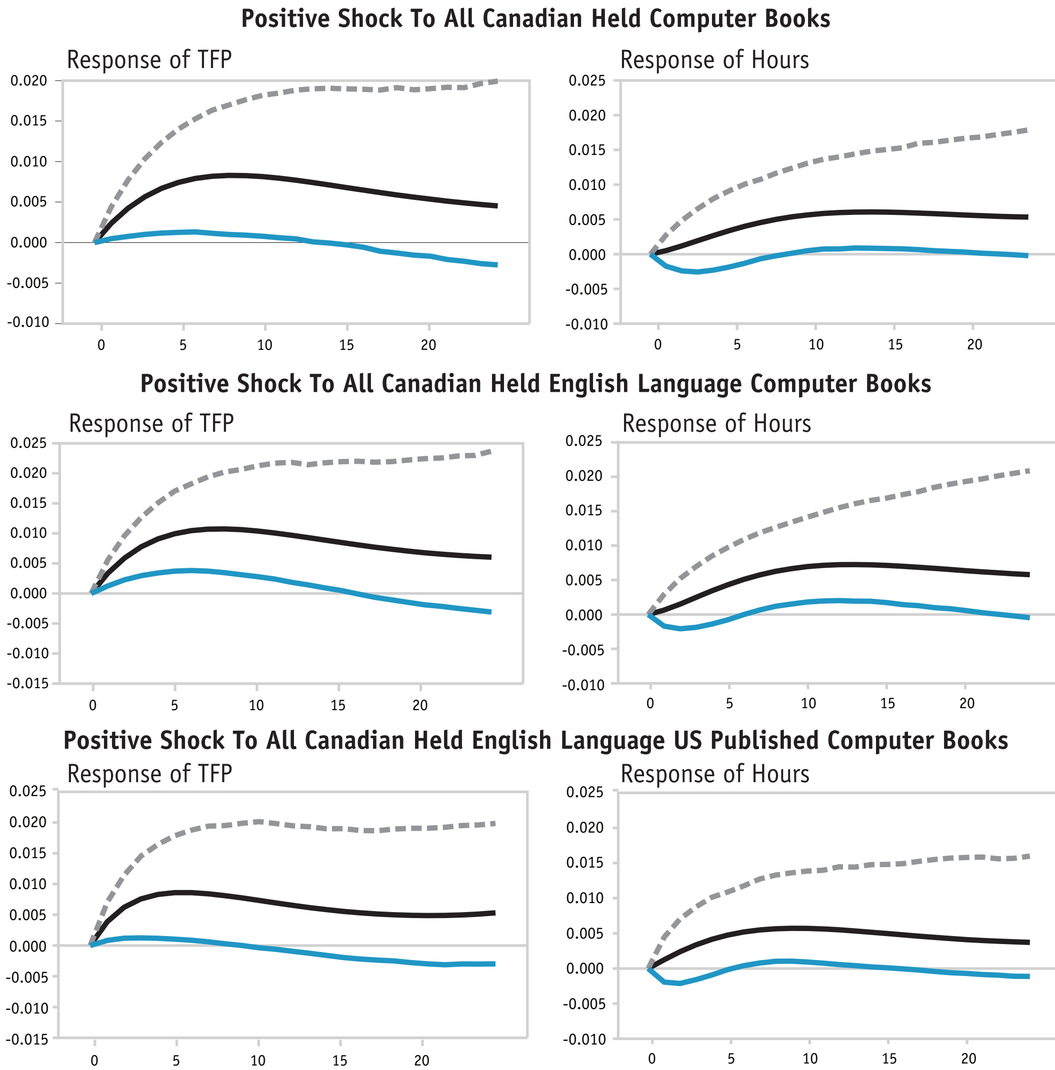
The impulse response functions associated with our VARs can be seen in Chart 3. As the first panel in Chart 3 shows, GDP significantly rises above trend for approximately 25 years following a positive shock to computer technologies (as identified by our indicators) with the peak effect occurring after approximately seven years. Panels 2 and 3 demonstrate that at least part of the increase in output is attributable to rises in hours worked and TFP – both of whose responses are similar to that of GDP.[13] Each of these variables significantly rise for 15 to 25 years with their peak effect occurring between years 5 and 7. Of equal interest, the effects for all of the variables are roughly the same for all three indicators.

The variance decompositions are reported in Table 3. We find, first, that in the initial years the impact of technical change in computers on our three variables is relatively weak. To be more precise, in year three, the indicators accounted for 3.4–6.9 per cent of the variation in GDP, 2.8–5.5 per cent of the variation in TFP and 2.2–5.1 per cent of the variation in hours. By year 6, however, the effect has changed quite noticeably: technical advances in computers now account for 9.0–22.0 per cent of the variation in GDP, 11.8–21.3 per

13 While the analyses in Alexopoulos (2011) and Alexopoulos and Cohen (2011) are based on a slightly different time period, 1955-1997 and 1980-2008, their findings suggest the peak impacts for a computer innovation occur earlier in the United States.

**Chart 4**

**Impulse Response Function: Tri-Variate VAR**




cent of the variation in TFP and 9.1–14.8 per cent of the variation in hours. By year 12, the levels have jumped again: 13.1–40.8 per cent of the variation in GDP, 21.5–45.0 per cent of the variation in TFP and 22.3–27.3 per cent of the variation in hours.[14] In general, the impact of computer technologies on the three variables is largest at medium-run horizons. Second, the indicators based on new English language computer titles account, on the whole, for a much larger percentage of the variance in our three variables than do the other two.

Table 4 and Chart 4 report the variance decompositions and impulse responses related to the tri-variate VAR:

$$Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t \qquad (1)$$

where $Y_t = [\ln(TFP_t), \ln(Hours_t), \ln(X_t)]'$. As above, the technology indicators are ordered

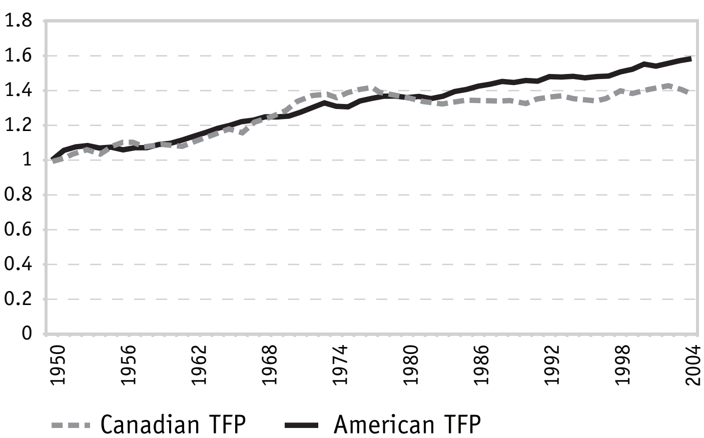
14 The variation in GDP and TFP attributable to computers reported by Alexopoulos (2011) and Alexopoulos and Cohen (2011) are of similar magnitude. However, for the United States, the computer innovations tend to explain a larger share of the variance in years 3-6.

**Table 4**
**Per cent of Variation Due to Computer Technologies in the Tri-variate VARs**

| | Horizon (Years) | ln(TFP) | ln(Hours) |
|---|---|---|---|
| All Canadian held computer books<br>(LNCOMPA) | 3 | 3.368 | 0.256 |
| | 6 | 13.311 | 2.715 |
| | 9 | 23.273 | 8.010 |
| | 12 | 30.742 | 14.239 |
| All Canadian held computer books in English<br>(LNCOMPE) | 3 | 7.136 | 0.421 |
| | 6 | 25.226 | 4.658 |
| | 9 | 39.543 | 13.441 |
| | 12 | 48.307 | 22.863 |
| All Canadian held computer books in English<br>Published in the US<br>(LNCOMPUE) | 3 | 6.571 | 1.119 |
| | 6 | 15.683 | 6.110 |
| | 9 | 20.348 | 11.656 |
| | 12 | 22.568 | 15.515 |

Notes: For all cases $Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t$ , where $Y_t$ = [ln($TFP_t$), ln($Hours_t$), ln($X_t$)]′ and $X_t$ is the value of the indicator at time t.

**Chart 5**
**Total Factor Productivity in Canada and the United States, 1950-2005 (1950=100)**




Source: The TFP measures for the total economy are from Madison (2007).

last. Again, we find evidence that a positive computer technology shock significantly increases productivity and hours worked. However, the confidence intervals for this case do not exclude the possibility that hours worked may initially decrease immediately following the shock. On the other hand, the results in Table 4 do confirm that new computer technologies play a strong role in productivity movements and a moderate one in variations in hours worked in the medium run.

## Canadian Productivity and the U.S.-Canada Productivity Gap

In Chart 5, we present Canadian and American TFP indices from Madsen (2007). Two trends are apparent. First, his estimates suggest that Canadian TFP in 2005 was approximately the same as it was in the mid-1970s. Second, starting in the late 1970s, Canada's TFP growth failed to keep pace with that of the United States, giving rise to a well-known productivity gap.[15]

On the face of it, the first trend would seem to be inconsistent with the analysis in the previous subsection. In addition, it appears to be at odds with the upsurge in computer titles held in Canada and, accordingly, with the apparent advances in computer technology in this country. As it happens, the problem lies not with the data or with our argument but with the misunderstanding that TFP is a proxy for technological innovation. As we all know but often forget, TFP is a residual that contains all those factors other than labour and capital that affect GDP growth. These include, among other things, changes in scale economies, organizational capital, utilization rates, measurement errors and so on, some of which could easily affect the size and rate of change of the residual. The bottom line, for our purposes, is that TFP does not measure pure technical change – which is exactly what our book based indicator is capturing. Moreover, although computer-based technical change did

15 This gap is also seen in labour productivity measures.

play an important role in driving productivity advances in Canada, there were other, counter-balancing forces at work as well. Although unpacking the contents of the residual exceeds the scope of this article, it is a worthwhile project for future research.

As for the second trend, the productivity gap has, naturally enough, attracted the attention of Canadian academics and policy makers.[16] The central questions are the obvious ones – what caused the gap and why has it grown? The answers matter for at least two reasons. First, we cannot begin to address the problem until we identify its source and, second, our ability to compete with our neighbor to the south is closely linked to the relative productivity in the two countries.

Results reported in papers such as Sharpe (2010), Rao (2011), Rao *et al*. (2004), Rao and Tang (2001) and Van Ark *et al.* (2003) suggest that differences in the use and the rate of adoption of information technologies, especially computers, in the two countries are likely a major contributor to gap. While there are always issues with cross-country comparisons, both our metrics, and our overall findings tend to support this view. First, as noted earlier, technological advances in the field of computers have had a significant impact on Canadian productivity. Moreover, as reported in Alexopoulos (2011) and Alexopoulos and Cohen (2011), a similar relationship can be observed in the United States. It follows, then, that if there were a gap in the adoption of new computer technologies between the two countries, this may have been a non-trivial contributor to the productivity gap.

The question is: did such a gap exist? Cross border data on ICT investment in Sharpe (2010) points to a gap, as does our new book-based indicators. Specifically, Chart 6 shows the number of new computer titles held by libraries in the United States as recorded by OCLC alongside the number of new computer titles held by Canadian libraries. It shows that a gap begins to emerge in the early 1970s.[17] A similar pattern can be seen in Chart 7, based on indicators created from the holdings of the largest library in the United States, the Library of Congress, and the largest in Canada, the University of Toronto

**Chart 6**
**New Computer Books Held in Canada and the United States by Copyright Date**

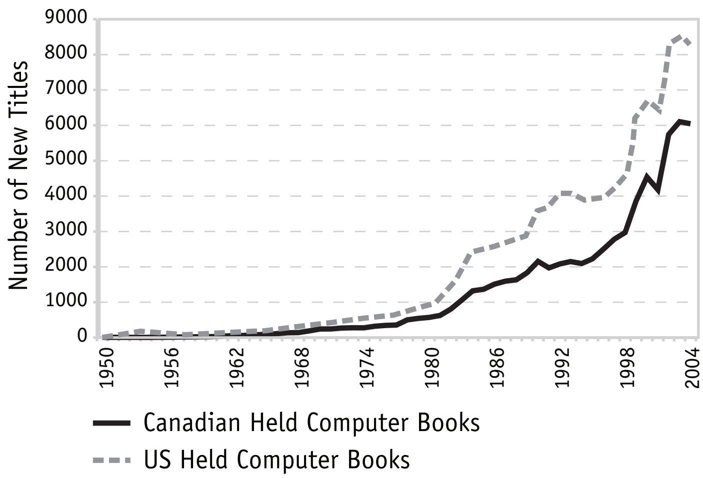
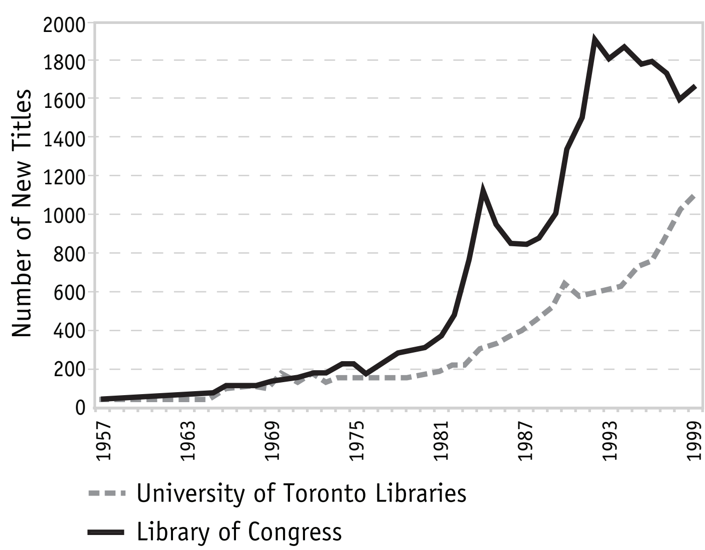



**Chart 7**
**New Computer Titles by Copyright Date**




16 See, for example, Rao and Tang (2001), Rao *et al.* (2004, 2008), Baldwin, Gu and Yan (2008), and Rao (2011).

Libraries.[18] Since our VAR results suggest that a lag exists between the commercialization of new computer technologies (as measured by our new indicators) and their impact on productivity, the appearance of a productivity gap in the 1980s is perfectly consistent with the emergence of an adoption gap a few years earlier.[19] In short, the computer-related technology gap measured by our book-based indicators does appear to have contributed to the emergence of the productivity gap beginning in the 1980s.[20]

## Conclusion

In this article, we draw on the holdings of Canadian libraries to develop new book-based indicators of technical change in the field of computers for the years 1950-2005 and use them to determine the impact in Canada of technological advances in this area on output, productivity, and employment. As we have argued elsewhere (Alexopoulos (2011, 2008) and Alexopoulos and Cohen (2009, 2011), these new indicators resolve many of the problems that plague traditional measures of innovative activity such as patent citations and research and development expenditures. They also have the additional advantage that because they are consistent across countries as well as over time, they facilitate international time series comparisons. We are able to show, for example, that most of the computer innovations identified in publications held in Canada actually originate in the United States. More, we can demonstrate, using VARs, that similar to our results for the United States, positive computer-related technology shocks in Canada lead to increases in GDP, TFP and hours worked in the short and medium run. Finally, we can make use of our new approach to show that starting in the 1970s, the number of new computer titles in Canada began to lag significantly the number in the United States (the appearance, our indicators suggest, of a technology gap), contributing a decade or so later to the emergence of a productivity gap between the two countries. This finding still leaves open the question of why the technology gap emerged in the first place, but with the identification of this problem, we hope policy makers can take steps to address it.

17 One might be concerned that funding differences could affect the comparability of the indicators across the two countries. However, statistics available from http://www.oclc.org/reports/escan/economic/educationlibraryspending.htm suggest that Canada spends slightly more per capita (4.6 per cent) on its library collections than does the United States, and more as a fraction of GDP (0.20 per cent versus 0.12 per cent). Given that all major U.S. and Canadian libraries are represented in our sample, and that the budgets are sufficient to allow Canadian libraries to accumulate in aggregate the same titles as their American counterparts, we believe the indicators do provide important information about the knowledge gap.

18 The University of Toronto Libraries has one of the largest collections in North America. According to statistics based on the number of titles and volumes held, its collection is approximately 53 per cent of the size of the Library of Congress despite the fact that the Library of Congress serves a much larger population than the University of Toronto Libraries.

19 It should be noted that a widening productivitty gap beween Canada and the United States does not require that there be a growing gap in computer titles in relative terms. The current level of TFP depends on the lags of all of the new titles in the economy (not in relative terms). The fact that the Americans are still accumulating more new titles would imply that the gap should be there. However, as the current gap on the new books shrinks, the gap would widen less provided that the coefficients on the lagged titles are the same in the two countries.

20 Alexopoulos and Tombe (2011) identify a gap in management techniques which may also contribute to the presence of the gap.

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## Appendix A
## Sample Marc Record and Associated Online Display

Marc Record:

00992cam 2200253 a

4500001000800000005001700008008004100025035002100066906004500087010001700132020004600490400018001950500027002130820016002401000027002562450089002832600122003723000034004945000020005286500043005486500043005916300038006349910066006672-4768599-19930312102159.8-860214s1986 waua 001 0 eng - 9(DLC) 86002512- a7bcbccorignewd1eocipf19gy-gencatlg- a86002512 - a0914845705 (pbk.) :c$17.95 ($27.95 Can.)- aDLCcDLCdDLC-00aQA76.8.I2594bA541986-00a005.265219-1 aAndrews, Nancy,d1945--10aWindows :bthe official guide to Microsoft's operatingenvironment / cNancy Andrews.- aRedmond, Wash. :bMicrosoft Press ;a[New York] :bDistributed to the book trade in the U.S. by Harper & Row,cc1986.- axii, 292 p. :bill. ;c24 cm.- aIncludes index.- 0aIBM Personal Computer XTxProgramming.-0aIBM Personal Computer ATxProgramming.-00aMicrosoft Windows (Computer file)- bc-GenCollhQA76.8.I2594iA54 1986p00034791090tCopy 1wBOOKS

Online display of information in Marc Record:

**Windows: the official guide to Microsoft's operating environment**

4768599

LC control no.: 86002512

Type of material: Book (Print, Microform, Electronic, etc.) Personal name: Andrews, Nancy, 1945-

Main title: Windows : the official guide to Microsoft's operating environment / Nancy Andrews.

Published/Created: Redmond, Wash. : Microsoft Press ; [New York] : Distributed to the book trade in the U.S. by Harper & Row, c1986.

Description: xii, 292 p. : ill. ; 24 cm.

ISBN: 0914845705 (pbk.) : $17.95 ($27.95 Can.)

Notes: Includes index.

Subjects: Microsoft Windows (Computer file)

IBM Personal Computer XT --Programming.

IBM Personal Computer AT --Programming.

LC classification: QA76.8.I2594 A54 1986

Dewey class no.: 005.265

## Appendix B
## Computer Classifications in Library of Congress Classification and the Dewey Decimal System

In the Library of Congress, the books pertaining to Computers and Computer science are typically listed under the subclass QA Mathematics. For the indicators created in the paper, we used books classified under the QA 75 and QA 76 groups. Specifically, these are the books classified under QA75-76.95 Calculating machines which include titles on electronic computers, computer science, and computer software.

The indicators also include books classified under the Dewey Decimal System classifications 004 – 006. The items under these designations are grouped as follows:

004 Data processing & computer science

005 Computer programming, programs & data

006 Special computer methods