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Measuring Our Ignorance, One Book at a Time: New Indicators of Technological Change, 1909-1949

By Michelle Alexopoulos and Jon Cohen

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Measuring Our Ignorance, One Book at a Time: New Indicators of Technological Change, 1909-1949*

Michelle Alexopoulos§ and Jon Cohen¤

Abstract:

We present new indicators of U.S. technological change for the period 1909-49 based on information in the Library of Congress' catalogue. We use these indicators to estimate the connections between technological change and economic activity, and to investigate the relationship between fluctuations in innovative activity and the Great Depression. Although we do find links between technological change, output and productivity, our results suggest that the slowdown in technological progress in the early 1930s did not contribute significantly to the Great Depression. On the other hand, the remarkable acceleration in innovations after 1934 did play a role in the recovery.

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§Department of Economics, University of Toronto, e-mail: malex@chass.utoronto.ca

¤Department of Economics, University of Toronto, e-mail: jon.cohen@utoronto.ca

I. Introduction

Economists today generally agree that advances in total factor productivity (TFP) are a principal source of economic growth. While Abramovitz observed many years ago that TFP (a.k.a. the Solow residual) is “a measure of our ignorance”, most would still endorse the notion that technological change is a major component. The irony is that, in spite of this endorsement, we still lack compelling ways to measure innovative activity. In short, all the usual suspects – patents, expenditures on and/or numbers engaged in research and development, and enumeration of innovations – are, for various reasons, flawed, especially for the years prior to WW II (see, for example, Cyert and Mowery (1987)) and we have come up with very little to put in their place.

In this paper, we present new indicators of technological change for the period 1909-49 that, we argue, help to resolve the measurement problem. Our new measures are created using previously unexploited information from the Library of Congress (LOC) catalogue on the number of new technology titles (manuals, handbooks, and the like) published in the United States during this period. To illustrate the value of these indicators, we employ them to evaluate a number of hypotheses in the literature that deal with the relationship between technical change and economic activity in the 1930s.

Before we describe our indicators and outline our approach, we review briefly the shortcomings associated with previous attempts to quantify technological change. It is generally agreed that patent statistics provide an imprecise measure of innovative activity. Patent applications, the usual metric, offer no guarantee that a commercially viable innovation will be forthcoming[1] and, even if it were to occur, knowledge of the filing date provides no information on the release date of the product or process. Furthermore, according to Schmookler (1961), patent statistics for the 1930s are especially unreliable because the propensity to patent by corporations was adversely affected by the increase in political and judicial antipathy towards corporate patents.

The other widely accepted measure of innovation is R&D expenditures and/or numbers employed in private, non-farm research facilities. The problem with these data, at least for the period prior to WW II, is that figures on R&D employment are limited to a few benchmark dates while those on R&D expenditures pertain to one sector of the economy (manufacturing).

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[1] Schmookler (1961, p. 55) observes, on the basis of patent applications for the period 1901 to 1945, that roughly half of patented inventions never result in commercial innovations.

Although useful as broad indicators of trends in innovative effort, the numbers available for this period have little value for detailed statistical analysis. Moreover, R&D data, like patent applications, record inputs into the inventive process not the output of commercially viable innovations. It is the latter not the former that matters to those interested in the impact of technical change on economic activity.

The enumeration of important innovations – the method used by Mensch (1979) and others to calculate innovative activity - remains the best direct measure of technical change but it too has drawbacks. In particular, both the significance of the product/process and the timing of its introduction are highly subjective. The predicament is clear: if we want to evaluate quantitatively the link between technical change and economic activity in the pre-WW II period, we need a measure that provides consistent, complete, objective, and direct estimates of commercially viable innovations.

Our new indicators of technological change, we believe, satisfy these requirements. They are based on data drawn from the LOC on the number of new technology titles in various fields published in the United States during the first fifty years of the last century.[2] Since the LOC is the largest in the United States and acts as the country's copyright depository, these data provide an accurate representation of the flow of new technology books available to the trade and to the public. Moreover, publication statistics on new technology books in the early part of the twentieth century are likely to offer first rate indicators of technological change for the simple reason that there were few alternatives to books as a way to "spread the news".[3]

Our new measure is superior in a number of respects to the traditional indicators of technical change. First, it is amenable to statistical analysis because the LOC data can be used to create a consistent time series on an annual basis for the entire period 1909-49, both for technology in general and for various sub-groups of technologies that would have been used in

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[2] Alexopoulos (2006) creates and analyses similar measures for the period 1955-1997. We are aware of only one other attempt to use publications to measure technological change. Sullivan (1984) successfully employs books on agricultural techniques published between 1523 and 1900 to measure technological change in English farming during this period. (We are grateful to Giovanni Federico for this reference.)

[3] It is probably safe to say that new books on technology provide an even more complete picture of technological change during our period than they do for the years covered by Alexopoulos (2006). This is encouraging because Alexopoulos was able to show that these data offer an excellent measure of advances in commercially viable innovations.

the private, non-farm economy. Second, unlike patents and R&D statistics, publications of new technology books are timed to coincide with the commercialization of new products or processes. That is, the books appear at the precise moment that the innovations are most likely to exert their influence on output and productivity. Third, these indicators suffer from none of the arbitrariness associated with enumeration exercises – timing and numbers are strictly determined by their first appearance in the MARC records of the LOC.

To summarize briefly our results, we find first that our indicators are, for the most part, consistent with the case studies reported by Mensch (1981), Field (2003), and others. Second, using vector autoregressions (VARs) – a standard statistical technique for such analyses[4] - we are able to identify a strong causal connection between technological advances as measured by new publications and changes in TFP and GNP per capita for the years 1909-49. We find, moreover, that while the impact of technical change on economic activity was substantial, our results also indicate that some innovations mattered more than others. Thus, advances in electrical and mechanical machinery, manufacturing, and automobiles had a powerful, positive influence on both GNP per capita and measured TFP, new chemical technologies pushed up the latter but not the former, while innovations in telecommunications, although numerous, had little impact on either variable.

This brings us to the literature on the 1930s where our new indicators, we believe, help shed light on three issues. First, Field (2003, 2006), has argued on the basis of advances in TFP and a variety of microeconomic case studies and sectoral evidence, that the 1930s (1929-41) was the most technologically progressive decade of the twentieth century in the United States. Moreover, he notes that certain sectors – telecommunications, electric utilities, structural engineering, wholesale and retail trades, and so on - were much more innovative than others. There are two difficulties with this approach. His TFP numbers, drawn from Kendrick (1961) and Solow (1957), provide, at best, an imprecise estimate of technical change. As Cyert and Mowery (1987, p. 30) point out, since TFP is derived as a residual, it does not provide, in fact, a direct measure of technological change. That is, since other factors aside from new technology influence the size of the residual, changes in TFP fail to supply a fool proof estimate of innovative activity. Similarly, while case studies may help pinpoint areas of technological

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[4] See, Sims (1980), Burbidge and Harrison (1985), Francis and Ramey (2004) and Harrison and Weder (2006) for some examples that focus on the period of the Great Depression.

change, they tell us very little about the quantitative impact of the different innovations on TFP or GNP. Our new indicators resolve both of these problems. We are able to corroborate Field's contention that the 1930s was a technologically progressive decade – whether it was the most progressive of the century remains, for us, an open question since our data stop in 1949. We also find, in keeping with Field, that some areas were more progressive technologically than others. However, our results suggest that not all advances were created equal – some had a much greater impact on growth and productivity than others.

The second issue deals with technology shocks and the onset of the depression. Although many causes of the Great Depression have been presented in the literature, a number of economists, prominent among them Cole and Ohanian (1999), Ohanian (2001), and Francis and Ramey (2004), have argued that broadly defined negative productivity shocks (often simply referred to as negative technology shocks) contributed to the fall in production after 1929. Although compelling, especially to those who embrace the real business cycle paradigm, the question remains, what do these broadly defined productivity shocks actually represent? That is, since these shocks are identified using either the Solow residual or the Gali (1999) long run identification method, and since factors other than technology may be contained in these measures, we still need a way to distinguish between changes in pure technology and changes in other factors.[5] In an effort to address precisely this problem, Ohanian (2001) attempts to estimate how much of the decline in Kendrick's measured TFP in the early 1930s can be attributed to various components of the residual including changes in: capacity utilization, the quality of factor inputs, the composition of production, labor-hoarding, and economies of scale. He finds that these factors explain less than one third of the eighteen percent decrease, leaving unexplained the remaining two thirds. Although he observes that the decrease in TFP is unlikely to be attributable to "technological regress" (and we agree), this does not rule out the possibility that the decline may be linked to negative pure technology shocks which caused the rate of innovative activity to drop below its trend level.[6] With our new indicators, however, we can evaluate with some precision the role played by pure technology shocks in the downturn. We find that while broadly defined productivity shocks reduced the efficiency with which inputs

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[5] See, for example, Basu, Fernald and Kimball (2006) for a discussion of this point.

[6] R. Szostak (1995) argues that the slowdown in innovative activity in the late 1920s was a major contributor to the great depression but he lacks evidence to support his contention.

were transformed into outputs and thus fostered the depression, narrowly construed, pure technology shocks – as captured by our measure - did not.

Third, Mensch (1979), Kleinknecht (1987), and others maintain, following Schumpeter, that recovery from the depression was directly linked to the burst of innovative activity that occurred in the second half of the 1930s. The problem, once again, is that the evidence, while suggestive, fails to establish a causal connection between innovations, output, and productivity. Our new measures solve the problem. Briefly, we find that the acceleration of technical change after 1934 did play a significant role in the recovery to the end of the decade. More generally, on the assumption that technological progress remained at rates achieved in the 1920s, our calculations suggest that it would have taken an additional 14 years for GNP per capita to have matched the actual level reached in 1939 because of slower growth in TFP. Technological change does not offer a complete explanation for the recovery – other forces were clearly at work - but it does seem to have made a significant contribution to it.

We proceed as follows in the remainder of the paper. In the next section, we first describe in more detail our new indicators and the intuition that underlies them and then show that they are, for the most part, consistent with the case studies reported by Mensch (1981), Field (2003) and others. Following this, we use Vector Autoregressions (VARs) to establish a causal link between technological advances as measured by new publications and changes in TFP and GNP per capita during the period 1909-49. In section four, we use the coefficients and shocks generated by our regression to answer three questions: first, were the 1930s technologically progressive; second, did pure technology shocks (based on our indicators) contribute to the depression: and, third, what would have happened to output and productivity had the rate of technological innovation been less vigorous in the 1930s than it was? In the final section, we conclude and offer suggestions for further research.

II. Book Publications as an Indicator of Innovative Activity

Although much of the basic science underlying an innovation is likely to be known, at least by others in the field, knowledge of the commercial product or process developed out of the science is, almost by definition, unknown until it hits the market. Thus, successful launch necessitates dissemination of information and this is where books enter. In this section, we describe our indicators, give the intuition behind them, and then compare them with the traditional measures of technical change.

II.A. Description:

Following the methodology proposed by Alexopoulos (2006), we have constructed our new indicators of technological change from the LOC's MARC (*MA*chine *R*eadable *C*ataloging format) records.[7] These files are used by the library to run its online book search program, and are available to other libraries to help them catalogue new books. Since the LOC is the copyright depository for the U.S. and by far the country's largest library with over 130 million items on approximately 530 miles of bookshelves, the records provide a virtually complete list of all new titles copyrighted within the United States across a vast range of subjects.

Each MARC record contains, among other things, information on the type of book (for example, a new title or a new edition of an existing one), the country of publication, the language of publication, the LOC's Classification Code, and a list of major subjects treated in the book. To create measures of technical change for the private non-farm economy, we use the first three categories plus the classification code to identify new titles in different fields of non-military technology (found in the subgroups of the T classification listed in Appendix A) published in English in the US between 1909 and 1949. Since we are interested in new technologies used in the private economy, we exclude books on handicrafts (under subgroup TT) and all books in the subgroup TX (Home Economics) with the exception of books on the hospitality industry. Finally, we remove all books that include history as a descriptor (either in the title or in subject keywords) for the obvious reason that they are unlikely to have much to do with the new innovations. Thus, a recent book that chronicles the early years of Alexander Graham Bell's invention will be excluded since it tells us nothing about the current state of technology in the communications industry. The remaining list of titles includes manuals and books that deal with all technology related topics including their nature and function, how they work, and how to use and/or repair them. Some are published or sponsored by the innovator/company that developed the new technology, others by third parties who hope to profit from book sales.

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[7] Our measure differs from the one presented in Alexopoulos (2006) in terms of both time period and sub-groups of technical change.

An example will help illustrate the type of publications included in our indicators (We include additional examples in Appendix B.) The early part of the twentieth century witnessed a number of technological advances in automobile tires including the introduction of the first inflatable tire and changes in the materials used to make them. In the LOC's collection, we find repair manuals produced by tire companies such as Goodyear and Firestone, books on tire maintenance released by general publishers, and publications by the United States Bureau of Standards on government standards and endurance tests and tips on use and care. The motive for publishing, in all cases, was the same: to spread the word about the new innovation, for the most part, in pursuit of financial gain.

In Figure 1, we report the results of our efforts. The graphs represent the number of new titles by year drawn from the following fields chosen, with three exceptions, to correspond with those identified by Mensch (1979) and Field (2003) as technologically dynamic in the 1930s: total technology, chemicals, automobiles, electrical machinery and electronics, mechanical machinery/manufacturing, telecommunications. Since the three exceptions, children's and medical books and titles in fiction, poetry, and music have no obvious connection with technological innovation we can use them to answer two questions. First, is the pattern of new titles that we observe among our indicators simply an artifact of the publishing industry and, second, to the extent that we find a statistically significant relationship between our indicators and output and productivity, is it simply a case of correlation without causation? We deal with the latter question in the next section but address the former here.

Although the years covered by our study encompass some extraordinary events, including two world wars and the Great Depression, there is little evidence to suggest that these events so overwhelm our indicators that they reflect nothing more than overall trends in publishing. With regard to the two wars, for example, articles in the New York Times suggest that neither had much impact on the publishing industry. This is the unequivocal message of the article "Books and Figures" that appeared on February 3, 1918. Roughly twenty-five years later, on November 12, 1943, it was reported in "A New Cut in Book Paper" that the War Production Board intended, on the recommendation of the book publishing and manufacturing industry advisory committee, to restrict the supply of print paper for books to seventy-five percent of the 1942 level. It was noted, however, that this was unlikely to affect the supply of reading material because publishers, to compensate, planned to use thinner paper, narrower margins, and smaller type face.

As for the depression, we can again refer to articles in the New York Times for anecdotal evidence. For example, in "Book Industry Thrives Despite Depression, Finding Strong Trend to Serious Reading" (August 31, 1931) and "Hopeful Publishers" (September 1, 1931), it was reported that the types of publications that were cut during the Depression were, on the whole, marginal ones, the kinds that publishing houses, in better times, were willing to gamble on. The important point is that the titles that compose our indicators were not marginal and were, therefore, unaffected by the slump.

More generally (and somewhat less anecdotally), the graphs in Figure 1 indicate that the pattern traced by new technology titles overall and by subgroups differs from that sketched by the three exceptions which, it should be noted, do not themselves conform to a single pattern.[8] Moreover, even among the subgroups, patterns differ. For example, as can be seen in the graphs, while there is virtually no change in the number of new titles in telecommunications between 1924 and 1940, the number of titles in manufacturing jumps between 1924-30, drops sharply during the dark days of the depression, then experiences an equally dramatic upswing between 1933 and 1943. This is reflected in the low correlation (0.22) between these series' growth rates. New automotive titles, on the other hand, rise during the early 1930s despite the slumping sales of automobiles, trucks and moving equipment. There is also substantial variation in the behavior of the subgroups during WWII. For example, while the total number of technology books decline after the onset of the war, there are many new titles on manufacturing technologies and telecommunication technologies introduced from 1941-1943. Automotive titles do not fall until after Roosevelt bans the production of civilian automobiles and trucks in 1942. While at least part of the decline in the number of new titles between 1942 and 1945 may be attributable to self-imposed restrictions by the publishing industry and quotas placed on paper usage, a large part of the decline in our technology indicators reflects a shift in interest towards military technologies. Consequently, for a significant number of technology subgroups including automobiles, chemicals, and electrical engineering, many of the new technologies developed for

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[8] The correlations between the growth rates of the subgroup indicators and the total technology indicator range from 0.30 to 0.58, and the correlation between the growth rate of the exceptions indicators and the total technology indicator range from 0.248 to 0.37.

wartime use, such as advances in explosives, artillery, electronics linked to weapons, and telecommunications geared to combat, appear as titles under the Library of Congress' U and V classifications (that is, under military and naval science). In short, our indicators represent more than simply the ebb and flow of output in the publishing industry.

The patterns we observe here also support our contention that the indicators are capturing changes in innovation rather than simply reflecting changes in demand for technical books. For example, if new technology titles were introduced because of a large demand for them by workers looking to retrain during a slump – as opposed to being introduced because of new innovations coming to market - then the number of titles should have sharply increased during the period 1931-33. As the figures show, this did not happen.

II.B. Intuitive Appeal:

A good indicator of technical change needs to capture innovations at the moment of their commercialization. As Alexopoulos (2006) argues, publications, for sound economic reasons should do precisely that. Innovating companies want to promote their innovations; independent writers want to sell books. For both, timing is critical – too early and the publication is useless, too late and it is, at best, dated.[9] Our new measures for the years 1909-49, therefore, overcome one of the principal defects associated with indicators based on patent applications and R&D expenditures – long and indeterminate lags between conception and commercialization.

The indicators have an additional attractive feature as measures of technical change - they weight the various new technologies differently, an important factor in determining the impact of the different innovations on economic activity. The argument runs as follows. Since more titles are likely to appear on a major (or general purpose) technology than on a minor (or sector specific) one, our indicators more closely resemble citation-weighted patent ones, discussed, for example, in Jaffe and Trajtenberg (2002), than they do those based on a simple count of annual

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[9] We are aware that some new titles may appear after the initial release date (e.g., new titles linked to the radio do come out after 1922). However, we would argue that, since new titles are costly to produce and market, the majority appear because: (1) the product/process has been redesigned (e.g., today's radio differs significantly than the one marketed in 1922) or (2) the existing product/process has been adopted by a different segment of the economy (which would represent a new technological advance among this group).

patent applications. However, in our case, the weight given to each technology annually is determined by the number of new titles released on it each year. This means that our indicators are high for one of two reasons: (1) lots of small innovations are brought to market during the course of the year, each accompanied by a couple of new publications, or (2) a major innovation debuts that affects many sectors and fosters numerous new titles. In both cases, we would expect to observe a positive correlation between the number of new publications and output and productivity. And, this, of course, is exactly the relationship that we are trying to capture.

There are, finally, innovative changes in management, factory organization, and power sources that traditional measures of technical change may overlook. They are often not amenable to the patent process, they may have little to do with the research lab, and they are unlikely to be embodied in some major new piece of equipment. They can, however, show up in publications for the simple reason that someone stands to profit from writing about them.[10] Moreover, their impact may be considerable. Thus, as Weintraub (1939, p. 24) points out, in a number of manufacturing industries, including cotton-garment production and automobiles, changes in factory layout and, more generally, in the organization of production, resulted in substantial increases in productivity through improvements in the flow of work and savings in supervisory labor, equipment, floor space, and inventories in the 1930s with little, if any, changes in equipment.

Books, of course, are not the only way to disseminate information about new technologies. Even in the pre-WW II period, trade journals, professional and/or scientific conferences, and direct marketing, among others, served as sources of information on new technologies. However, it is reasonable to believe that these other methods of communications acted as complements to our book based measures of technical change. In any case, to the extent that our indicators omit some innovations, the bias runs against (and not in favor of) our finding a relationship between publications and increases in economic activity and should, therefore, be viewed as establishing a lower bound on the true impact of technological change over this time period.

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[10] There are many books in the LOC T classification that have the terms Factory management or industrial efficiency as subject keywords, for example. The list includes titles such as: Future of mechanization in production management; Industrial management in this machine age; The control of quality in manufacturing; The principles of factory organization and management; and Ford production methods.

II.C. Old and New Indicators Compared

While perhaps intuitively appealing, we must still demonstrate that our new measures provide an accurate, quantitative account of innovative activity. In a previous article, Alexopoulos (2006) established a strong positive link between new publications of technology books – in general and by sub-categories – and innovations for the post-WW II period. The question is whether a similar connection can be shown to exist for the pre-WW II period? Although we are prevented by data problems from repeating the statistical analysis carried out by Alexopoulos, we can show that our new indicators are, at the very least, consistent with the findings of Mensch (1979) on major innovations and Mowery and Rosenberg (2000) on R&D expenditures and personnel.

Mensch (1979, p. 127-8) presents a table, based on case studies of inventors and inventions reported in Jewkes, Sawers, and Stillerman (1969), in which he lists major new inventions by date of conception and by date of innovation, that is, by the date that the invention either enters into production or an "organized market" for it appears. The numbers, he maintains, confirm his view that the 1930s, particularly from 1933 on, was a time of intense innovative activity. (See also Field 2006) Although the years chosen by Mensch (1979) for his innovations are often less cut-and-dried than he would like us to believe (see Jewkes, et al (1969) for the details), they do offer widely accepted benchmarks with which we can evaluate our indicators.[11] A comparison of innovation dates from Mensch (1979) and commercialization dates from Jewkes, et al (1969) with the dates that the same innovations made their first appearance in the LOC database reveals, on the whole, a reasonable coincidence of timing between the series (See Appendix B for examples). Although we are reluctant to draw too much comfort from these results, they do suggest that publications are in general agreement with a standard measure of innovations during this time period.

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[11] Although the dating of major innovations can help to single out periods of intense innovative activity, as we mentioned before, both timing and significance are highly subjective. A good example of this is the radio. An apparently straightforward innovation, the radio was, in fact, the outcome of a series of independent innovations, each one of which gave rise to something that resembled the modern radio. It was, without question, a major innovation but it is unclear which of the many steps should be used for dating purposes.

In Figure 2, we compare our publication series with the estimates of scientists employed in R&D laboratories, spending on R&D in industry and Mensch's (1979) series on important innovations. Although the R&D figures measure inputs into the inventive process not the output of commercially viable innovations and Mensch's (1979) series is subjective, the results reveal a rough correspondence in trend between the measures. On the basis of these, it seems safe to conclude that new technology titles drawn from the MARC records of the LOC do offer reliable indicators of innovative activity in the U.S. in the first half of the twentieth century.[12] And, of course, they have advantages that the other measures lack. The next step is to determine the extent to which productivity improvements and growth in per capita GNP during this period were driven by innovative activity during this period.

III. Technological Change, Productivity, and GNP

III.A. The Data

In our analysis we use annual data for the time period 1909-1949 drawn for the most part from four sources: the LOC MARC records for our technical change indicators, and Kendrick (1961), the National Industrial Conference Board's Economic Almanac (various years), and Goldsmith (1956) for input and output statistics. Aside from the MARC records, these are the standard sources for data on inputs and output during the period. To be more precise, our real GNP series for the private non-farm economy in 1939 dollars, taken from the Economic Almanac, various years, are based on series computed by Kendrick.[13] Following Solow (1957),

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[12] Since none of these measures match the pattern traced by patent applications reported by the U.S. Patent and Trademark Office, especially in the 1930s, we would argue, following Schmookler (1961) and Griliches (1993), that the problem lies with the latter not the former.

[13] To determine if our results are sensitive to the choice of the base year, we repeated the exercise using real GNP series expressed in 1929, 1939 and 1947 dollars and performed a similar operation for TFP. We report our findings in a working version of the paper (Alexopoulos and Cohen 2008). The results using the data in constant 1947 dollars are virtually identical to the ones presented here, and, while there are some differences when we use the 1929 constant dollar data, these are most likely attributable to shortcomings (noted by Kendrick) associated with the 1929 price deflators. Furthermore, we again obtain very similar results if we use Kendrick's data for 1909-28 spliced with the official BEA series for the period 1929-49.

we obtain our labor input measure from the Economic Almanac and our estimate of the capital stock from Goldsmith (1956). Since these capital stock estimates are only available in 1929 dollars, when we calculate our TFP series, we convert these numbers to 1939 prices using the GNP deflators. Finally, in order to compute our TFP series, we employ Solow's (1957) figure for the share of property in income which he, in turn, bases on data in the Economic Almanac and Burkhead (1953).

III.B. GNP and technology

We begin by estimating a bi-variate VAR to examine the links between technological change (as measured by our indicators) and non-farm private sector GNP per capita. Our results will permit us to identify two important relationships, the impact first of technical change, as measured by our indicators, on GNP and, second, the relationship, if any, between the level of economic activity on the number of technology titles.

To determine if the series have unit roots we ran the standard KPSS, Dickey-Fuller and ERS tests. The tests suggest that our indicators are stationary around a linear time trend. However, similar to the findings of Christiano and Eichenbaum (1990), the KPSS test for the ln(TFP) and ln(GNP per capita) series could not reject the null hypothesis that the series were stationary around trend, while the Dickey-Fuller and ERS tests could not reject the hypothesis that they have unit roots. Given these ambiguous results, we opt to use levels instead of first differences and include a time trend. Specifically, we estimate the following bi-variate VAR:

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

for the case using the total technology, automobiles, mechanical/manufacturing, electrical machinery and electronics, and telecommunications measures, and

$$Y_t = \alpha+\gamma t+\rho_1 Y_{t-1} +\rho_2 Y_{t-2} +\varepsilon_t \qquad (2)$$

for the case where the chemical technologies and patent measures are used . In the equations , α is a constant, ε_t is a vector of time t residuals, ρ_i=[ρ_{i1} ρ_{i2}], Y_t = [ln(GNP_t/POP_t), ln(X_t)] ′, where GNP_t is real GNP in year t measured in 1939 dollars, POP_t is the population at time t, and X_t is one of our technology indicators. As in Shea (1998) and Alexopoulos (2006), we identify technology shocks by assuming that they only affect GNP per capita with a lag.[14] Moreover, we include an additional lag for both patents and chemicals, because we anticipate longer lags for these variables than for our other indicators. There are well known delays associated with patents, and chemicals innovations are, for the most part, intermediate goods. In Figure 3 and Table 1, we report the response of GNP per capita to various technology aggregates including: all technology, automobiles, chemicals, mechanical/manufacturing, electrical machinery and electronics, and telecommunications.

Before we turn to our results it is useful to state clearly what we define as "technology" and "non-technology" shocks. We define a "technology shock" at date t as any unanticipated disturbance which alters the flow of new technology titles at that date but does not contemporaneously affect output (or TFP). "Non-technology" shocks at date t, on the other hand, include any shock that contemporaneously affects output (or TFP), such as monetary and/or fiscal policy shocks, uncertainty shocks as well as more broadly defined "technology shocks" which may include, among other things, shocks to work rules, organizational capital or regulations. [15] In our framework, since technology growth (and the publication of new titles) is positive or zero, a negative technology shock is a shock that causes the rate of technological innovation to fall below the average.

Panels A and B of Figure 3 displays the impulse responses of GNP per capita to a technology shock for each of the indicators along with 90 percent confidence intervals computed using the Monte Carlo method. Three main findings emerge. First, as shown in Panel A, GNP per capita rises in response to a technology shock identified by our measure but decreases in reaction to a technology shock identified by the patent series. This counterintuitive outcome of a patent-identified shock provides further confirmation that patents are poor indicators of technical change during this period. Second, Panels A and B show that GNP per capita rises in response to our positive technology shock with the peak response occurring after 2-4 years. They also

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[14] To determine if the ordering of the variables in our VARs matters, we reran the regressions with the technology indicator entering before ln(GNP/POP) and found that our results were, on the whole, unaffected. We do not report these findings in the paper but are happy to make them available upon request.

[15] To see if our results are affected by including the war years, we also estimated a set of VARs that included real per capita military spending and a set that included dummy variables for the war years. Our findings are virtually unaltered by these modifications.

indicate (as we would expect) that some shocks have a more powerful effect on GNP per capita than others. Thus, technological change in manufacturing, automobiles, and electronics/electrical machinery appears to have had a significant impact on GNP per capita while shocks associated with chemical technologies do not.

These results are confirmed by point estimates, Granger-causality tests, and the variance decompositions reported in the first columns of Tables 1-3. As is revealed by the point estimates in Table 1, technical change in chemicals and telecommunications have little success in explaining movements in GNP per capita while innovations in manufacturing, electrical, and automobiles technologies have a strong and significant impact on output; in fact, the last three are significant at the five percent level.

The variance decompositions reported in Table 3 provide further information on the role technological change played in determining the variance of GNP per capita. They suggest that about 14 percent of the short-run variation is attributable to electronics and electrical technology, 12.5 percent to automobiles, and 9 percent to manufacturing technologies.[16] Moreover, these effects increase significantly over the medium to long term, an indication that the shocks in all likelihood had long-lasting consequences for output.

Our results raise an obvious question. Does the increase in new technology titles represent nothing more than a serendipitous upswing in all publications in tandem with increases in GNP per capita or do they instead capture a causal link between technological change and output growth? To help us answer this question, we replaced new technology books in the regressions and re-ran them using three groups of titles, children's books, medical publications, and books in fiction, poetry and music, that should be unrelated to cyclical fluctuations in output. The coefficients on these series in the GNP per capita equation are reported at the bottom of Table 1. On the basis of the standard errors and the Granger-causality tests we reject the hypothesis that these other titles predict GNP per capita. This result is further confirmed by the impulse responses shown in Panel C of Figure 1. Shocks to these other series fail to have a significant impact on output. Overall, then, it is safe to conclude that while new technology titles do seem to affect economic activity, these other types of books do not. Although not foolproof, the finding is, at the very least, reassuring.

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[16] See Jovanovic and Rousseau (2005) for a discussion of how electrification affected the U.S. economy during this time period.

III.C. TFP and technological change

Our next task is to examine the impact of technical change on TFP.[17] Before we do this, it is necessary to say a few words about the TFP statistics. There are two widely employed ways to compute TFP for the early part of the twentieth century, that of Kendrick (1961), based on a linear production function with the weights on inputs determined by their prices in a given base year, and that of Solow (1957), based on the more general function Q=F(K,L) where the weights assigned to inputs are based on factor shares.[18] We use the latter in this paper for two reasons. First as Domar (1962), among others, has pointed out, over long horizons the Solow (1957) method is likely to prove the more reliable of the two. Second, the Tornqvist/Solow approach is now the method of choice for those interested in measuring changes in productivity over time and across sectors.

We also present two sets of findings for TFP. The first is based on TFP unadjusted for capital utilization, the second adjusted using Solow's (1957) assumption that utilization rates vary with the unemployment rate. Unadjusted TFP is calculated using the equation:

$$\frac{\Delta TFP}{TFP} = \frac{\Delta\left(\frac{GNP}{L}\right)}{\left(\frac{GNP}{L}\right)} - \omega_K \frac{\Delta\left(\frac{K}{L}\right)}{\left(\frac{K}{L}\right)} \tag{3}$$

while the adjusted one is calculated according to

$$\frac{\Delta TFP}{TFP} = \frac{\Delta\left(\frac{GNP}{L}\right)}{\left(\frac{GNP}{L}\right)} - \omega_K \frac{\Delta\left(\frac{K(1-u)}{L}\right)}{\left(\frac{K(1-u)}{L}\right)}. \tag{4}$$

where GNP in the equations represents private non-farm output, L the number of hours worked, K the capital stock, ω_K is Solow's (1957) share of property in income and u the unemployment rate.

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[17] We also ran regressions using output per man-hour as the relevant productivity measure. While there are some differences in magnitudes, the results are broadly similar to those for TFP and therefore are not reported here.

[18] For example, Cole and Ohanian (1999) and Ohanian (2001) report Kendrick's (1961) productivity numbers, while Field (2003) reports both Solow's (1957) and Kendrick's (1961) measures.

In both cases, we estimate bi-variate VARs, this time to uncover the relationship between productivity and technological change. Again, we use $Y_t = [\ln(TFP_t), \ln(X_t)]'$, for total technology, automobiles, mechanical/manufacturing, electrical machinery and electronics, and telecommunications:

$$Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t \tag{5}$$

and

$$Y_t = \alpha+\gamma t+\rho_1 Y_{t-1} +\rho_2 Y_{t-2} +\varepsilon_t \tag{6}$$

for chemical technologies and patents. We again assume that technology shocks only affect TFP with a lag. The estimated coefficients for the TFP regressions are reported in Columns 3-6 of Table 1 with the Granger-causality tests and the variance decompositions for the regressions reported in Tables 2 and 3 respectively.

We begin with the point estimates reported in Table 1. They indicate, much as they did for private non-farm GNP per capita, that increases in technological change raise productivity.[19] The impact, once again, varies across technologies. However, correction for capital utilization, it turns out, has little impact on our basic results.

In Table 2, we report the Granger causality tests for the TFP measures. As can be seen, TFP has a significant relationship at the five and ten percent levels with technical change across all subgroups save telecommunications. [20] Finally, Table 3 contains the variance decompositions based on the TFP VARs. The numbers indicate that the percent of variation in TFP explained by new technology grows over time. It is much greater in year nine than in year three and the effect is substantial for all sub-sectors, again with the exception of telecommunications. The major player is manufacturing which accounts for roughly 16-29 percent of the variation in TFP by year three and between 29 and 41 percent by year nine. Automotive, electrical, and chemical technologies while less powerful are still non-trivial – by year three, between 8.8 and 14 percent of the variation in total TFP is explained by these three indicators with their effect growing to between 15 and 25 percent by year nine.

The impulse responses for both adjusted and unadjusted TFP are reported in Figure 4, along with 90 percent Monte Carlo confidence intervals. In many respects they echo the GNP per

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[19] Coefficients that are negative are insignificantly different from zero at conventional levels of significance.

[20] The failure of telecommunications to predict changes in TFP may due to the relatively short time series and to the fact that many innovations in this area, like television, were still in their infancy.

capita responses depicted in Figure 3. In particular, a positive total technology shock significantly increases productivity for approximately 7 years with the peak response occurring 1-2 years after the shock. Moreover, we observe similar responses of TFP (both unadjusted and adjusted) to sub-group specific technology shocks – chemical, automotive, electrical, telecommunications and manufacturing – where, with the exception of telecommunications, we find that TFP goes up significantly for 5-8 years following the shock.

IV. Technological Change and the Great Depression.

We now turn to the 1930s and employ our indicators to address three questions related to technological change and the Great Depression: were the 1930s, as Field maintains, technologically progressive; did negative technology shocks contribute to the sharp drop in economic activity in the early years of the decade; and, did positive technology shocks aid in economic recovery after 1934?

IV.1. Believe it or not!! The 1930s was a technologically progressive decade

As the graphs in Figure 1 illustrate, our new indicators support the claim that the period 1929-41 was technologically more progressive than either 1909-29 or 1941-49. The value of this partial corroboration of Field should not be underestimated. He makes his case, for the most part, on the basis of Kendrick's productivity numbers, rearranged to capture peak to peak changes in TFP. However, as we noted in the introduction, since changes in TFP during the period may have been caused by factors other than technology – for example, attrition of the least efficient firms or retention of the most efficient workers - the former provides at best a very rough guide to variations in the latter.[21] In contrast, our indicators measure technological change directly and thus provide a precise estimate of both the path of innovative activity and its impact on output and productivity.

Quantification permits us to shed light on a subsidiary issue. Since technological change during the period was not evenly distributed across sectors, the obvious question is which

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[21] In support of the attrition argument see Bresnahan and Raff (1991) and Goldin (2000) for evidence on selective retention of workers. Field (2003, p. 1409-10) rejects both of these arguments.

of the changes had the greatest impact on output and productivity? As our regression results show, new technologies in manufacturing, electrical machinery and electronics, automobiles, and, to a lesser extent, chemicals mattered most while those in telecommunications were least significant. The implication of these findings is worth emphasizing. If we want to identify the impact of new technologies on economic activity, as Cyert and Mowery (1987, p.94) point out, it is necessary to take a broad analytical perspective. Although case studies do help us identify innovations and, perhaps, their potential contribution to output and productivity, they cannot on their own offer a measure of their overall impact because they are generally unable to incorporate effects beyond the confines of a single firm or sector. For example, although Mensch's (1979) list of major innovations in telecommunications and chemicals in the 1930s is long, suggesting that they played a major role in productivity gains during the period, our results indicate, instead, that their impact was relatively modest. In short, the ability to identify economy wide effects depends crucially on having a quantifiable measure of technical change – thus the value of our new indicators.

IV.2. Technology or Not Technology…That is the question

Since the two remaining questions deal with the impact of fluctuations in innovative activity on the downturn and recovery during the 1930s – essentially two sides of the same coin – we use a single framework to respond to both. In terms of the literature, Francis and Ramey (2004) and Cole and Ohanian (1999) argue that negative technology shocks in the early 1930s may have been a major contributor to the economic downturn while Mensch (1979) and Kleinknecht (1981), among others, maintain that an upsurge in innovations in the latter part of the decade played a key role in the country's economic recovery. Our new measures indicate a pattern of ups and downs in technological change over the decade (see Figures 1 and 2) that is compatible with the arguments of both groups. Moreover, our regression results suggest that the economy was hit by a series of negative technology shocks between 1929 and 1935, and a series of positive ones from 1936 to 1941 (See Figure 5). In short, then, prima facie evidence lends support to both sets of arguments. However, this leaves unanswered the key question: did these fluctuations in technological change during the 1930s affect the performance of the economy?

To answer this question, we use counterfactual analysis to show what the economy would have looked like had technology not progressed as it did during the decade.

To begin, we pose another question: what would have happened to TFP and GNP per capita in the period 1929-41 had there been less innovative activity? In a nutshell, we find that without innovations, TFP improvements would have been much more modest and GNP per capita in 1941 would have been substantially below the level actually achieved. This is illustrated by the Panel A in Figure 6. Here we display the paths that GNP per capita and TFP would have taken had technological progress in the economy continued in the 1930s at: (1) the average rate that was achieved in the 1920s, and (2) the 1929 rate that was greater than the decadal average. (It is worth noting that 1916 and 1922 were the only years prior to the depression that achieved higher levels of technical change than 1929.) Quantitatively, we assume that from 1930 onwards, GNP per capita and TFP are determined by the following relationships:

$$\ln(GNP_t/Pop_t)=\underset{(0.6298)}{-0.0435}+\underset{(0.0017)}{0.0006}*t+\underset{(0.0747)}{0.8651}*\ln(GNP_{t-1}/Pop_{t-1})+\underset{(0.0794)}{0.1439}*\ln(Tech_{1920s}) \tag{3}$$

$$\ln(GNP_t/Pop_t)=\underset{(0.6298)}{-0.0435}+\underset{(0.0017)}{0.0006}*t+\underset{(0.0747)}{0.8651}*\ln(GNP_{t-1}/Pop_{t-1})+\underset{(0.0794)}{0.1439}*\ln(Tech_{1929}) \tag{4}$$

and

$$\ln(TFP_t)=\underset{(0.2224)}{-0.4690}+\underset{(0.0011)}{0.0009}*t+\underset{(0.0849)}{0.8337}*\ln(TFP_{t-1})+\underset{(0.0365)}{0.0774}*\ln(Tech_{1920s}) \tag{5}$$

$$\ln(TFP_t)=\underset{(0.2224)}{-0.4690}+\underset{(0.0011)}{0.0009}*t+\underset{(0.0849)}{0.8337}*\ln(TFP_{t-1})+\underset{(0.0365)}{0.0774}*\ln(Tech_{1929}) \tag{6}$$

where GNP_{1929}/Pop_{1929} and TFP_{1929} are the values observed in the data, and the numbers in parenthesis are the standard errors of the estimates. The figures suggest that had technological innovation held steady over the 1930s, and had there been no shocks hitting the economy, we would not have had the dramatic downturn in economic activity in the early 1930s and by 1941 real GNP per capita would have been 16% - 26% lower (depending on the growth rate assumed) than the actual 1941 value and TFP would have been 8.5% – 13.5% lower.

Panel B of Figure 6 shows what paths these variables would have taken if only the 'non-technology' shocks (depicted in the first two Panels in Figure 5) had hit the economy and technical change had remained at either the average rate of the 1920s or the 1929 rate. Although, as the results in Figure 5 illustrate, both technology and 'non-technology' shocks are negative in the early 1930s, non-technology shocks seem to have played the lead role in the onset of the Great Depression. The paths in the counterfactual economy with constant rates of technical progress and non-technology shocks shown in Panel B mimic well those seen in the actual economy in the early 1930s.[22] The obvious conclusion is that the type of technology shocks identified by our indicators was at most a minor contributor to downturn in the early 1930s. These results, of course, do not exclude the possibility that more broadly defined technology shocks played a significant role in the downturn but they do indicate that pure technology shocks (as measured by our indicators) were relatively unimportant.[23] As a consequence, the sharp drop in TFP in the period 1929-34 cannot be attributed to a decline in innovative activity but, instead, must have its source in some other component of the residual.

While pure technical change seems to have played little role in the onset of the depression, we do find that technical change made a significant contribution to recovery - without the realized rates of innovation from 1936 onwards, by 1941 the economy would still have had much lower levels of both GNP per capita and TFP. Panels C and D of Figure 6 confirm the importance of technological change in achieving the 1941 levels of real GNP per capita and TFP. In panel C we report the paths the variables would have taken had: (1) the economy not been hit by shocks from 1929 onwards, and (2) technology evolved according to

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[22] Given that the results in Sims (1980) and Burbidge and Harrison (1985) suggest only a part of the downturn can be explained by monetary policy shocks, these negative non-technology shocks may represent the liquidity shocks proposed by Christiano, Motto and Rostagno (2003), the sunspot shocks identified by Harrison and Weder (2006) and/or the type of uncertainty shocks discussed by Bloom (2007), Greasely and Madsen (2006), Greasely, Madsen and Oxley (2001), Leahy and Whited (1996) and Romer (1990).

[23] For example, the type of "news shocks" (interpreted as news about future technical progress) introduced by Beaudry and Portier (2006), and examined by Jaimovich and Rebelo (2006) are not excluded as a contributor by our findings. Since the "news shocks" are highly correlated with the broadly defined technology shocks identified using Gali's (1999) method, we assessed the sensitivity of our results by re-estimating our VARs with Beaudry and Portier's (2006) measure included (which is defined by the change in the log of the Standard and Poor's 500 Index divided by the population and the GNP deflator). We found that news shocks did contribute to economic fluctuations during this period. However, the explanatory power of our indicators did not decrease nor did our basic findings change.

the equations estimated in section three. In other words, we now allow technical progress to deviate from the 1920s average or 1929 rate and assume that real GNP per capita and TFP after 1929 evolved according to the following estimated equations:

$$\ln(GNP_t\,/Pop_t)= \underset{(0.6298)}{-0.0435}+ \underset{(0.0017)}{0.0006}*t+ \underset{(0.0747)}{0.8651}* \ln(GNP_{t-1}\,/Pop_{\,t-1})+ \underset{(0.0794)}{0.1439}*\ln(Tech_{\,t-1}) \tag{7}$$

$$\text{where } \ln(Tech_t)= \underset{(1.1173)}{3.5388}+ \underset{(0.0032)}{0.0073}*t+ \underset{(0.1326)}{(-0.0617)}*\ln(GNP_{t-1}\,/Pop_{\,t-1})+ \underset{(0.1408)}{0.4877}*\ln(Tech_{\,t-1}) \tag{8}$$

and

$$\ln(TFP_t)= \underset{(0.2224)}{-0.4690}+ \underset{(0.0011)}{0.0009}*t+ \underset{(0.0849)}{0.8337}* \ln(TFP_{t-1})+ \underset{(0.0365)}{0.0774}*\ln(Tech_{\,t-1}) \tag{9}$$

$$\text{where } \ln(Tech_t)= \underset{(0.8504)}{3.1613}+ \underset{(0.0043)}{0.0091}*t+ \underset{(0.3246)}{(-0.2514)}* \ln(TFP_{\,t-1})+ \underset{(0.1394)}{0.4857}*\ln(Tech_{\,t-1}) \tag{10}$$

The results demonstrate the importance of increased innovative activity in the 1930s. Unlike the paths depicted in Panels A and B, the values of GNP per capita and TFP in this counterfactual economy are only about 5 and 1.6 percent below the actual values in 1941. However, as Panel D illustrates, once the impact of the technology shocks depicted in Figure 5 are added to equations (8) and (10) above, the counterfactual economy does achieve the 1941 values although the path taken by the counterfactual economy differs significantly from that of the actual economy. That is, in our counterfactual economy, the negative technology shocks of the early 1930s would have caused output and TFP growth to stagnate between 1931 and 1936 while the positive technology shocks after that date would have fostered GNP per capita growth of over 17% between 1936 and 1941.

Figure 7 repeats the counterfactuals for the recovery period, 1933-41. Based on the results in Panel A, we find that if technical change had only occurred at the 1920s average rate after 1933, a rate virtually identical to that in 1933, TFP levels would have been ten percent lower in 1939 than they actually were and GNP per capita eighteen percent lower. In fact, had the rate of technological change remained at the average of the 1920s even after 1939, the country would have had to wait until 1952 to reach 1939 levels of GNP per capita and until the late 1950s to match 1939 TFP. The outcome is similar even when the 1929 rate of technological progress is used. In this case, we find that it would have taken until 1945 for the economy to have reached 1939 levels of GNP per capita and TFP. The figures in Panel B indicate that positive non-technology shocks played an important role in determining the speed of the recovery from 1933 to 1936. They also reveal, however, that had the rate of technological change fallen below that actually achieved in the later half of the 1930s, GNP per capita in 1941 would have lagged the actual level by 16.8 to 25.5 percent, and TFP by 8.6 to12.8 percent.

Panels C and D of Figure 7 again highlight the importance of stepped up technological progress for the economy's recovery. Although these figures suggest that the 'non-technology' shocks did contribute to the speed of the recovery during the period 1933-38, they also confirm that without the major increases in technological change that occurred in the late 1930s, the economy would have taken a much longer time to recoup the losses caused by the Great Depression. As Field (2006) observes, Schumpeter (1950) was on to something - the accelerated pace of technological change after 1933 did wonders for economic recovery.

In summary, we find that while the technological change identified by our indicators does help explain the recovery path of the US economy from the Great Depression, it provides a much less compelling account of the initial drop in economic activity at the beginning of the 1930s. Although it would be unwise to claim too much for this observation given the inherent problems associated with counterfactuals and the fact that our indicators only pick up a portion of what could broadly be defined as technological change, our results are, nevertheless, suggestive. Since the slowdown in innovative activity as measured by our indicators began, for the most part, after 1930, it would appear unlikely that the onset of the Great Depression can be ascribed to the type of negative technology shocks identified by our indicators.

V. Conclusions

We present in this paper a novel and we believe compelling way to measure technological change based on annual fluctuations in the number of new technology titles (both aggregate and by sub-groups) in the Library of Congress. We argue that our indicators dominate the standard measures of technical change such as patent applications, research and development expenditures, and direct enumeration of major innovations during the years 1909-49 for a number of reasons. They provide a consistent series available on an annual basis, they are based on strictly objective criteria – appearance in the data base of the LOC – and, perhaps most important, new technology publications are likely to track closely the timing of the commercialization of innovations. We use bi-variate VAR regressions to show that causal links did, in fact, exist for our period between innovative activity as captured by our indicators (an important caveat) and GNP per capita and TFP – although, as we point out, some technologies mattered more than others. In particular, manufacturing, automobile, and machine technologies had a much greater impact on output and productivity than those in chemicals and telecommunications.

Field's provocative claim (2003) that the 1930s was the most technologically progressive of the twentieth century gains at least some support from our results – the 1930s, we find, were much more technologically innovative than the periods 1909-1929 and 1941-49. In the final section of the paper we demonstrate how our new indicators can help use better understand the relationship between technology and economic activity in the 1930s. Specifically, we employ a counterfactual analysis to isolate the contribution of technological change to both the start of and recovery from the depression. As we report, the slowdown in technological change measured by our indicators in the early 1930s does not appear to account for much of the drop in output during this period. Instead we find that non-technology shocks are the primary culprit. However, we do find that the positive technology shocks we identify and the trend increase in technological change after 1933, as Field (2003, 2006) and others maintain, did play a major role in the economic recovery. Given that negative pure technology shocks do not appear to have been a major contributor to the downturn in the early 1930s, and the type of monetary policy shocks identified by Sims (1980) and Burbidge and Harrison (1985) only explain part of the downturn, future research should reexamine other possible contributors. These would included the liquidity shocks proposed by Christiano, Motto and Rostagno (2003), the sunspot shocks identified by Harrison and Weder (2006) and the type of uncertainty shocks discussed by Bloom (2007), Greasley and Madsen (2006), and Romer (1990).

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Appendix A. Library of Congress Classification Overview

Subclass T Technology (General)

Subclass TA Engineering (General). Civil engineering

Subclass TC Hydraulic engineering. Ocean engineering

Subclass TD Environmental technology. Sanitary engineering

Subclass TE Highway engineering. Roads and pavements

Subclass TF Railroad engineering and operation

Subclass TG Bridge engineering

Subclass TH Building construction

Subclass TJ Mechanical engineering and machinery

Subclass TK Electrical engineering. Electronics. Nuclear engineering

Subclass TL Motor vehicles. Aeronautics. Astronautics

Subclass TN Mining engineering. Metallurgy

Subclass TP Chemical technology

Subclass TR Photography

Subclass TS Manufactures

Subclass TT Handicrafts. Arts and crafts

Subclass TX Home economics

Appendix B. A Comparison of Dates and Examples of Publications

Below we provide invention and innovation dates for a number of major new breakthroughs identified by Mensch (1979), along with dates of commercialization, the copyright dates of the first books available from the Library of Congress, and examples of different types of publications that appeared in the first three years after the commercialization of the new technology. In light of the inherent subjectivity of Mensch's (1979) exercise, in a few instances we modified his dating on the basis of a reconsideration of the case studies in Jewkes et al (1969), with corroboration, where possible, from other sources. Moreover, for those cases in which commercialization dates were unavailable in Jewkes, et al (1969), we base our dates on information from http://inventors.about.com.

The thumbnail sketches presented below were chosen because they provide good examples of the range and nature of publications that one finds in the LOC data base for the different technologies. They include both foreign and domestic titles released by corporations, publishing houses, and government organizations.

Insulin

Date of Invention: 1889, Date of Innovation: 1922, Date of Commercialization: 1922,

First Copyright date: 1922

Examples of Titles:

1) The effects of insulin on experimental hyperglycemia in rabbits, by F. G. Banting, C. H. Best, J. B. Collip, J., J. R. Macleod, and E. C. Noble. Reprinted from the American journal of physiology, vol. 62, no. 3, November, 1922.

2) A primer for diabetic patients; a brief outline of diabetic treatment, including directions for the use of insulin, sample menus, recipes, and food tables, by Russell M. Wilder, Mary A. Foley, and Daisy Ellithorpe, 1923.
3) The biological standardisation of insulin, Publshed/Created by League of Nations, Health Organization. 1925.

Neoprene/Duprene

Date of Invention: 1906, Date of Innovation: 1932, Date of Commercialization: 1932 for Duprene and 1937 for Neoprene

First Copyright date: 1937

Examples of Titles:

1) The story of neoprene (formerly sold under the trademark "DuPrene") Its discovery, commercial development, and significance to science and industry. A Du Pont news bulletin, 1937
2) The Neoprene notebook, Published monthly by Rubber Chemicals Division of E.I. Du Pont de Nemours & Co., 1938- (after 1956 the monthly publication is re-titled the Elastomers notebook and is still published today)

Nylon

Date of Invention: 1927, Date of Innovation: 1938, Date of Commercialization: Dec. 1939

First Copyright date: 1939 (in Japanese), 1940 (in English)

Examples of Titles:

1) Nylon, Published/Created by Ōsaka-fu Senpoku-gun Takaishi-machi : Bōshoku Zasshisha, Shōwa in Japan, 1939

2) Women's full-fashioned hosiery, nylon and silk. Published/Created by Indianpolis, Ind., National youth administration for Indiana, 1940
3) Electrophoretic studies of nylon, Published/Created by Washington, U. S. Govt. print. off., 1941

Penicillin

Date of Invention: 1922, Date of Innovation: 1941, Date of Commercialization: 1943, First Copyright date: 1943

Examples of Titles:

1) Penicillin and other antibiotics produced by microörganisms; an annotated bibliography. Published/Created by E. R. Squibb & sons, 1943.
2) Penicillin Merck, its action and uses. Published/Created by Merck & co., inc. 1943.
3) Abstracts on penicillin and other antibiotic substances, by Muriel E. Whalley, Research plans and publications section. Published/Created by the National Research Council Canada Ottawa, 1943.
4) Penicillin, by Sir Howard Florey. Published/Created by Nelson, R.W. Stiles & co., ltd., 1944.
5) Penicillin. Published/Created by United States. Office of War Information. 1944

Streptomycin

Date of Invention: 1921, Date of Innovation: 1944, Date of Commercialization: 1945, First Copyright date: 1945

Examples of Titles:

1) The chemotherapeutic action of streptomycin and promin in experimental tuberculosis. Published/Created by U. S. Govt. print. off., 1945.

2) Miracles from microbes, the road to streptomycin by Samuel Epstein and Beryl Williams. Published/Created by Rutgers University Press, 1946.
3) The clinical use of streptomycin. Published/Created by Merck & Co. 1947.

Kodachrome Film

Date of Invention: 1910, Date of Innovation: 1935, Date of Commercialization: 1935/6, First Copyright date: 1937

Examples of Titles:

1) Natural color film; what it is and how to use it; a work devoted to the technique and handling of "Kodachrome" in motion picture and still photography. By Clifford A. Nelson; Published/Created by The Galleon press, 1937.
2) How to make good color prints from Kodachrome; a manual of instruction for users of Curtis color printer 4 x 5, model K, 2d ed. Published/Created by Thomas S. Curtis laboratories, 1940.

Silicones

Date of Invention: 1904, Date of Innovation: 1946, Date of Commercialization: 1946, First Copyright date: 1946

Examples of Titles:

1) An introduction to the chemistry of the silicones, by Eugene G. Rochow. Published/Created by J. Wiley & sons, inc., 1946.
2) Des caoutchoucs synthétiques aux silicones by Maurice de Buccar. Published/Created by Elzévir (Paris), 1946.

Terylene Polyester fiber (marketed under the name Dacron by Dupont)

Date of Invention: 1941, Date of Innovation: 1955, Date of Commercialization: 1953,

First Copyright date: 1953

Examples of Titles:

1) Home methods of spot and stain removal from most fabrics, including rayon, nylon, orlon, dacron, etc. Published/Created by MacKay and Associates, inc.,1953.
2) The dyeing of Terylene polyester fibre, second ed. Published/Created by Imperial Chemical Industries, ltd. Dyestuffs Division, 1954.

Automatic Transmission

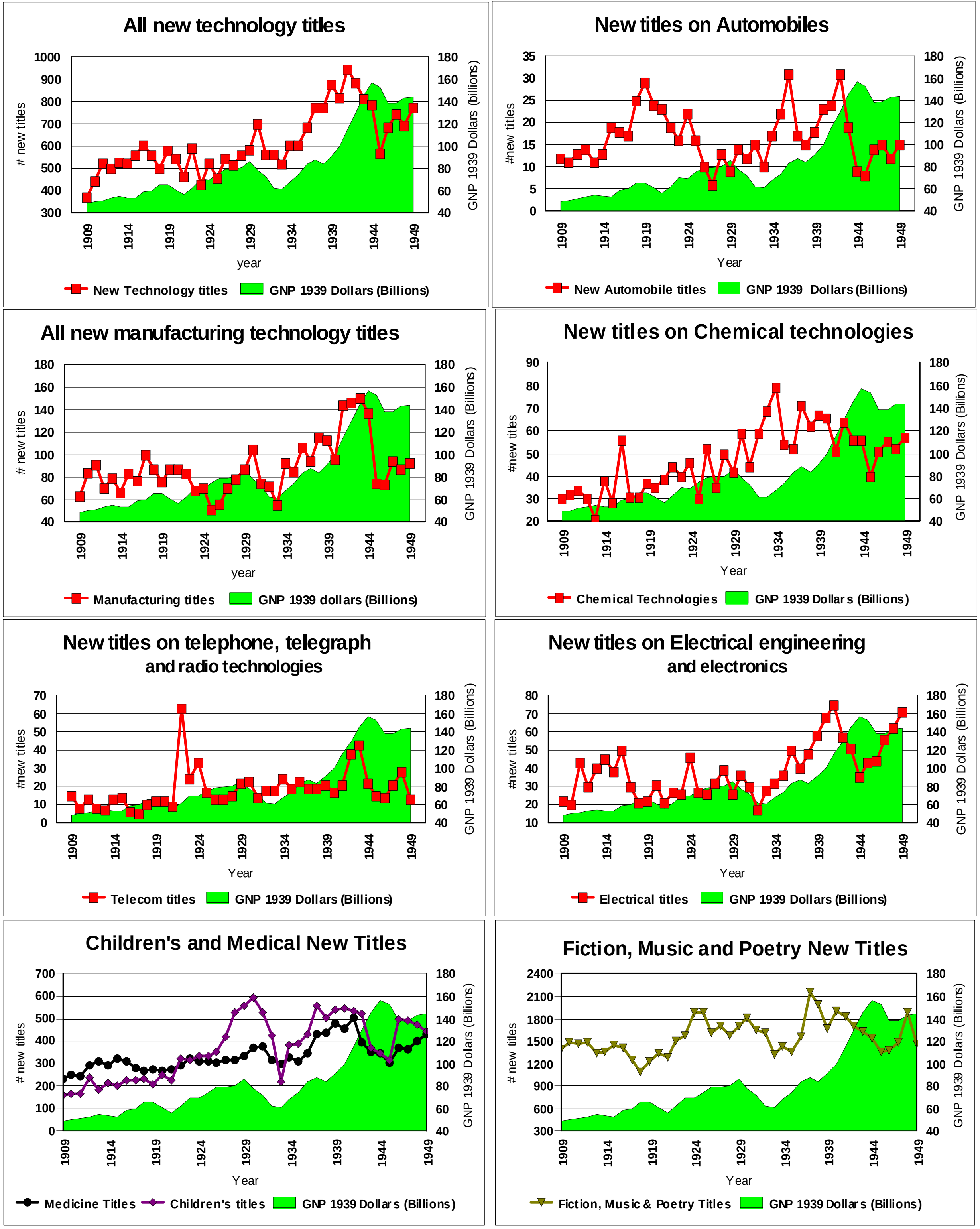
Date of Invention: 1904, Date of Innovation: 1939, Date of Commercialization: 1939,

First Copyright date: 1939

Examples of Titles:

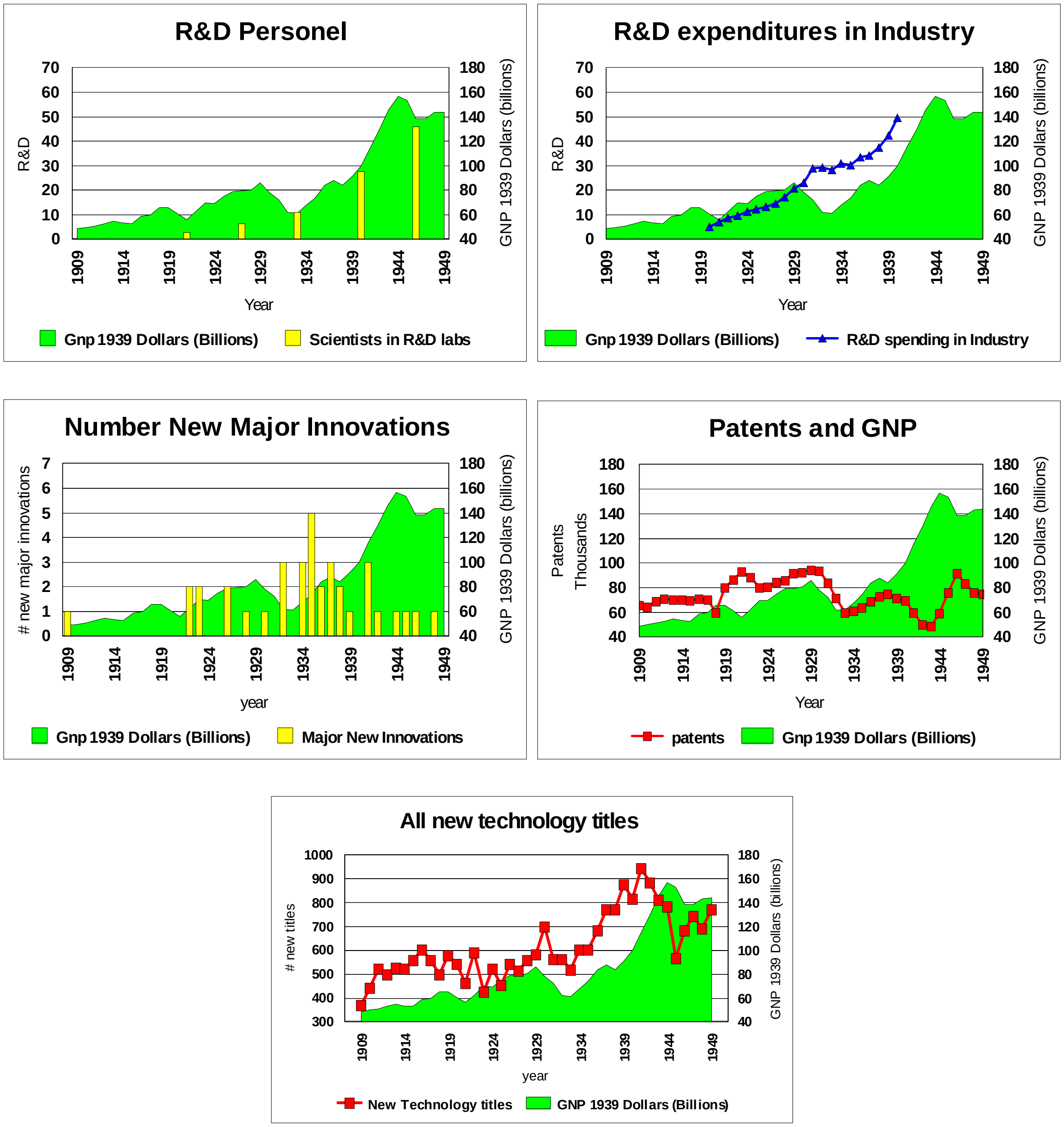
1) Automatic overdrive and remote-control gear shifts, by Charles Ray Strouse. Published/Created by International correspondence schools, 1939.
2) Automobile friction clutches, prepared especially for home study ... , by Charles Ray Strouse. Published/Created by International correspondence schools, 1939.

Figure 1. The Indicators



Notes: All technology series, as well as the new children's, medical, fiction, music and poetry titles are derived from the Library of Congress' MARC record database, while the GNP series is from the Economic Almanac (1953-54)

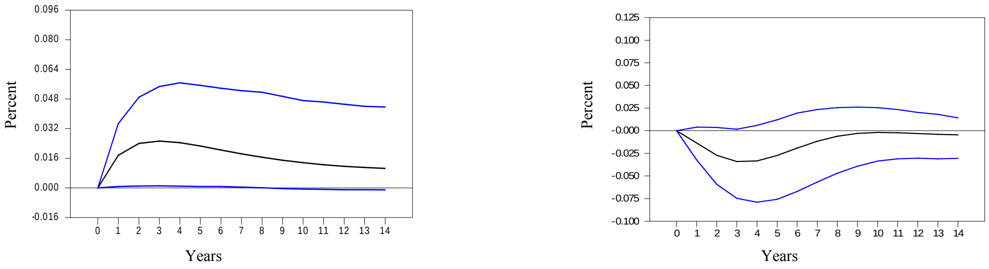
Figure 2. Measures of Technological Change



Notes: The technology indicator is based on the Library of Congress' MARC record database, the GNP series is from the Economic Almanac (1953-54), the R&D personel series is from Mowery and Rosenberg (2000), the Major innovation count is derived from data in Mensch (1979), Industrial R&D series is from the Report of the Committee on Science and the Public Welfare, National Science Foundation (1945) and the patent series is obtained from the U.S. Patent and Trademark Office.

Figure 3. Impulse Response of Real GNP per capita

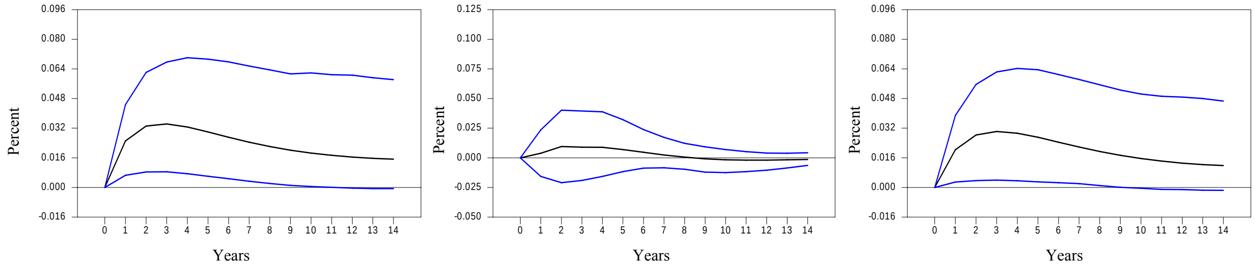
PANEL A: Aggregate Technology Measures



Total Technology

Patents

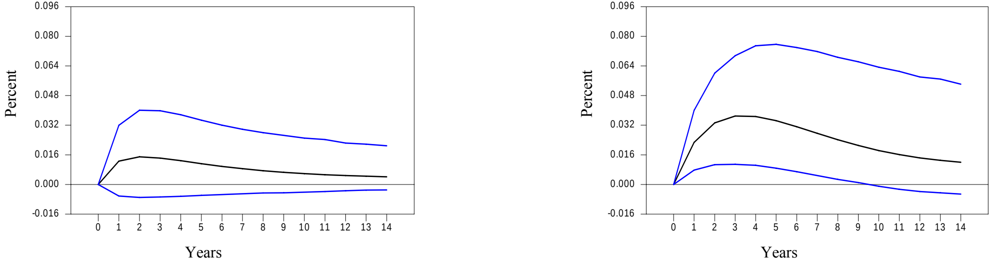
PANEL B: Specific Technology Group Measures



Electrical Technology

Chemical Technology

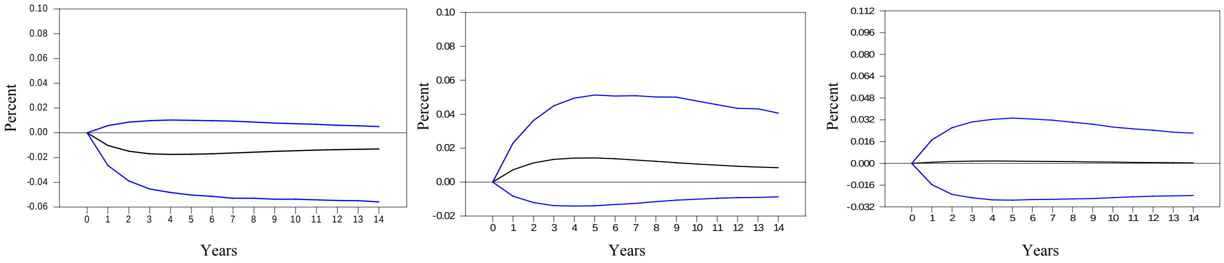
Manufacturing Technology



Traditional telecommunications
(radio, television, telephone and telegraph)

Automotive Technology

PANEL C: Other Publication Measures



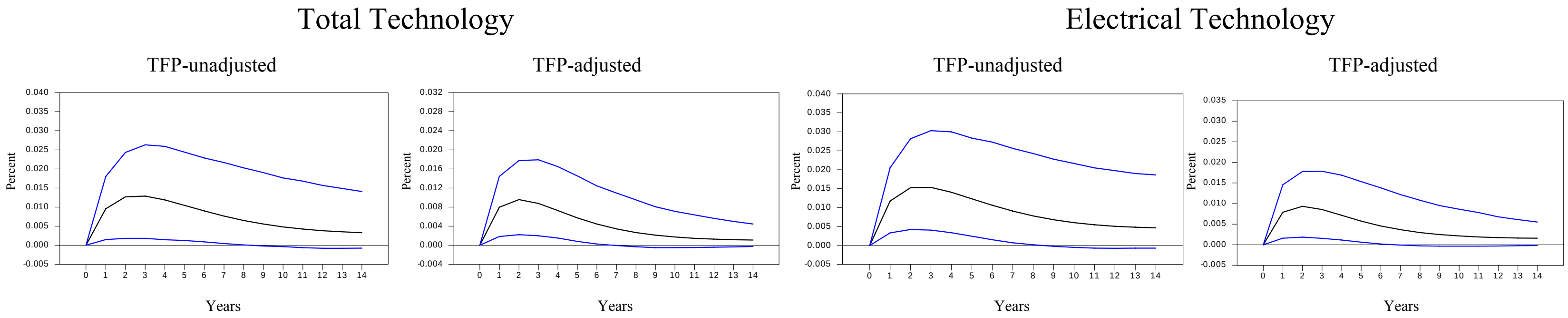
Children's books

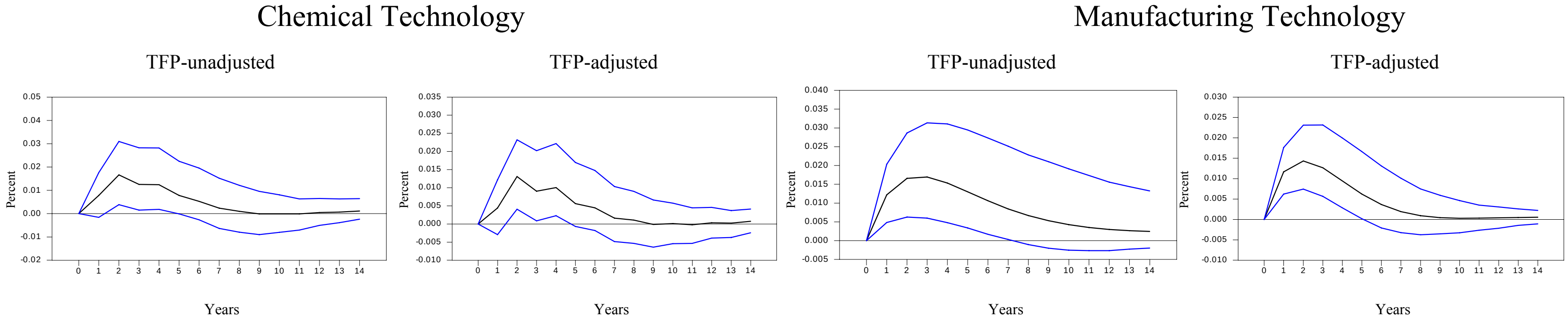
Medical Books

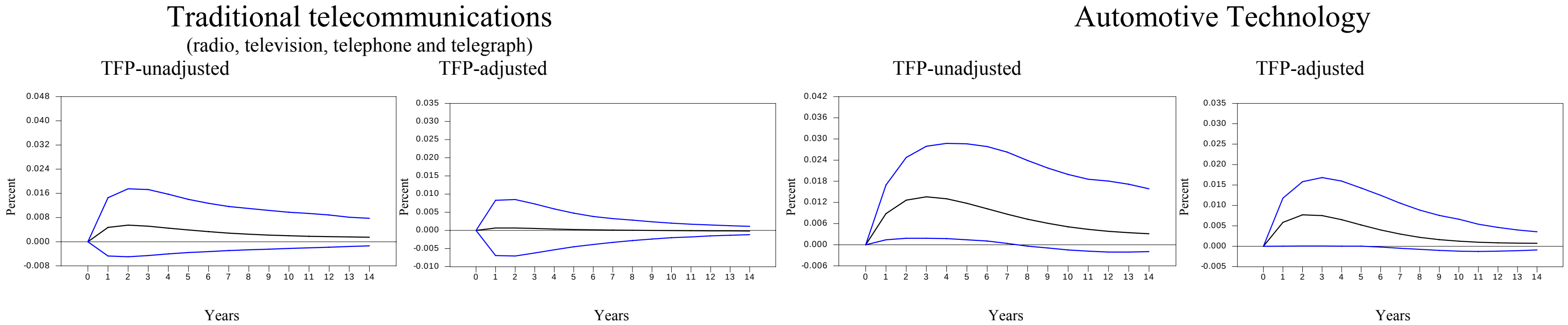
Fiction, Poetry & Music

Notes: These VAR Cholesky orthogonalized impulse response functions are estimated using annual data from 1909-1949. Each panel displays the response to a one-standard deviation shock to technology and the 90% confidence interval. In each case, ln(real GNP per capita) is the first variable in the bi-variate system.

Figure 4. Impulse Response of TFP to a Positive Technology Shock

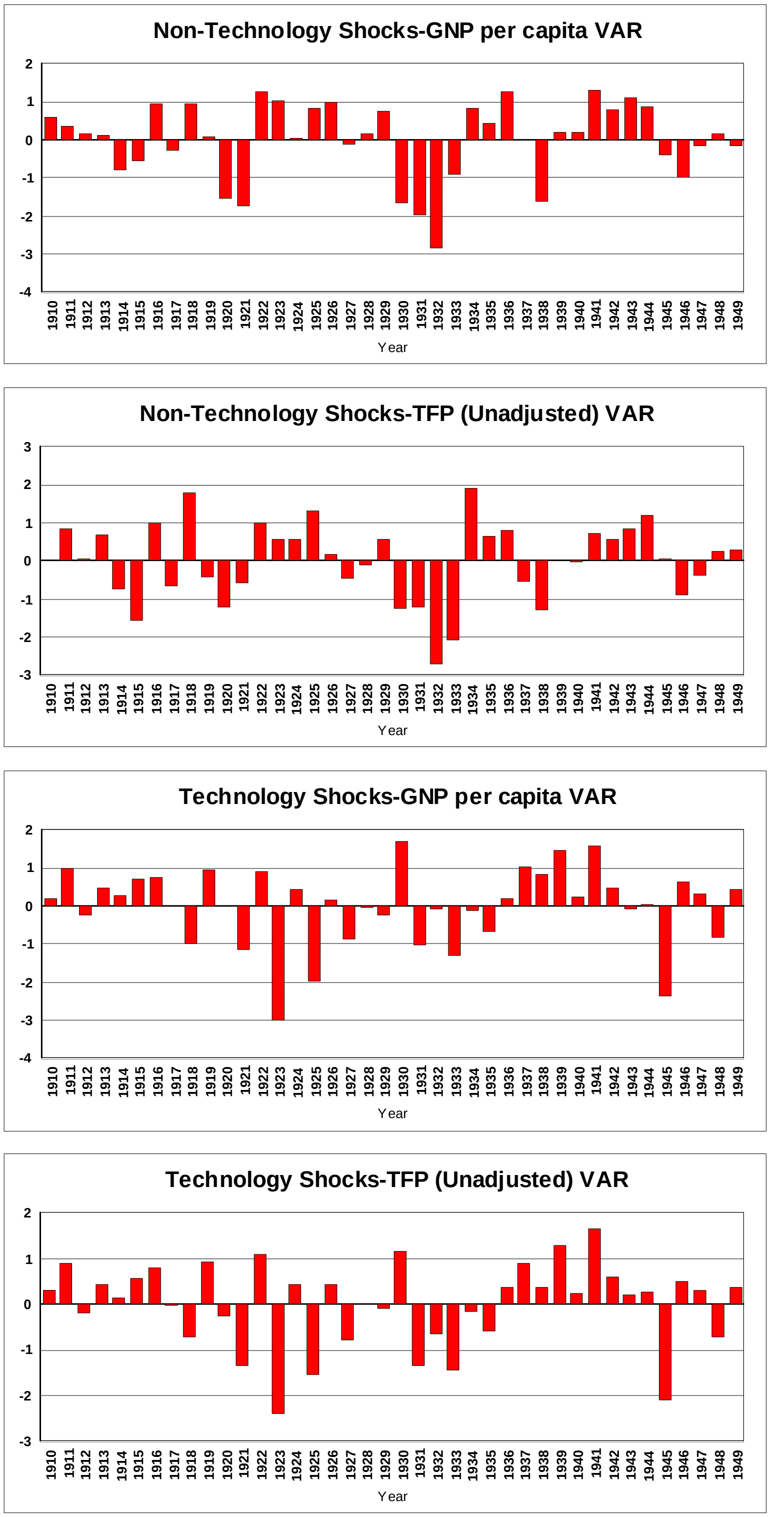






Notes: These VAR Cholesky orthogonalized impulse response functions are estimated using annual data from 1909-1949. Each panel displays the response to a one-standard deviation shock and the 90% confidence interval. In each case, ln(TFP) is the first variable in the bi-variate system.

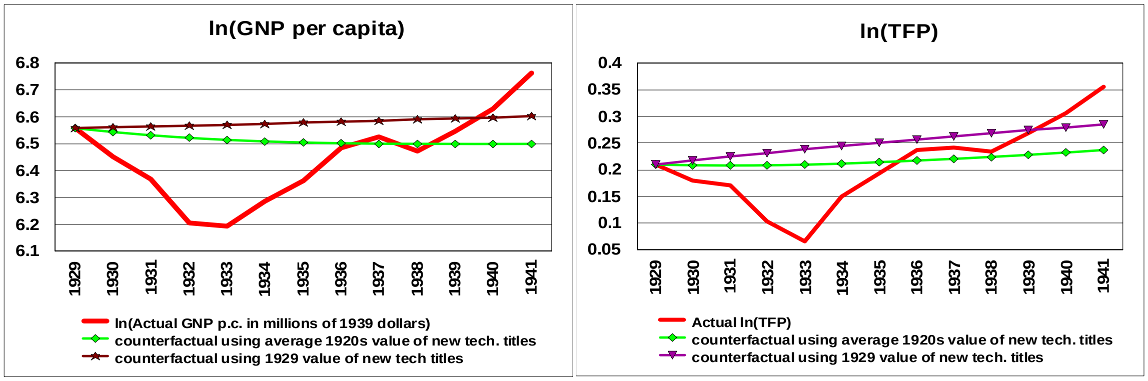
Figure 5. Technology and Non-Technology Shocks



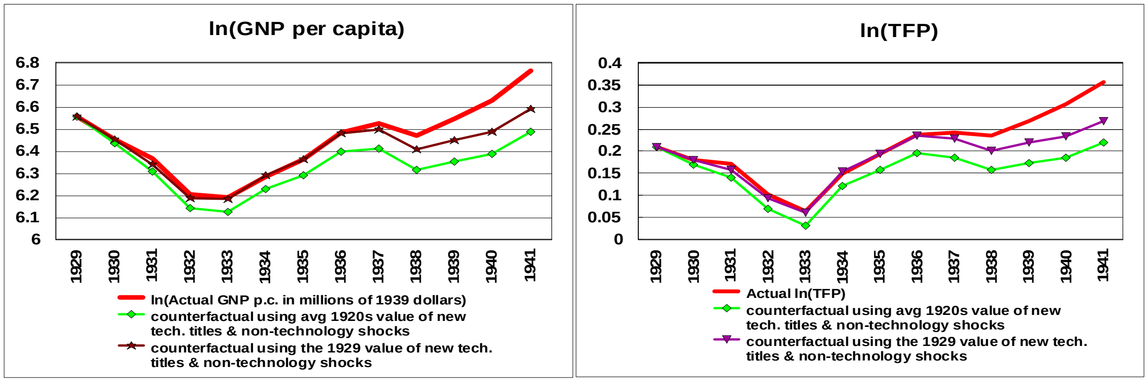
Notes: The shocks are obtained from the following bi-variate VARs: $Y_t = \alpha + \gamma t + \rho Y_{t-1} + \varepsilon_t$, where $Y_t = [\ln(TFP_t), \ln(Tech_t)]'$ or $Y_t = [\ln(\text{GNP per capita}_t), \ln(Tech_t)]'$. Based on the recursive ordering, the technology shock at time t is defined as the component of the technology residual which is orthogonal to the contemporaneous GDP (or productivity) residual.

Figure 6. GNP per capita and TFP Counterfactuals: 1929-1941

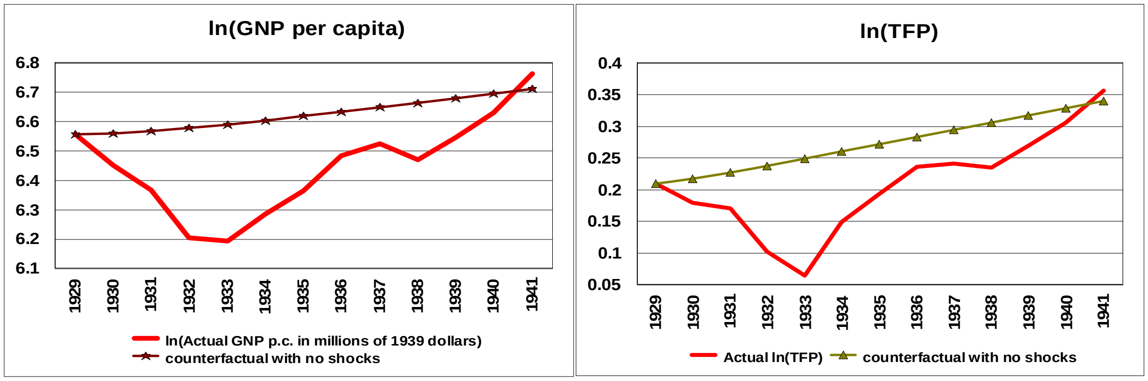
Panel A:



Panel B:



Panel C:



Panel D:

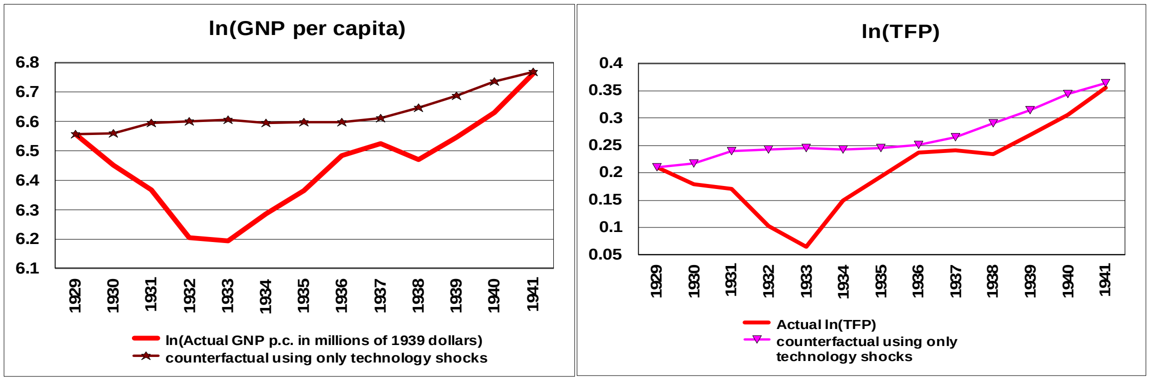
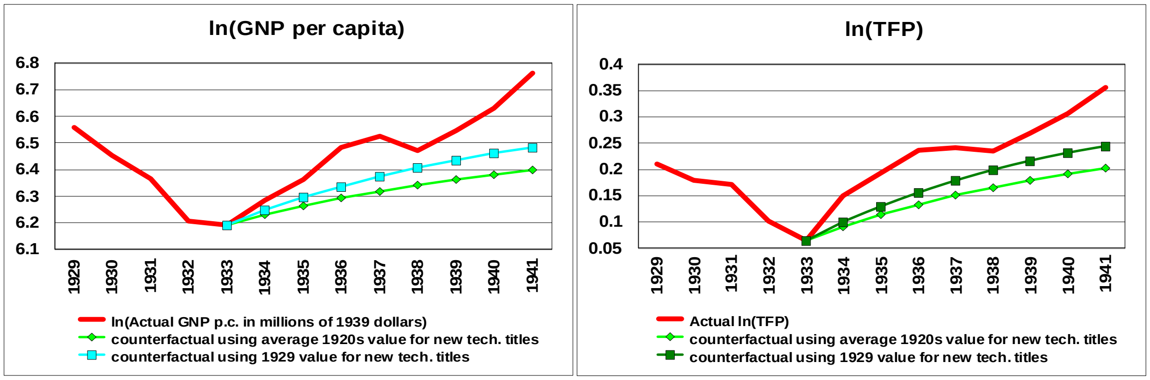
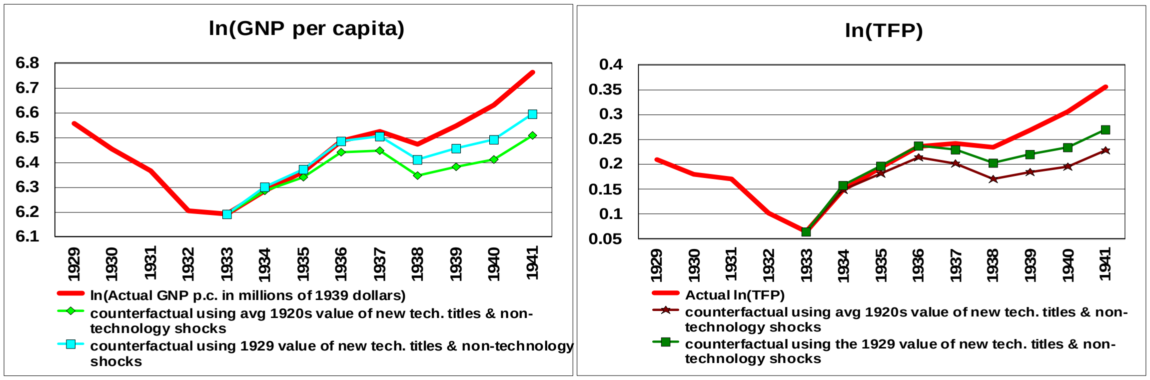


Figure 7. GNP per capita and TFP Counterfactuals: 1933-1941

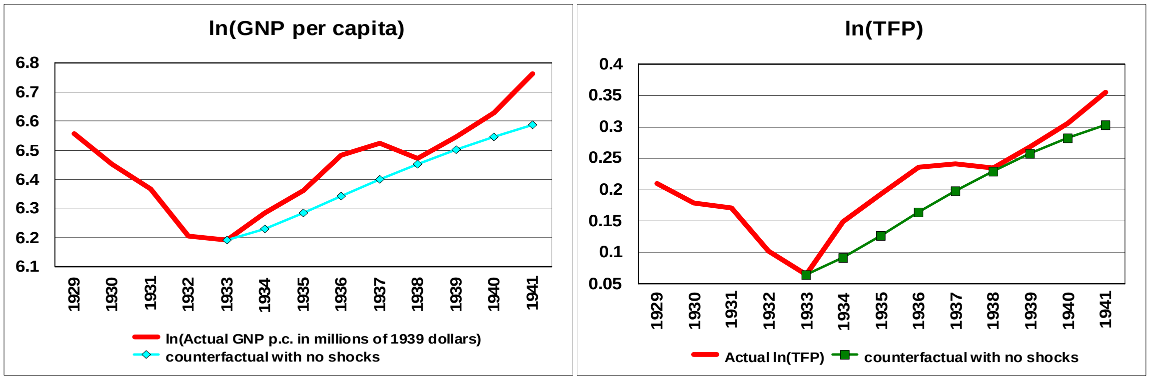
Panel A:



Panel B:



Panel C:



Panel D:

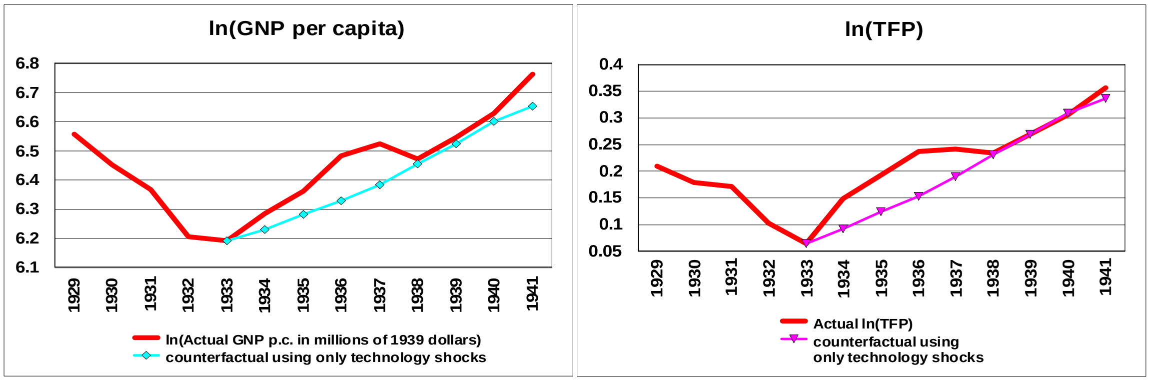


Table 1. Point Estimates for Real GNP per Capita and TFP regressions

Indicator*	GNP p.c. (1939 dollars)		TFP Unadjusted		TFP Adjusted	
	ρ_{11}	ρ_{12}	ρ_{11}	ρ_{12}	ρ_{11}	ρ_{12}
All Technology	0.8651	0.1439	0.8337	0.0774	0.7239	0.0640
	(0.0571)	(0.0797)	(0.0728)	(0.0320)	(0.0927)	(0.0260)
Manufacturing	0.8395	0.1025	0.7943	0.0625	0.6555	0.0591
	(0.0596)	(0.0480)	(0.0722)	(0.0203)	(0.0887)	(0.0170)
Chemical**	1.3066	0.0230	1.0828	0.0493	0.8416	0.0253
	(0.16056)	0.02863)	(0.1648)	(0.0214)	(0.1306)	(0.0273)
	-0.4354	0.0401	-0.0268	0.0774	0.1485	0.0629
	(0.1752)	(0.0711)	(0.1592)	(0.0348)	(0.1377)	(0.0219)
Electrical	0.8339	0.0894	0.8006	0.0415	0.6958	0.0275
	(0.0489)	(0.0333)	(0.0643)	(0.0180)	(0.0912)	(0.0134)
Telecom	0.8872	0.0296	0.8448	0.0108	0.7280	0.0015
	(0.0631)	(0.0210)	(0.0766)	(0.0123)	(0.1026)	(0.0113)
Automotive	0.9070	0.0719	0.8526	0.0281	0.7268	0.0185
	(0.0621)	(0.0359)	(0.0768)	(0.0135)	(0.1048)	(0.0094)
Patents	1.2038	-0.1548	0.9552	-0.0916	0.6731	-0.0863
	(0.1346)	(0.0742)	(0.1718)	(0.0436)	(0.1335)	(0.0371)
	-0.3636	0.0595	-0.1228	0.0214	0.0683	0.0231
	(0.1216)	(0.0885)	(0.1437)	(0.0504)	(0.0848)	(0.0343)
Children's Books	0.8577	-0.0513	0.8108	-0.0335	0.6870	-0.0193
	(0.0593)	(0.0618)	(0.0741)	(0.0244)	(0.1031)	(0.0119)
Medical Books	0.8901	0.0788	0.8547	0.0342	0.7535	0.0353
	(0.0680)	(0.1247)	(0.0832)	(0.0471)	(0.1131)	(0.0237)
Fiction, Poetry & Music	0.8808	0.0071	0.8425	-0.0003	0.7352	0.0096
	(0.0666)	(0.0983)	(0.0788)	(0.0432)	(0.1079)	(0.0269)

Notes: For all cases except Chemical and Patents the results correspond to the regression $\ln(GNP_t/Pop_t)=\alpha+\gamma t+\rho_{11}\ln(GNP_{t-1}/Pop_{t-1})+\rho_{12}\ln(Tech_{t-1})+\varepsilon_t$ and $\ln(TFP_t)=\alpha+\gamma t+\rho_{11}\ln(TFP_{t-1})+\rho_{12}\ln(Tech_{t-1})+\varepsilon_t$. For the cases of chemicals and patents the regressions are: $\ln(GNP_t/Pop_t)=\alpha+\gamma t+\rho_{11}\ln(GNP_{t-1}/Pop_{t-1})+\rho_{21}\ln(GNP_{t-2}/Pop_{t-2})+\rho_{12}\ln(Tech_{t-1})+\rho_{22}\ln(Tech_{t-2})+\varepsilon_t$ and $\ln(TFP_t)=\alpha+\gamma t+\rho_{11}\ln(TFP_{t-1})+\rho_{21}\ln(TFP_{t-2})+\rho_{12}\ln(Tech_{t-1})+\rho_{22}\ln(Tech_{t-2})+\varepsilon_t$, where the first row reports the estimated values of ρ_{11} and ρ_{12} and the second row corresponds to the estimates of ρ_{21} and ρ_{22}.

Table 2. P-values for Granger Causality Tests

Panel A: Does Technology Granger Cause GNP per capita?

Indicator	Lag Length	GNP p.c. 1939 dollars	TFP Unadjusted	TFP Adjusted
All Technology	1	0.071	0.016	0.014
Manufacturing	1	0.033	0.002	0.001
Chemical	2	0.626	0.001	0.004
Electrical	1	0.007	0.021	0.041
Telecom	1	0.158	0.379	0.896
Automotive	1	0.045	0.037	0.050
Patents	2	0.022	0.004	0.0018

Panel B: Does GNP per capita Granger Cause Technology?

Indicator	Lag Length	GNP p.c. 1939 dollars	TFP Unadjusted	TFP Adjusted
All Technology	1	0.669	0.471	0.538
Manufacturing	1	0.804	0.299	0.134
Chemical	2	0.000	0.000	0.000
Electrical	1	0.957	0.659	0.686
Telecom	1	0.055	0.049	0.818
Automotive	1	0.080	0.077	0.086
Patents	2	0.114	0.211	0.211

Panel C: Do Other Titles Granger Cause GNP per capita or TFP?

Indicator	Lag Length	GNP p.c. 1939 dollars	TFP Unadjusted	TFP Adjusted
Children	1	0.406	0.169	0.105
Medical	1	0.527	0.468	0.136
Fiction, Poetry & Music	1	0.942	0.994	0.722

Panel D: Does GNP per capita or TFP Granger Cause Other Titles?

Indicator	Lag Length	GNP p.c. 1939 dollars	TFP Unadjusted	TFP Adjusted
Children	1	0.553	0.533	0.496
Medical	1	0.475	0.436	0.445
Fiction, Poetry & Music	1	0.532	0.674	0.860

Notes: For the cases of total technology, automotive, manufacturing, electrical, telecommunications, children's, medical and fiction, poetry and music books, $Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t$, and for the case of patents and chemical technologies $Y_t = \alpha+\gamma t+\rho_1 Y_{t-1} +\rho_2 Y_{t-2} +\varepsilon_t$, where $Y_t = [\ln(TFP_t), \ln(X_t)]'$ or $Y_t = [\ln(\text{GNP per capita}_t), \ln(X_t)]'$ and X_t is the value of the indicator at time t.

Table 3. Variance Decompositions

Indicator	Horizon	GNP p.c. 1939 dollars	TFP Unadjusted	TFP Adjusted
All Technology	3 years	6.55	9.53	13.07
	6 years	11.87	16.87	21.11
	9 years	13.56	18.75	22.17
Manufacturing	3 years	9.02	15.77	28.62
	6 years	16.69	27.17	40.53
	9 years	19.12	29.40	40.70
Chemical	3 years	0.59	10.11	14.26
	6 years	1.05	14.78	23.15
	9 years	1.10	15.08	23.45
Electrical	3 years	13.24	14.01	12.45
	6 years	21.95	23.25	19.81
	9 years	24.38	25.38	20.82
Telecom	3 years	2.71	1.87	0.07
	6 years	4.01	2.79	0.10
	9 years	4.35	3.01	0.10
Automotive	3 years	12.41	8.81	7.52
	6 years	24.58	17.83	14.22
	9 years	28.61	20.44	15.23

Notes: These decompositions are based on bi-variate VARs where ln(GNP per capita) and ln(TFP) are ordered first. For the cases of total technology, automotive, manufacturing, electrical, and telecommunications, the VAR takes the form $Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t$, while for the case of chemical technologies $Y_t = \alpha+\gamma t+\rho_1 Y_{t-1} +\rho_2 Y_{t-2} +\varepsilon_t$, where $Y_t = [\ln(TFP_t), \ln(X_t)]'$ or $Y_t = [\ln(\text{GNP per capita}_t), \ln(X_t)]'$ and X_t is the value of the indicator at time t.