Volumes of Evidence:

Examining Technical Change Last Century Through a New Lens

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Abstract

Although technical change is central in much of modern economics, traditional measures of it are, for a number of reasons, flawed. We present in this paper new indicators based on data drawn from the MARC records of the Library of Congress on the number of new technology titles in various fields published in the United States over the course of the last century. These indicators, we argue, overcome many of the shortcomings associated with patents, research and development expenditures, innovation counts, and productivity figures. We find, among other things, the following: the pattern and nature of technical change described by our indicators is, on the whole, consistent with that of other measures; they represent innovation not diffusion; a strong causal relationship between our indicators and changes in TFP and output per capita; innovations in some sub-groups have had a greater impact on output and productivity than others and, moreover, the key players have changed over time. Our indicators can be used to shed light on number of important issues including the empirical relationship between technology shocks and employment, the role of technology in cross-country productivity differences, and the part played by technological change in growing skills premia in the U.S. during the last few decades.

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I. Introduction

We have three objectives in this paper: first, to present new indicators of technological change that, we believe, resolve many of the problems associated with traditional ones; second, to show that they do, in fact, provide compelling measures innovative activity; and, third, to indicate potential uses for them. Our motivation is obvious. Although technical change is central in much of modern economics, our ability to identify empirically the factors that shape its pace, nature, and impact are constrained by data limitations. New and improved measures of technological change are, therefore, likely to advance our empirical work and to have significant theoretical and policy implications.

For our purposes, an effective measure of technical change should be able to do the following: first, capture inventions as close as possible to the moment of commercialization and, second, provide quantifiable, comprehensive, consistent, and objective indicators of innovative activity over time, across sectors and, preferably, across countries.[1] The problem with current measures is that in one way or another they all fall short of the mark. For example, research and development expenditures measure inputs into the inventive process, not outputs of commercial innovations, and, furthermore, for the pre-WW II, their coverage is, at best, spotty. Indicators based on membership in scientific or related organizations – a measure favored by scientists and bibliometricians - suffer from similar shortcomings. Innovation counts do pick up innovations at the moment of their commercialization (or, at least, purport to do so) but fail both the objectivity and the completeness-of-coverage tests. While productivity estimates (either TFP or output per worker) have many attractive features, they are compromised by the problem that factors other than technical change affect productivity. Efforts to identify and eliminate these "other factors", while often

[1] See Griliches (1990).

ingenious (see Basu et al. (2006) and Ohanian(2001)), are technically demanding and, in the final analysis, still have to deal with the opaqueness of the residual.

There are finally patent statistics. For all their appeal – they are objective, quantifiable, comprehensive, and, on the whole, consistent – they do have well known drawbacks. Thus, although patents do measure potentially viable commercial innovations, they do so prior to their commercialization. Since the lags between the former and the latter are often long and variable, patents are unlikely to provide fool-proof indicators of innovative activity that impact the economy. Moreover, as Griliches (1990) and Schmookler (1962) note, fluctuations in the number and nature of patents may stem from changes within the patent office or from incentives to patent, neither of which have anything to do with changes in innovative activity.

Our new indicators, based on data drawn from the Library of Congress (LC) on the number of new technology titles in various fields published in the United States over the course of the last century do appear to fit the bill. Since the LC is by far the largest in the United States (probably in the world) and serves as the nation's copyright depository, these data provide a fairly comprehensive list of the flow of new technology titles available to the trade and to the public. They are, moreover: (1) objective (since what is and isn't defined as technology is determined by rules followed by library cataloguers), (2) quantifiable, and (3) consistent over time (the overall classification system has been in place since the late 1800s). Finally, there is every reason to believe that new technology publications are timed to coincide with the commercialization of new products or processes.[2]

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[2] There is the additional attractive feature that this type of indicator can be used in other countries provided that: (1) they have catalogued their library holdings using a subject based classification system (such as LC, Dewey ,or Bliss), and (2) the set of library records is large enough to ensure that they provide a relatively accurate picture of the publications used within the country.

Nothing of course is perfect, including our new indicators but, we would argue, the imperfections are relatively minor. Thus, while it is probably true that not all technological advances are captured by books, as we attempt to show in the next section, the net cast by new titles is remarkably wide. Changes in the number of new publications may be affected by ups and downs in the publishing industry, but our findings suggest that the patterns, on the whole, appear to be dictated by changes in innovations.[3] Finally, although LC librarians must assume responsibility for cataloguing new titles, there is very little evidence to indicate that misclassification is a problem.

To summarize briefly our results, we find, first, that our indicators are, for the most part, consistent with others that have been used to measure technological change. Second, despite the substantial difficulties in distinguishing between an innovation and its diffusion, we demonstrate that our indicators, by and large, represent the former not the latter. Third, in keeping with the conventional wisdom, we find that technological change (not including computers) accelerated from 1933-1941 again during the years 1958-1970 and, and after a couple of relatively sluggish decades jumped sharply in the early 1990s. As one might suspect, computer technologies burst on the scene with vigor in the early 1980s and again in the early 1990s. Fourth, our bi-variate vector autoregressions run over the two sub-periods 1909-49 and 1950-1997 indicate for both time periods a strong causal link between technological advances as measured by new publications and changes in TFP and GNP per capita. Finally, our results suggest, not surprisingly, that some innovations had a much greater impact on output and productivity than others – and, moreover, that the sub-groups that mattered changed over time. Thus, in the early period, 1909-1949, electrical, manufacturing and mechanical, and automotive technologies were the main drives of output and productivity growth,

[3] In other papers, we have examined changes in the number of titles in other book categories to demonstrate that the indicators are not generally driven by overall trends in the publishing industry. (See Alexopoulos (2006) and Alexopoulos and Cohen (2007))

while in the later period (1950-1997), electrical, civil engineering and infrastructure, and computer technologies were the principle agents of expansion.

We proceed as follows in the paper. In the next section, we discuss the data, in the following, we report the results of our regressions, and, in the final, we indicate potential uses of these new indicators and areas for future research.

II. The Evidence

In this section we describe our new indicators, review their intuitive appeal, compare their performance with that of traditional ones, consider the issue of diffusion, and, finally, present the pattern of innovations traced by our indicators over the course of the twentieth century. Although much of the basic science associated with an innovation is known, at least by others in the field, prior to its commercialization, knowledge of the commercial product or process is unknown (or at least limited) until it appears on the market. Successful launch, therefore, necessitates dissemination of information – and this is where books enter.

II A. Description

Our indicators are based on the MARC (**MA**chine **R**eadable **C**ataloging) records of the LC (See Figure 1). 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.[4] As indicated in the introduction, the LC is the largest library in the U.S. with over 130 million items and receives roughly fifteen thousand new publications each day. It is safe to say the MARC records of the LC provide a

[4] The LC, often sells large portions of their records to other libraries. As a result, they take great care to ensure that their product is free of errors. If errors are noticed, users are encouraged to report them so that they can be corrected.

virtually complete list of all major new titles copyrighted within the United States across a vast range of topics.

A MARC record contains a large quantity of information on each publication including**:** the type of book (for example**,** a new title, a new edition of an existing one, a reprint, or translation), the country and language of publication, the publisher, the LC's Classification Code, and a list of major subjects treated in the book. We use these data to compile a list of new titles in different fields of technology (subgroups of T)[5] and computer titles (a subgroup of QA) published in English in the U.S. each year between 1909 and 1997.[6] We exclude from the list all books that include history as a descriptor (or use the word history in the title) since history-related technology books are unlikely to have much to do with the introduction of new products or processes. The final tally includes all manuals and books in the MARC records that deal with new technologies including 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 the new technology, others by third parties who hope to profits from sales of the book or pamphlet. In all cases, the motive for the publications is the same: to obtain financial gain from spreading the word.

II. B Intuition

As we outlined in the introduction, a good indicator of technical change needs to capture innovations at the moment of their commercialization. This property is crucial for a number of reasons. First, it approximates the timing of technological change or technology shocks that feature

[5] See Appendix A for an overview of the types of technologies in LC T Classification. To focus sharply on technologies likely to be used in the market economy, what we refer to as our T class excludes titles dealing with handicrafts and home economics.

[6] Here we cut off the data in 1997 to avoid any biases created by the relatively large backlog of uncatalogued titles at the LC.

in many economic models. Second, it is through the adoption of new technologies that innovations affect output and productivity. Third, if we ever hope to develop a deep understanding of what affects the nature and timing of technical change, we must have data that permit us to make a sharp distinction between invention and innovation. In this section, we first explain why it makes sense to believe that publications are closely linked to commercialization and, second, present some empirical evidence to bolster our intuition.

It is essential for innovating companies to promote their innovations (this is how they maximize return on them) and to teach their customers how to use them – and books, manual, and pamphlets are clearly considered by these companies to be an effective way to accomplish this.[7] Of course, the innovating firm is not the only, or even the major source of new titles on new products or processes for the simple reason that independent publishers and writers stand to profit by entering the market. For all these groups, timing is critical – if the publication is released too early, it is unlikely to have much of a market while if it appears too late, the market will be saturated and the information, at best, dated. Thus, for sound economic reasons, these agents are motivated to publish their books and manuals as closely as possible to the release date of the innovation – precisely the feature we seek in an indicator of technical change and one that R&D expenditures and patent applications, with their long and indeterminate lags, fail to provide.

If we are correct, we would expect to find a relatively close chronological coincidence between the first appearance in the LC database of a book on a particular technology and the

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[7] Many companies ship new products with manuals and other in-house produced books and also sell them in bookstores. This is a good example of the belief by these companies that publications are an effective way to spread the word and instruct the public. This would seem to suggest that the internet and other forms digital communication act as complements rather than substitutes for old technology.

commercialization dates for the innovation as reported in books such as those by Mensch (1979)[8] and Jewkes, Sawers, and Stillerman (1969) which focus explicitly on dating important innovations in the first half of the twentieth century. By the same token, we would expect a similar level coincidence to be observed between the dating of innovations in management techniques and information technologies (neither of which are included in Mensch (1979) and Jewkes, et.al. (1969)) and the appearance of new titles in the LC database. The results of our comparisons, presented in Tables 1 and 2, support our priors – and, as it happens, even the anomalies are informative. For example, one of the longest lags between commercialization date and first book appearance in the LC catalogue is associated with Neoprene/Duprene. When the product debuted in 1932 under the name Duprene, it was reported to have an unpleasant smell which seriously compromised its commercial appeal. While a limited amount of the product was supplied to the market over the next few years, Dupont went back to the drawing board, changed the formula to eliminate the odor and improve the product, and re-released it, under the name of Neoprene, in 1937.[9] The rest, as they say, is history.[10] The book data, instead of misleading, is actually more informative about the successful commercialization of Neoprene than the 'original' commercialization data.

. Our measure of technical change has an additional attractive feature – by its nature, it tends to assign more weight to important innovations where the weight given to each technology annually is

[8] In light of the inherent subjectivity of Mensch's (1979) exercise, in a few instances we modify his dating on the basis of a reconsideration of the case studies in Jewkes et al (1969), with corroboration from other sources. Moreover, the commercialization dates we report are based on information from Jewkes et al (1969) and http://inventors.about.com.

[9] See Smith (1985).

[10] The first book, published by Dupont, was entitled, "Story of neoprene (formerly sold under the trademark "DuPrene"), its discovery, commercial development, and significance to science and industry."

determined by the number of new titles released on it each year.[11] The reason is simple. Given that the market is generally larger for major innovations, more titles are likely to appear on a major (or general purpose) technology than on a minor (or sector specific) one. Consequently, our book based indicators will be high for one of two reasons: (1) lots of small innovations are brought to market, each accompanied by a couple of new publications, or (2) a major innovation debuts that affects many sectors and fosters numerous new titles. In either case, we would expect to observe a positive relationship between the number of new titles and economic variables, such as output and productivity, which is, of course, the relationship that we are trying to explore.

II.C. Old and New Indicators Compared

As in all things, indicators of technological change are not created equal. Each has strengths and weaknesses which makes it attractive for some purposes and not for others. In this sub-section we first create tables (Tables 3 & 4) that permit us to put side by side the pros and cons of our new indicators and those of tradition measures such as patents, patent citations, R&D expenditures, and major innovation counts. This exercise shows clearly what each of these indicators can and cannot do. We then compare the trends in technological change traced by our indicators over the course of the twentieth with those of other measures. While the similarities are striking, the differences are revealing.

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[11] As a result, the new indicator more closely resembles patents weighted by citations than it does the simple number of patent applications. See Jaffe and Trajtenberg (2002) for some examples of papers that use patent citations as the measure of technical change.

Although all of the indicators have been used to track technological change, there are clear differences in coverage, comprehensiveness, objectivity, ability to weight innovations by their importance, and timing. A summary of these differences is provided below.

Availability of Statistics: Patent applications, book measures, and major innovation counts are available for the greatest length of time. Reliable, continuous R&D statistics for the U.S. date from the 1950s while citation weighted patent data are, at this point, only available from the mid 1970s.

Objectivity: Of all the measures, only major innovation counts fail this test.

Linkages to disaggregate data: Virtually all of the traditional indicators**,** as well as our new one**,** can be linked to disaggregate data.

Timing: The various measures pick up innovations at very different stages of the development process. As Griliches (1990) points out, R&D should be viewed as an input into the knowledge function, not an output, whereas patents (both regular and citation-weighted) can be thought of as proxies for output. However, again as Griliches (1990) notes, patent applications do not provide a foolproof measure of commercially viable innovations. Some patents never become commercial products or processes, some innovations are not patented, and even those that do make the transition can take from months to years to do so. Our book measure does not suffer from these uncertainties since new titles appear in the MARC records of the LC when the innovation hits the market. While major innovation counts should, almost by definition, pick up new technologies at the moment of their commercialization, ambiguities in introduction date make timing highly subjective. On the whole, we find that Mensch's (1979) innovation dates lie somewhere between the date of a patent and the date of the product's commercialization.

Weighting of Different Technologies: Only the citation-weighted patent measure and the book based measure give more weight to major technological innovations. Major innovation counts obviously include only major innovations but suffer from a lack of objectivity.

Coverage: Some measures are clearly more comprehensive than others. In particular, our book based indicators, aside from their broad coverage of traditional areas, also capture innovative changes in management, organization, and other non-technical aspects of the production process. Since these types of innovations are usually unamenable to the patent process, have nothing to do with the research lab, and are not often embodied in some new piece of equipment or the equivalent, they are unlikely to be picked up patents, R&D expenditures, and even innovation counts. On the other hand, they do show up in publications for the simple reason that someone stands to profit from writing about them.[12] Despite that fact that these advances are notoriously hard to measure, their impact may be substantial. For example, in the first half of last century Weintraub (1939) argued that, in many cases, it was these types of innovations that increased productivity in the late 1930s.

Despite these differences, there are also similarities. There is a payoff to R&D spending – otherwise, it would not take place – and many patents do result in commercial products or processes. We would, therefore, expect to observe a similarity in the time series traced by these various innovation indicators. This is exactly what Alexopoulos (2006) noted in a previous article where she found a statistically significant link between new publications of technology books – in general and in the IT field– and research and development for the post-WW II period.[13] One natural question to ask at this point is: How do these new indicators compare with previous ones seen in the literature.

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[12] Good contemporary examples include Total Quality Management (TQM) and just-in-time production and inventory management, both of which spawned a large number of new technology titles.

[13] She also found a relationship between patents and the book measure for the computer technologies.

Figures 2 and 3 help answer this question. In the first of these figures, we focus on the first half of the century. Specifically, we compare our measure of technical change with the available data on the number of patent applications, R&D expenditures, personnel in R&D laboratories, membership in scientific societies, and Mensch's major innovations count. Overall there appears to be a rough correspondence in trend between these indictors, even though the R&D figures, and to a lesser extend the number of members in major Scientific Organizations, measure inputs into the inventive process not the output of commercially viable innovations,[14] and Mensch's (1979) series is subjective the results reveal a rough correspondence in trend between these indicators. The exception during this period seems to be patents. It is the only indicator that indicates a decline in innovative activity during the 1930s. However, this anomaly may be explained by changes in the propensity to patent during this time period.[15]

In Figure 3, we present the most commonly used traditional indicators, Patents and R&D statistics, with the membership in scientific organizations and our technology measures for the later time period. Again, there appears to be a rough correspondence in trend between the measures. All suggest that innovative activity was alive and well during the 1950 and 1960s, slowed during the 1970s, and started to pickup again thereafter.

II. D. Confusion about Diffusion?

There is, of course, the possibility that our indicators measure diffusion not innovation. While we have tried to guard against this by excluding from our titles serial publications and new

[14]Although R&D outlays may be a good measure of the intensity of inventive activity, it is important to note, as Mowery and Rosenberg (2000) and others do, that many innovations are not lab based and much lab research does not result in commercially viable innovations.

[15] See e.g., Schmookler (1961) and Griliches (1993) for a discussion.

editions, some may still question the integrity our indicators. Given the importance of this issue, we present in this sub-section additional evidence in support of our innovations indicators.

In trying to distinguish between innovations and diffusion, it is essential to get the level of aggregation right. An example will help clarify this point. Assume that we want to measure advances in computer technology over the last thirty or so years. If we take the computer as our product innovation and sales as the measure of its diffusion, the last thirty or so years would appear to have been the story of the diffusion of computer technology. At one level, this is clearly an accurate statement but, for our purposes, it hides more than it reveals. That is, the personal computer of 2008 is vastly different from that of 1978 or even 1998, a difference that is largely attributable to a number of major technological innovations. If the computer is our unit of observation, this evolution will appear as one long process of diffusion. On the other hand, if we disaggregate and distinguish, for example, between the mainframe, the PC, the laptop, the notebook, the PDA and so on, we will observe a whole series of innovations with different diffusion patterns. Our book measure allows us to do this – in fact, the distinctions are clearest if we do so.

We can put some flesh on these bones. If we assume that diffusion occurs over a number of years – in effect, tracing a regular S-shaped diffusion curve – we can show that our indicator captures innovation not diffusion.[16] In Panel A of Figure 4, we present sales figures – our proxy for diffusion – and the number of new titles for two products, the Commodore 64 and Windows 3.1, both of which remained, more or less, unchanged over the period during which these products were marketed. The overall pattern is striking – the number of new titles for each product declines well before sales begin to drop. This, we would argue, provides compelling evidence that our measures pick up commercialization not diffusion.

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[16] If diffusion is extremely rapid, it is impossible to make a distinction between the two and, in any case, probably does matter since the two are essentially simultaneous events.

In Panel B, we use a slightly different metric to get at the same issue: in this case, we rely on the number of books available from Amazon.com on a monthly basis for Windows Vista. [17] Although sales of the new software remain brisk and may even be accelerating in response to the release of a new service pack, the number of titles (including paperback and other editions since we have no way of excluding them) is declining.[18] Thus, in spite of the very brief time span involved and the inclusion of various editions of the same publications, the pattern replicates those observed in Panel A.[19]

Innovations and sales in areas other than information technology display similar patterns. Consider, for example, Neoprene, a major innovation introduced by Dupont in the 1930s.[20] Neoprene, still the same basic product as the original, continues to sell well as a high-profile product in the polychloroprene rubber market. Thus, in 2000, sales of polychloroprene topped 315 metric tons with Neoprene used as a component in a wide range of products from bridge pads to dive suits, athletic shoes, and airplane seats.[21] If we were to count all titles, that is, new books plus serial

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[17] There are two reasons that we use data from Amazon.com for this exercise. First, it provides information on the day, month and year that the book was made available, and second, because of the backlog in cataloguing at the LC, the list of books on Vista, at this stage, is likely incomplete.

[18]It is worth noting that the number of books available on pre-order has also dropped to almost zero. We are aware of this because major publishers will inform the Library of Congress about planned titles in advance of their printing as part of the CIP program in order to get an LC control number and classification code so that this information may be printed in the first few pages of the book with the ISBN and copyright information.

[19] One might wonder why a publisher would issue a new title six months after introduction. One possibility is that this title is timed to take advantage of a small market that wants a title that incorporates (1) information on the updates contained in service packs or fixes to the original product, (2) information on the interaction of Vista with other software. Of course there is always the possibility that the book will not be released.

[20] See Table 1 above.

[21] See Morris (1997).

publications and subsequent editions, we would come up with over 600 publications, a good indication, we would argue, of the importance of the product.[22] However, if we drop the periodicals and new editions, the number of new titles falls to five with none appearing during the last 40 years. In short, our indicator picks up Neoprene at the time of its innovation – as a good indicator should - but does not track its diffusion. On the other hand, it is worth noting that Neoprene's enormous success (and its impact) has been associated with other innovations and applications - not with innovations in the composition of Neoprene itself.

Pharmaceuticals are another group of products that often have very long shelf lives and relatively clear cut innovation dates. For example, penicillin, discovered in 1928, commercialized in 1943 and patented for mass production in 1948, is still used extensively with global sales in 2002 in excess of $4,273 million.[23] New titles follow a very different trajectory. In the last five years, eleven books have appeared in the LC catalogue on penicillin, all labeled historical, and thus excluded from our technical change indicator. In fact, in the last thirty years only two titles make the cut, one a conference volume on drug interactions, the other a book on a new technique introduced in Denmark to produce penicillin. In contrast, of the approximately 115 titles (including new editions) in English on penicillin, forty-four appeared between 1943 and 1948, and if we exclude all publications with the subject keyword history, the total drops to seventy-three, of which forty-three (more than fifty-eight percent) were released between 1943 and 1948. In light of these statistics, it seems reasonable to conclude once again that new penicillin titles measure innovation not diffusion.

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[22] Dupont has published since the 1938 a periodical on neoprene initially entitled The Neoprene Notebook, then The Elastomers Notebook, then The Elastomers Times in which the Company reviews advances in the field associated primarily with new uses for the product. Although we do not pursue this idea here, it may be possible to use the total number of publications to weight the significance of an innovation. This could be used as a complement to citation weighted patents.

[23] This figure is taken from Datamonitor's 2003 report, "Commerical Insights: Antibacterials"

In Panels C and D of Figure 4, we present sales data and innovation measures for automobiles, trucks, and buses in the interwar years and for Apple's OS X operating system both of which support our contention that new titles measure innovation not diffusion. The first case is interesting because, contrary to what we might expect, the number of new titles on technologies affecting for automobiles, trucks, and buses declines over the 1920s (when automotive sales are growing) and increases over the 1930 – even though 4.6 million less cares were sold.[24] In fact, the correlation between these two series from 1920-1939 is virtually zero because of there vastly different patterns. At the very least, this lack of coincidence between the appearance of new titles and sales would seem to suggest that our indicators do not measure diffusion. A look between the covers confirms this hunch. Sales were robust during the 1920s and weak during the depression while innovative activity, for whatever reason, followed exactly the opposite pattern. Thus, safety glass and balloon tires were commercialized in the 1920s, non-trivial innovations but hardly comparable to those innovations in the 1930s: automatic transmission, front end suspension, the mass produced all-steel unitized body, and the mass-produced , fully reliable cast V single engine block. In a nutshell, then, our indicator would seem to track automobile innovations during the inter-war years in the U.S., not their diffusion.

The story of innovations associated with Apple's OS X operating system illustrates the need to get the level of aggregation correct before one decides whether the indicator measures diffusion or innovation. Apple still uses the OS X system in its computers and since their sales are growing, the operating system is still diffusing. At the same time, the number of titles linked to OS X continues to expand. New titles would appear to be picking up diffusion as well as innovation. Appearances, however, are deceiving. Apple has introduced five new versions of this system since its initial

[24] Here we focus only on new titles that are linked with automotive technology in the T classification (as opposed to all titles in the TL class) since we are examining sales of automobiles, trucks and buses.

release with the three later ones marketed under the names Panther, Tiger and Leopard. To see if the new titles are, in fact, merely tracking diffusion or if, instead, they are measuring significant innovations in Apple's operating system, we broke out the number of titles linked to Panther, Tiger, and Leopard.[25] The results are unequivocal. At this level of disaggregation, the pattern traced by new titles mimics that depicted in Panel A – as time from the initial release elapses, the number of books (including the new editions) drops.

II.E. Waves of Innovation

While the trend in innovative activity over the last century has been positive, there have been marked cycles around this trend. Moreover, at a less aggregate level, the chronological pattern of technological advance differs across sub-groups. Both these features have been noted in the extensive literature on technical change.[26] The question we address in this sub-section is what do our new indicators tell us about these waves of innovation?

We focus on six major groups:

- Electrical technologies including electrical generation and distribution technologies, electronics, electric motors, transformers, telecommunications, and works on the applications of electricity –TK class in the LC system.
- Mechanical and manufacturing technologies – LC classifications TJ and TS – which includes among things motors, hauling equipment, conveying equipment, robotics, production and operations management, and technologies associated with manufacturing

[25] To do this we focused on books listed on Amazon.com and in the LC catalogue that explicitly had the version named in the title or in the edition statement, for example, OS X Tiger for dummies or the Leopard edition. While one may argue that these new system are merely variations on a theme and not innovations, this is not the way either Apple or tech commentators or the public regard them.

[26] See, for example, Mensch (1979), David and Wright (2003), Mowery and Rosenberg (2000), and Kleinknecht (1987).

sectors such as metal manufactures, metalworking, stonework, wood, lumber and wood products, furniture, leather, tanning, and furs, paper, textiles, rubber, cereal and grain milling, tobacco, and animal feeds and feed mills.

- Transportation technologies - TL (Motor vehicles. Aeronautics and Astronautics) and TF (railroads) in the LC classifications.
- Chemical technologies (classification TP) including chemical engineering, biotechnology, explosives and pyrotechnics, fuel (including petroleum refining), food processing and manufacture, refrigeration, the production of oils, fats, waxes, paints, pigments, varnishes and polymers, textile bleaching, dyeing, and printing, clay, glass, gas, cement, and non-electric illumination.
- Residential and commercial construction (TH classification) and infrastructure, including civil engineering and bridge, road, highway and waterway engineering (found in classes TA, TC, TE and TG).
- Finally, computer hardware and software technologies (QA classification).

As we show in Figures 5 and 6, the general trend among all subgroups is positive, especially after WWII. To dispel the illusion that this trend represents nothing more than advances in publishing, we present in Table 5 the total number of new titles released each year by major U.S. publishers drawn from R.R. Bowker.[27] As can be seen, although the numbers in most categories do rise over the post-war period, technology titles (excluding computer technologies) increase more than non-technology ones, which would seem to suggest that we are observing more than trends in

[27] R.R. Bowker is the exclusive United States ISBN and SAN agency. It receives title information from all major publishers and is the world's leading source for bibliographic information. It publishes, among other things, Books In Print, AquaBrowser, and Pubnet.

publishing. Moreover, as noted above, this is consistent with trends based on traditional measures such as patents and R&D, providing additional evidence that our indicators are picking up changes in technology not publishing.[28]

To get some sense of the chronology of technological advance across the different subgroups, we can look at the ratio of new titles by sub-field to the total number of new technology books for both the pre and post 1950 years, where total new technology is defined as the titles under the T classification.[29] The results, presented in Figures 7– 9, are intriguing. In the first graph, focused on electrical technologies, we note that electrical technologies have increased in importance over the last century, going from approximately ten percent of new technology titles in the beginning to about twenty-five percent by the end. Telecommunications have played a significant role in the major spikes, first with the radio in the 1920s then with advances in computer networks and cellular telephones in the 1980s. Even the mini-spike in the 1940s was linked to innovations in telecommunications, in this instance, advances in radar.[30]

Transportation technologies, presented in the second half of Figure 7, follow a very different pattern. Railroad technologies peak early in the century and remain relatively unimportant

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[28] Here we do not mean to imply that the latest technologies are more important than some of the previous ones, only that the rate at which new advances come to market appears to be increasing.

[29] This comparison will likely not be biased by any general trend in the publishing industry since we would expect the different fields of technology to be more or less equally affected by factors such as the cost of printing.

[30] Even though radar was a classified technology during the war, the dating of radar technologies is still accurate since (1) even material that was classified was still copyrighted at the correct time, and the Library of Congress may receive copies after the technology is declassified, and (2) other books may be printed at the time that the declassified technology is adopted to civilian use. To see an example of the first point, the manual prepared by Philco Corp in 1942 for the navy entitled "Instruction book for navy models ASG, ASG-1, aircraft radar equipment" has the copyright date 1942, but was received by the LC in 1946 after the war according to the information stored within the LC control number.

thereafter. The heyday for trucks, cars, motorcycles, and airplanes, spans the middle decades of the century, jumping from just over ten percent of new titles in 1924 to close to thirty percent in the early 1950s, thereafter slowly drifting back to twelve percent by the century's end. This pattern is perfectly consistent with what we know about all three subgroups. Changes in rail technology were, for the most part, modest in the twentieth century. Technological change in automotive technology, on the other hand, accelerated in the 1920s and continued to boom into the 1950s with a number of significant innovations including automatic transmission, power steering, hydraulic brakes, the unitized steel body and so on. As change in this subgroup subsided, progress in aeronautical technology took up some of the slack with major innovations such as the jet engine, changes in aircraft design, and technologies linked to air traffic control and expansion of airport facilities.

The first graph in Figure 8 presents the pattern for manufacturing and mechanical technologies. It indicates that these technologies have declined in importance relative to others throughout the twentieth century with the notable exception of the early 1940s and the last twenty-five or so years of the last century. The 1940s burst of innovative activity was closely tied to advances in metal manufacturing, ordinance production, synthetic rubber, and operations management associated with the war effort while the second was linked to robotics and other developments in machine tools.

The fourth graph in the series (at the bottom of Figure 8) examines the pace of technical change in infrastructure (civil engineering, bridges, roads, and dams) and construction technologies (residential and commercial building). Although there is no observable trend in the relative importance of construction titles, there are large swings in that for infrastructure. Two episodes of intense innovative activity in infrastructure stand out, the first between 1919 and 1934, the second from the mid 1940s to the late 1960s. Both periods have attracted the attention of economists.

Fernald (1999), for example, argues that the build-out of roads and related public infrastructure in the 1950s and 1960s had a large positive impact on productivity in the U.S. Our indicators suggest that innovations in infrastructure technologies may have accompanied this process. Field (2006) notes that a surge in road building also occurred in the 1930s which, he believes, played a role in the jump in TFP during the depression. Although we find that the innovative surge in infrastructure technologies pre-dates the depression build-out, it is perfectly reasonable to suppose that the expansion of the highway system and related infrastructural projects benefited from these earlier technological advances. In fact, this may be another instance of diffusion following innovation, the former picked up by our indicators, the latter by the expansion of output.

The big moment for chemical technologies, as shown in the fifth graph (top of Figure 9), seems to have occurred in the 1920s and the 1930s. Although this may, at first, seem counter-intuitive given the huge presence in our world today of chemical based products, it is worth noting that many of the technologies on which these goods are based date from the pre-1950 period. These include, among other things, synthetic detergents, early plastics, Neoprene, and synthetic fibers.

As we might expect, the computer, defined broadly, came into its own during the second half of the twentieth century. As can be seen in the graph at the bottom of Figure 9, no matter how one measures the relative importance of computer technology – as a percent of all technologies (T class plus QA), as a percent of all technologies, excluding computers (just T), or computers plus telecommunications as a percent total plus computers (T plus QA) – the results are the same. The largest upswing, beginning in the 1980s, is propelled by the introduction of the personal IBM computer, its clones, the Macintosh, and, of course, all the related software. By the mid-1980s, computer books accounted for close to twenty-five percent of all technology titles and, with telecom titles included, peaked in 1984 at thirty-five percent of all titles. A slight divergence in trend can be seen from the early 1990s between IT and computers as the former embraces the internet while the latter, still important, begins to look more and more like a mature subgroup.

III. The relationship between GDP and Productivity

In this section we examine the relationship between economic output, productivity and our measures of technical change. We break our sample into two sub-periods: 1909-1949 (which we refer to as the Solow period), and 1950-1997. We do this for two reasons. First, official U.S. statistics for wages, salaries, indirect taxes, and so on – the kind of data needed to compute factor shares and TFP - only become available in 1929. Solow (1957) does, however, report his share estimates for the period 1909-1949 and these are the data we chose to use for these years. We could, of course, have used Solow's numbers for the pre-1929 period and have merged them with the official statistics after that date. We vetoed this option, however, because the merge date would have coincided with the start of the depression and very large swings in measured productivity which could have distorted our results. For the period 1950-1997, we computed a Tornqvist TFP measure using the available date from the BEA.

Second, our graphs in the waves of innovation section indicate that the various sub-groups varied in importance over the course of the twentieth century. As a result, it seems reasonable to suppose that we would also observe variations in the impact of the different types of technical change on TFP and output over the same time period. Since these differences matter, dividing the whole period into two parts allows us to highlight them more clearly. Our priors are supported by our results. Although it might have been of interest to report the failures as well as the successes, to economize on the number of graphs and tables, we report only the latter results.[31]

[31] Output for the Solow period is measured by GNP, for the post-war years by GDP. The data for the "Solow period" is obtained from: the National Conference Board's Economic Almanac (GNP per person in $1947

III.A. Examining the Links

To investigate the relationship between technological change (as measured by our indicators) and output (or TFP), we estimate the following bi-variate VARs:

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

where $Y_t = [\ln(Z_t), \ln(X_t)]'$, with Z_t being our measure of output or TFP, and X_t one of our technology indicators. [32] As in Shea (1998) and Alexopoulos (2006), we identify technology shocks by assuming that they affect the Z variables with a one year time lag.[33, 34] Figures 10 and 11 display the impulse responses to a one standard deviation technology shock (as identified by our indicators), and 90 percent confidence intervals for the Solow period and the post-war period respectively. Table 6 reports the point estimates for the technology variables from the output and TFP equations, Table 7 displays the Granger-causality tests, and Table 8 shows the variance decompositions for our two periods.

For the Solow period we find that technical change in the following groups had a significant impact on output and/or TFP: total technologies, electrical, manufacturing and mechanical,

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constant dollars and hours worked, Solow (1957) (the share data), and Goldsmith (1956) (the capital stock numbers).

[32] Due to the short time series available, the unit root tests are inconclusive. Therefore, we opt to use levels instead of first differences and include a time trend.

[33] See Francis and Ramey (2004) for an analysis that uses the long-run restrictions approach in a VAR to identify technology shocks in the pre-WWII period.

[34] To determine if ordering has a significant impact on our results, we also ran VARs with the technology indicator entering before ln(GNP/POP) and found little evidence to suggest that it mattered. We have not included them in the paper but they are available on request.

automotive, and chemical technologies. The Granger-causality tests generally indicate that output and TFP are Granger-caused by our technology indicators. However, with the exceptions of chemical technologies (and to lesser extent automotive), output and TFP do not Granger-cause our technology measures. Moreover, in response to the technology shocks identified by our indicators, output and TFP tend to rise significantly above trend for approximately 6 years – with the peak effect observed within the first two to three years.

As can be seen in Table 8, the strongest contributors to variations in TFP in the early period were manufacturing and mechanical technologies which explain, respectively, for over 20 and 30 percent of the variation in GNP and TFP by year 6. Although electrical and automotive technologies had a smaller impact than these two, they were still significant. For example, at a six year horizon, we find that they can account for between 16 and 18 percent of the variation in TFP and between 17 and 24 percent of the variation in output.[35] On the other hand, chemical technologies had the weakest relationship of the groups considered. Although chemical technologies did contribute to TFP growth, they did so with a longer lag than seen with the others (perhaps because of their role as intermediate goods), and they do not appear to have had a significant impact on output.

Results are noticeably different during the period 1950-1997. First, overall technology (T class in the LC records) played a larger role in driving output fluctuations than in the Solow period – in part because this group does not include the majority of titles on computer technologies. However, we did find that the TFP was significantly affected by changes in the number of new titles on non-

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[35] As Alexopoulos and Cohen (2008) demonstrate, telecommunications technologies, which are found in TK, did not play a significant role in TFP or output fluctuations during this period. Indeed, if the telecommunications technologies are excluded from our electrical and electronics technologies, the results suggest that an even larger role was played by the remaining electrical technologies.

computer technologies that were produced by major publishers.[36] One possible explanation for this result is that the large publishing houses are more likely to publish titles on major innovations (as opposed to minor ones) and that major advances account are more likely to influence TFP.

The subgroup results for the post-war period also differ from those in the Solow period. In particular, many of the technologies that had powered TFP growth in the early period – manufacturing and mechanical - were shouldered out by some new kids on the block, primarily electrical, civil engineering and infrastructure, and computer technologies. Once again, the Granger-causality tests generally indicate that TFP and GDP were Granger-caused by our technical change indicators not vice versa. Furthermore, the impulse responses plotted in Figure 11 shows that: (1) GDP and TFP increase following technology shocks for, in most cases, over 8 years - with the peak response occurring within the first 4 years, and (2) the largest responses are linked to computers.

Further confirmation that changes in computer technologies have a large, significant impact on TFP and GDP can be seen in Table 8 where the variance decompositions indicate that at the six year horizon, almost 40 percent of the variation in TFP and output can be linked to new technologies in computer hardware and software. Electrical technologies (which include telecommunications and computer networks) were also important, accounting for 30 percent of the variation in output and approximately 15 percent of the variation in TFP at a 6 year horizon. In contrast, changes in civil engineering and infrastructure technologies lost some of their punch in this period, contributing to approximately 10 to 15 percent of the variation in output and TFP.

Overall, it appears that the dominant technology subgroups identified in section II.E (Waves of Innovation) were also the main drivers of TFP and output during the Solow and the post-war periods. The one apparent anomaly is transportation technologies (which includes automobiles,

[36] To create this indicator, we used data from R.R. Bowker company.

trucks, and planes) since they were clearly important in the middle decades of the century and yet fail to act as significant predictors of TFP and output in either of the two time periods. The problem is, in fact, more apparent than real and highlights the importance (but also the hazards) of dividing the sample into two periods. That is, because the major advances in transportation technologies occurred between 1929 and 1959, their influence is split between the two time periods, thus weakening their impact in both. We provide support for this conjecture in Figure 12 which reveals a strong relationship between these technologies and TFP when the regressions are run for the period 1929-1959. Moreover, the variance decomposition suggests that fluctuations in transportation technologies explain almost 20 percent of the variation in TFP by year 3 and, by year 6, close to 30 percent.

IV. Other Applications and Concluding Remarks.

In this paper, we have presented new indicators of technical change for the last century using information on the publication of new titles in different fields of technology. We showed first, that these new measures are closely associated with the introduction of new technologies, second, that they have a significant impact on both output and productivity, and, third, that by looking at subgroups of technologies, we can identify the principal drivers of output and productivity growth in different periods. Moreover, we believe that our new indicators will advance research in a number of areas, some of which we review briefly in the following few paragraphs.

A hotly contested issue among macroeconomist is the impact of technology shocks on employment.[37] According to some, such as Basu, Fernald and Kimball (2006), Francis and Ramey (2004), and Gali (1999), technology shocks lead, at least initially, to a drop in employment while according to others, such as Christiano, Eichenbaum and Vigfussion (2003, 2004), and Fisher (2006)

[37] See Alexopoulos (2006) and Alexopoulos and Cohen (2008) for some examples of this application.

the impact is positive. There are at least two reasons why resolution of this controversy matters. First, a firmer grasp of the role played by technology shocks in short run fluctuations will contribute to our understanding of the factors that drive business cycles. Second, sorting out this relationship will help us discriminate among competing business cycle models, in particular, between the standard real business cycle model and the basic (sticky price) new Keynesian one. The problem faced by most researchers involved in this controversy is that standard approaches to measuring technical change in this literature including long run restrictions, assumptions about stationarity around trend, cleansing of the Solow residuals, and patents and research and development expenditures are all dogged by shortcomings. Our indicators will permit researchers to avoid many of the pitfalls associated with the other methods to identify the shocks and thus enhance our understanding of the underlying relationship.

These indicators can also be used for cross-country comparisons since the national libraries in many countries aside from the Library of Congress employ subject based classification schemes and keep theirs records in machines readable form. We can, as a result, address issues of international diffusion, similarities and differences in the nature and pattern of innovation, sources of differences in productivity growth, and so on. To give an example, it has been argued that the widening productivity gap between the U.S. and some of its competitors can be attributed to the more rapid introduction of information technologies in the former than in the latter. We present in Figure 13 book-based computer technology indicators for France, Italy, the UK, Canada, and the U.S. in the 1990s.[38] While the graph cannot on its own provide conclusive evidence that IT did all

[38] To cast the widest net, each indicator is based on all titles (including new titles and new editions in all languages) in the countries' largest libraries. For Canada, we base the indicator on records from the University of Toronto's library (the largest in Canada), for France, we use the catalogue records from the

the heavy lifting, it does appear that the extremely rapid growth of computer titles in the U.S. was not matched others in our sample. The idea, in short, may have considerable merit, a fact that our new indicator clearly demonstrates[39]

In an entirely different field of inquiry, it has been argued that the growing skill premium in the U.S. over the past two decades can be attributed to the introduction of new technologies, computers in particular, that has increased the relative productivity of skilled workers.[40] Since our measures capture technical change not diffusion, they can be used to address the Nelson-Phelps hypothesis, a key one in this literature, that the productivity of education and the size of the technology gap goes up with the rate of change of innovations.[41]

This list of applications is obviously illustrative not exhaustive. Technical change is a central feature of economic growth and structural change and, consequently, of great interest to economists. While a good measure of it is hard to find, we believe our search has turned up a compelling new indicator. And, as we tried to show in this paper, some of the proof is already in the pudding.

Bibliothèque nationale de France, for Italy the numbers are based on records from the National Library in Florence, and for the UK, we use the records of the British Library.

[39] See Baus et al (2003) for an interesting look the differences in productivity growth between the U.S. and the U.K. and the relationship to IT technologies.

[40] Krueger (1993), in his influential paper, argues that a large portion of this increase (almost 40%) is attributable to the rise in computer use.

[41] See Acemoglu (2002) for a good discussion of recent work in this area.

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Table 1: Comparison of Mensch's (1979) Invention and innovation dates, with Commercialization Dates and First Book Dates

Invention	Date of Invention	Date of Innovation	Date of Commercialization	Book Date
Diesel-electric locomotive	1895	1925	1925	1926
Insulin	1889	1922	1922	1922
Neoprene/Duprene	1906	1932 (Duprene) 1937 (Neoprene)	1932	1937
Nylon	1927	1938	Dec. 1939	1939 (1940 in english)
Penicillin	1928	1941	1943	1943
Radio	1887	1922	1922	1910 (1922)
Streptomycin	1921	1944	1945	1945
Automatic Transmission	1904	1939	1939	1939
Kodachrome	1910	1935	1935/1936	1937
Silicones	1904	1946	1946	1946
Terelyne/Polyester	1941	1955	1953	1953/1954
Transistor	1940	1950	1950	1950
Polyethylene (HDPE)	1933	1951 & 1953	1956	1956
Tungsten Carbide	1900	1926	1930	1930
Silicones	1904	1946	1946	1946
Xerography	1934	1950	1950 (first manual) 1955 (first fully automoated)	1952

Table 2: Comparison of Dates for Major Innovations (management and IT technologies)

Innovation	Date of innovation	Commercialization Date (in U.S.)	Book Date
Windows	Nov. 1983	Nov. 1985	1986
C++	1983	Oct. 1985	1986*
Lotus	Nov. 1982	Jan. 1983	1983
Apple II+	1978	June 1979	1981^
Macintosh	Jan. 1984	First Quarter 1984	1984
Lisa	1978	Jan. 1983	1983
IBM PC	July 1980	Aug. 1981	1982
IBM PC/AT	Aug. 1984	Fall1984	1985*
Commodore 64	Jan. 1982	Nov. 1982	1982
Cellular Telephones	1973	1984	1984
Scientific Management (Tayor)	1911	1911	1911
Time in Motion Studies (Gilbrath)	1911	1911	1911
Industrial and General Administration (Fayol)	1918	Early 1930s	1930 (in English printed in UK)

Notes:

* Information contained in the Library of congress control number indicates that they received the book (or information about the book) sometime during the previous year

^ Other sources confirm that there was at least one earlier manual released with this product that coincide with the commercialization date. However, it does not appear in the Library of Congresses Catalogue

Table 3: Pros and Cons of Traditional Indicators

Pros	Cons
Patents	
• Long time series available • Objective • Can be linked to industry and firm level data	• Not all goods/processes are patented • Propensity to patent can vary over time • Long and Variable time lags between moment of invention and commercialization • Patent application doesn't guarantee product/process ever makes it to market
Citation Weighted Patent Counts	
• Objective • Can be linked to industry and firm level data • Weights important innovations more heavily than minor innovations (as defined by citations)	• Relatively Short time series available • Not all goods/processes are patented • Propensity to patent can vary over time • Long and Variable time lags between moment of invention and commercialization • Patent application doesn't guarantee product/process ever makes it to market
R&D Measure	
• Long time series available • Objective • Can be linked to industry and firm level data	• More money/personnel doesn't guarantee a new product will be found • Long and variable time lags between R&D intensity and commercialization date • Not all goods/processes are the product of R&D endeavors
Major Innovation Counts	
• Long time series available • Can be linked to industry and firm level data	• Subjective dating • Determination of what is a Major innovation is subjective • Not comprehensive

Table 4: Pros and Cons of New Book Measure

New Book Measure	
Pros	**Cons**
• Objective • Can be linked to industry and firm level data • Weights important innovations more heavily than minor innovations (as defined by number of new titles released on product/process) • Can capture both product and process innovations (including those not caught by traditional measures) • Related to commercialization of product/process (short time lags) • Other categories of books can help correct for trends in the publishing industry	• Items may be misclassified by cataloguers • Not all innovations may be captured by titles kept by libraries (e.g., pamphlets may not be kept) • Despite copyright laws, some copyrighted material may not be sent to the depository

Table 5: Statistics on New Titles From Major Publishers

	1955	1997	Max between 1955 and 1997
#New Technology Titles	355	2279	2396
# New History Titles	572	3191	3191
# New Juvenile Titles	1372	3253	5032
# New Literature Titles	529	2308	2689
# New Fiction Titles	1459	4753	4753
Ratio Tech/History	0.621	0.714	1.620
Ratio of Tech/Juvenile	0.259	0.701	0.844
Ratio of Tech/Literature	0.671	0.987	1.481
Ratio of Tech./Fiction	0.243	0.479	1.061

*Source R.R. Bowker

Table 6: Point Estimates

Solow Period: 1909-1949					1950-1997				
Indicator	GNP (1947 dollars)		TFP		Indicator	GDP (2000=100)		TFP	
	β	ρ	β	ρ		β	ρ	β	P
All Technology	0.1411	0.8501	0.0855	0.8082	All Technology	0.0575	0.6515	0.0066	0.8100
	(0.0828)	(0.0812)	(0.0391)	(0.0895)		(0.0288)	(0.1118)	(0.0135)	(0.0951)
Manufacturing	0.1111	0.8248	0.0710	0.7686	Bowker	0.0421	0.8857	0.0131	0.8498
	(0.0508)	(0.0808)	(0.0233)	(0.0865)		(0.0195)	(0.0758)	(0.0077)	(0.0770)
Electrical	0.1201	0.8243	0.0537	0.7796	Electrical	0.0668	0.6811	0.0240	0.7263
	(0.0388)	(0.0757)	(0.0192)	(0.0874)		(0.0231)	(0.0897)	(0.0138)	(0.0974)
Automotive	0.0758	0.9049	0.0306	0.8342	Civil	0.0432	0.6646	0.0219	0.6888
	(0.0300)	(0.0796)	(0.0146)	(0.0899)		(0.0229)	(0.1103)	(0.0134)	(0.1174)
Chemical	0.0211	1.2760	0.0523	1.0553	Computers	0.0252	0.7727	0.0131	0.6946
	(0.0704)	(0.1544)	(0.0370)	(0.1589)		(0.0075)	(0.0809)	(0.0044)	(0.0922)
	0.0211	-0.4485	0.0726	-0.0352					
	(0.0696)	(0.1846)	(0.0366)	(0.2034)					

* For all cases the results correspond to the regression $\ln(Z_t)=\alpha+\gamma t+\beta\ln(Tech_{t-1})+\rho\ln(Z_{t-1})+\varepsilon_t$, where Z is either real GDP, GNP or TFP

Table 7: Granger-Causality Tests (P-Values)

Does Technology Granger Cause GNP or TFP?							
Solow Period: 1909-1949				**1950-1997**			
Indicator	Lag Length	GNP	TFP	Indicator	Lag Length	GDP	TFP
All Technology	1	0.097	0.035	All Technology	1	0.052	0.629
Manufacturing	1	0.035	0.004	Bowker	1	0.036	0.098
Chemical	2	0.937	0.134	Electrical	1	0.006	0.089
Electric	1	0.004	0.012	Civil	1	0.066	0.110
Automotive	1	0.016	0.043	Computer	1	0.002	0.005

Do Output or TFP Granger Cause the Technology Indicators?							
Solow Period: 1909-1949				**1950-1997**			
Indicator	Lag Length	GNP	TFP	Indicator	Lag Length	GDP	TFP
All Technology	1	0.533	0.415	All Technology	1	0.085	0.010
Manufacturing	1	0.625	0.336	Bowker	1	0.701	0.894
Chemical	2	0.001	0.000	Electrical	1	0.385	0.507
Electric	1	0.512	0.675	Civil	1	0.793	0.059
Automotive	1	0.079	0.141	Computer	1	0.231	0.414

Table 8: Variance Decompositions

Solow Period: 1909-1949				**1950-1997**			
Indicator	**Horizon**	**GNP**	**TFP**	**Indicator**	**Horizon**	**GDP**	**TFP**
	3 years	6.07	10.24		3 years	4.75	0.22
All Technology	6 years	11.10	17.75	Technology	6 years	13.37	0.74
	9 years	12.60	19.40	(T class LC)	9 years	18.76	1.16
	3 years	10.39	18.70		3 years	5.34	3.81
Manufacturing	6 years	19.19	31.12	Bowker	6 years	18.29	12.47
	9 years	21.71	33.06		9 years	27.72	18.61
	3 years	0.31	9.74		3 years	16.15	6.94
Chemical	6 years	0.56	15.05	Electrical	6 years	33.94	14.31
	9 years	0.57	15.26		9 years	38.23	16.90
	3 years	13.73	13.06		3 years	5.55	4.59
Electrical	6 years	17.13	16.20	Civil	6 years	16.39	10.48
	9 years	17.69	16.59		9 years	22.86	13.24
	3 years	12.45	9.27		3 years	19.02	17.42
Automotive	6 years	24.15	18.49	Computer	6 years	43.17	37.60
	9 years	27.50	20.81	(QA class LC)	9 years	49.93	43.38

Figure 1. Sample Marc Record and Associated online display

Marc Record:


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a005.13/3219-1 aStroustrup, Bjarne.-14aThe C++ programming language /cBjarne
Stroustrup.-  aReading, Mass. :bAddison-Wesley,cc1986.-  aviii, 327 p. ;c24 cm.-
0aAddison-Wesley series in computer science-  aBibliography: p. 10.-  aIncludes
index.- 0aC++ (Computer program language)-0 aC plus plus programming language.-
aAnother issue (not in LC) has: viii, 328 p. ta01 4-3-87-  bc-GenColl-
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Online display of information in Marc Record:

The C++ programming language / Bjarne Stroustrup.

LC Control Number:	85020087
Type of Material:	Text (Book, Microform, Electronic, etc.)
Personal Name:	Stroustrup, Bjarne.
Main Title:	The C++ programming language / Bjarne Stroustrup.
Published/Created:	Reading, Mass. : Addison-Wesley, c1986.
Related Titles:	C plus plus programming language.
Description:	viii, 327 p. ; 24 cm.
ISBN:	020112078X (pbk.) :
Notes:	Includes index. Bibliography: p. 10.
Subjects:	C++ (Computer program language)
Series:	Addison-Wesley series in computer science
LC Classification:	QA76.73.C153 S77 1986
Dewey Class No.:	005.13/3 19

Figure 2. Comparison of Technological Change Measures: 1909-1949

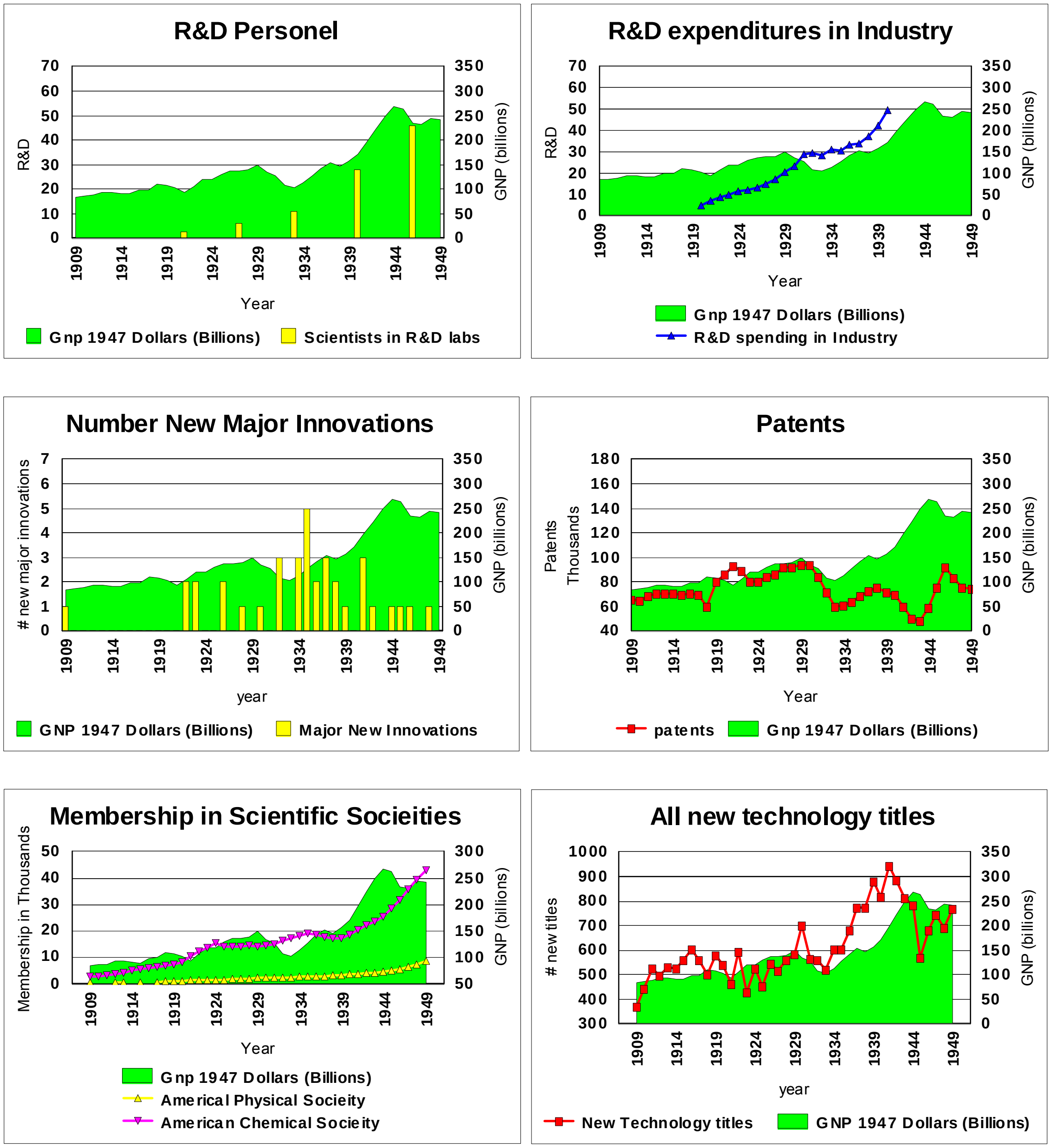

Figure 3. Comparison of Technical Change Measures: 1949-1997

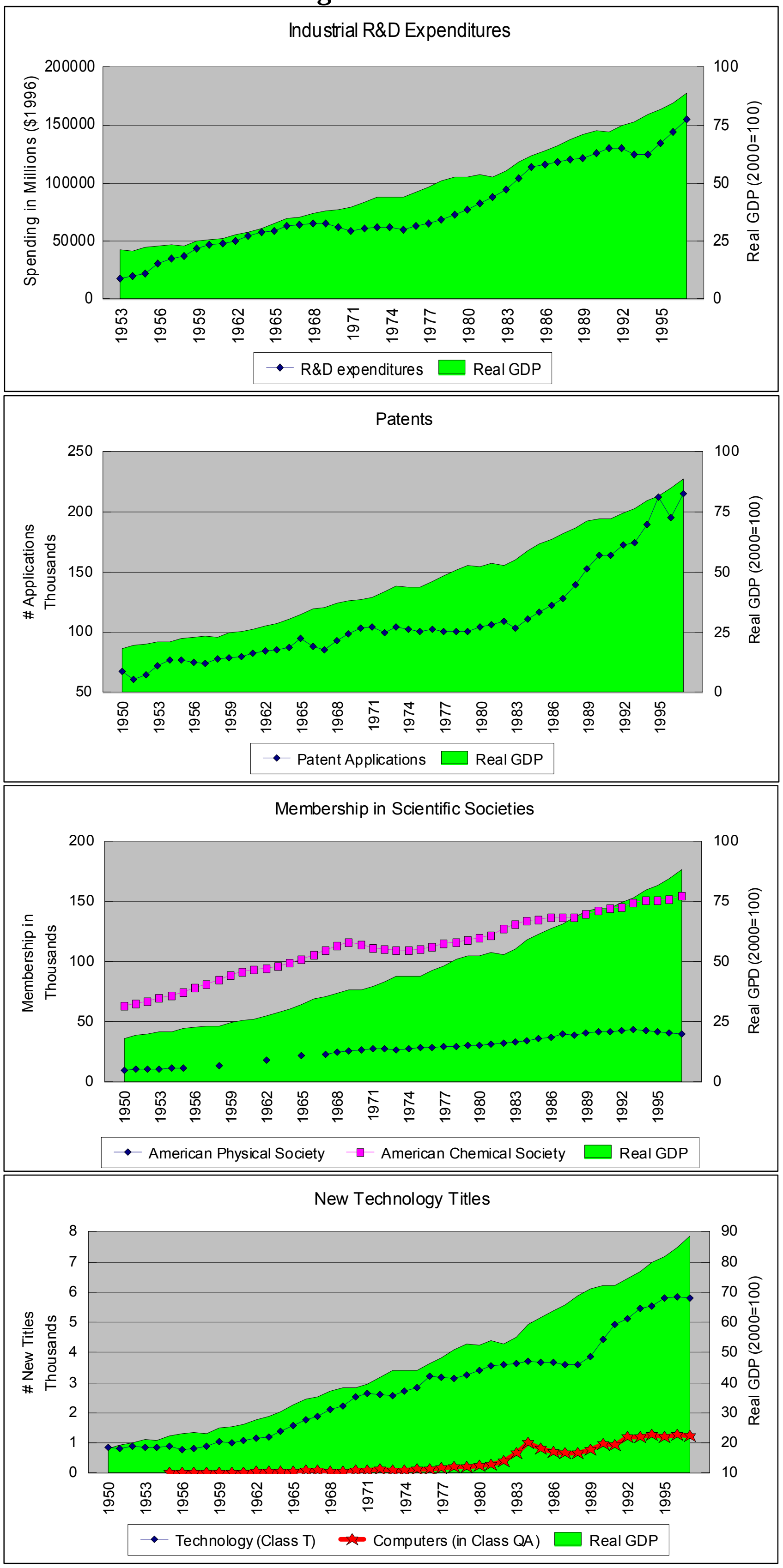

Figure 4: Diffusion vs. Measure

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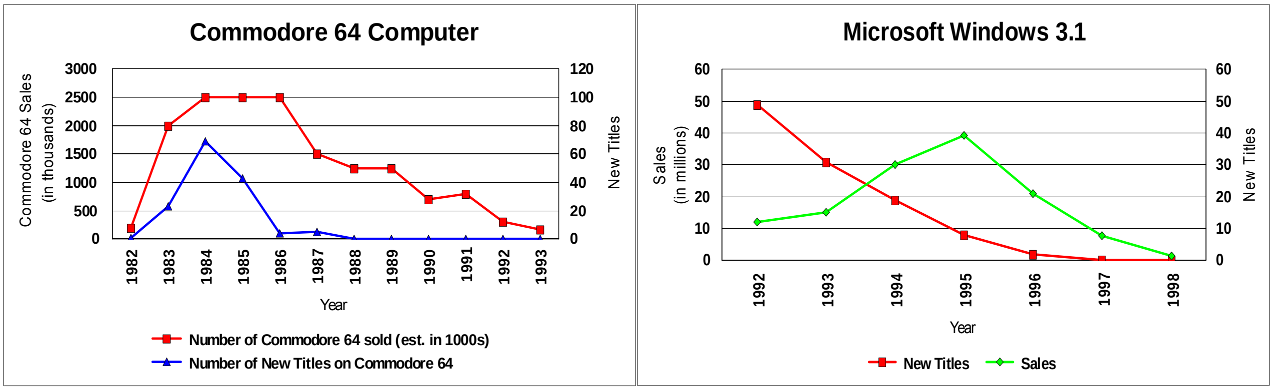

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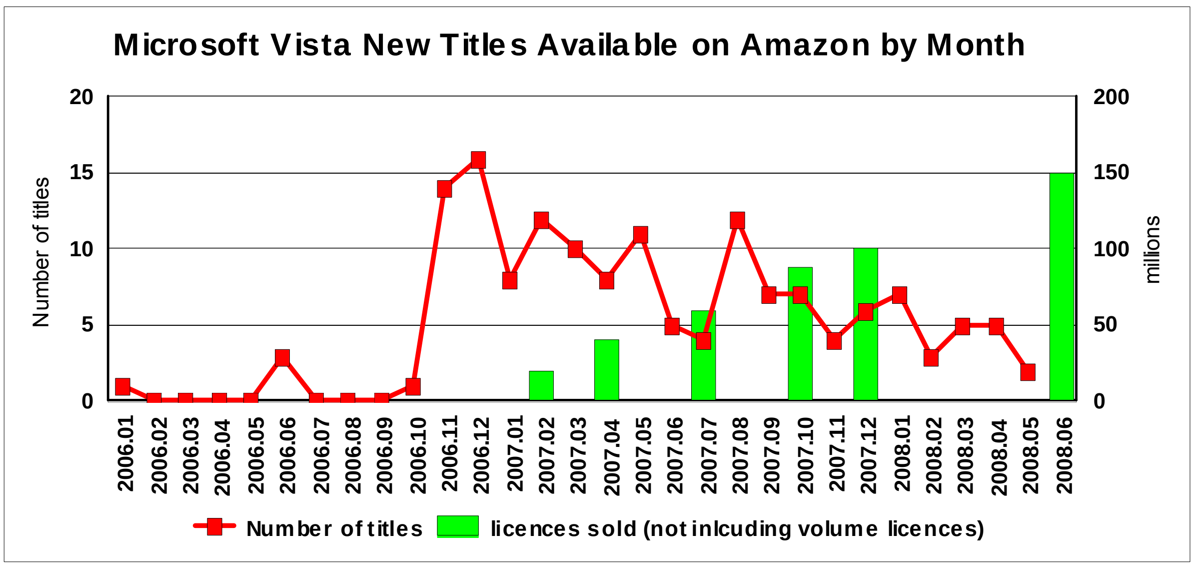

**The total sales figure for June 2008 is an estimate from

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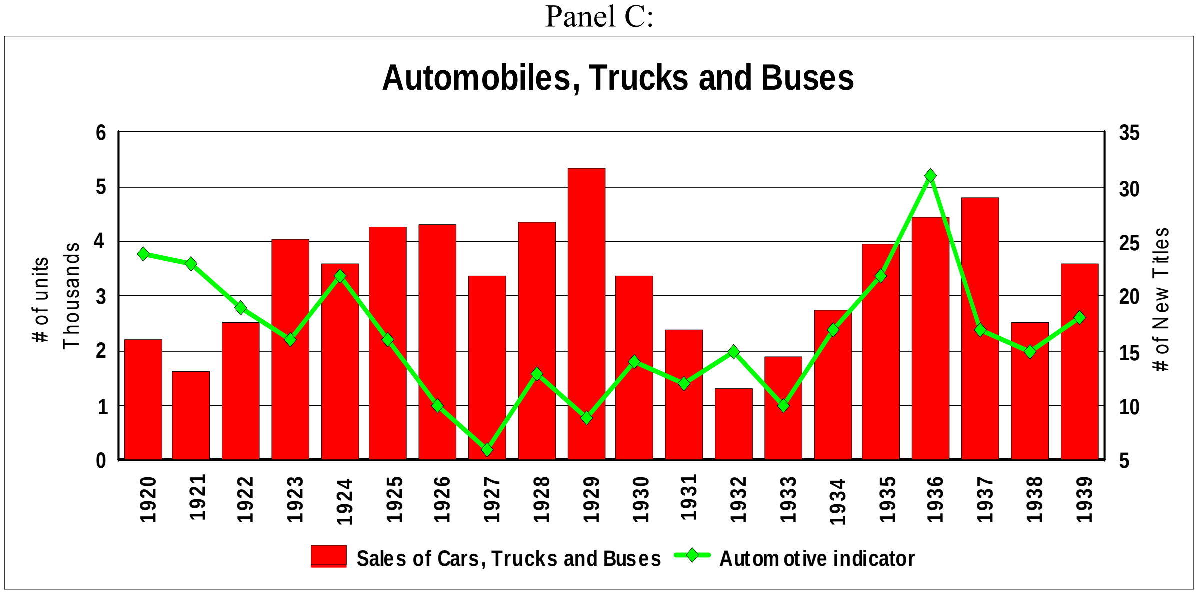

Figure 4, con't.

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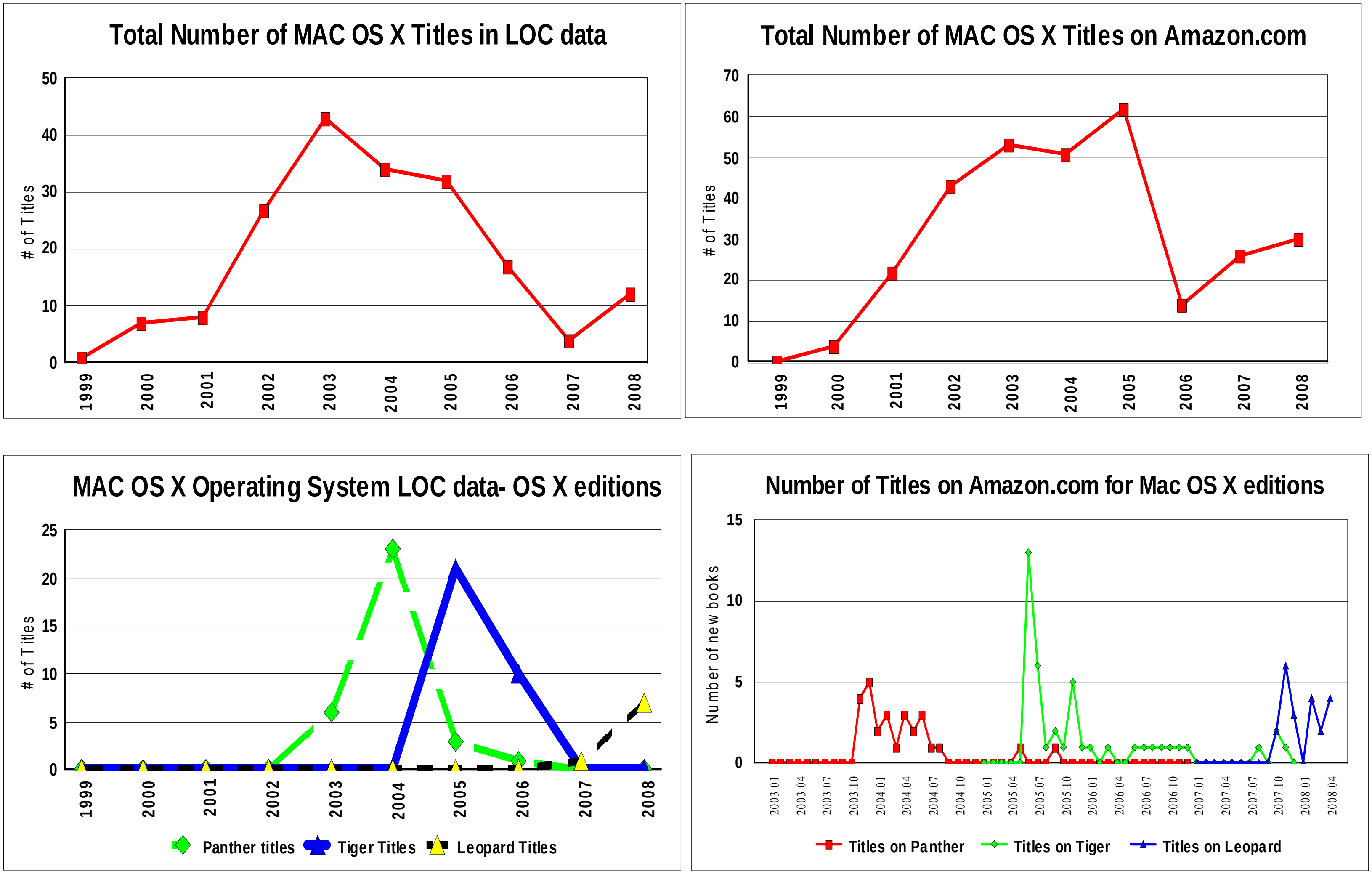
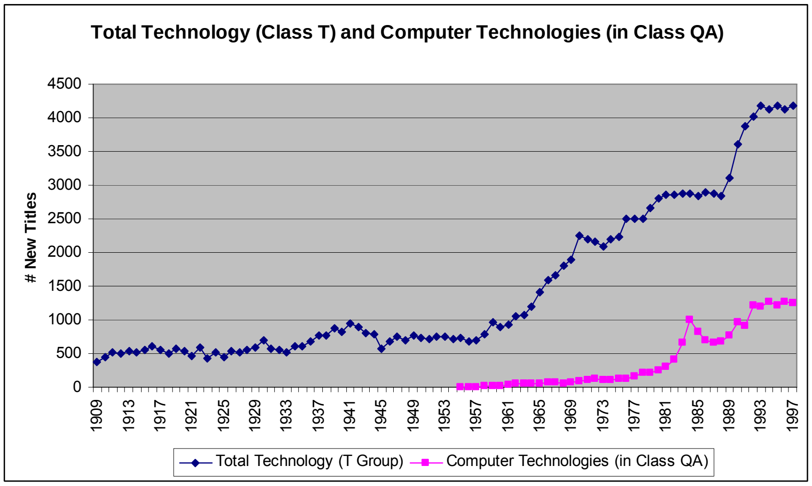
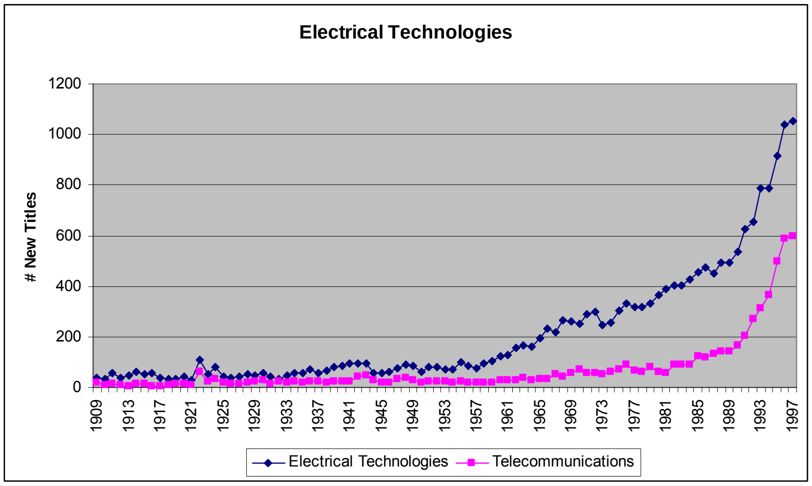


Figure 5: Graphs of Sub-group indicators





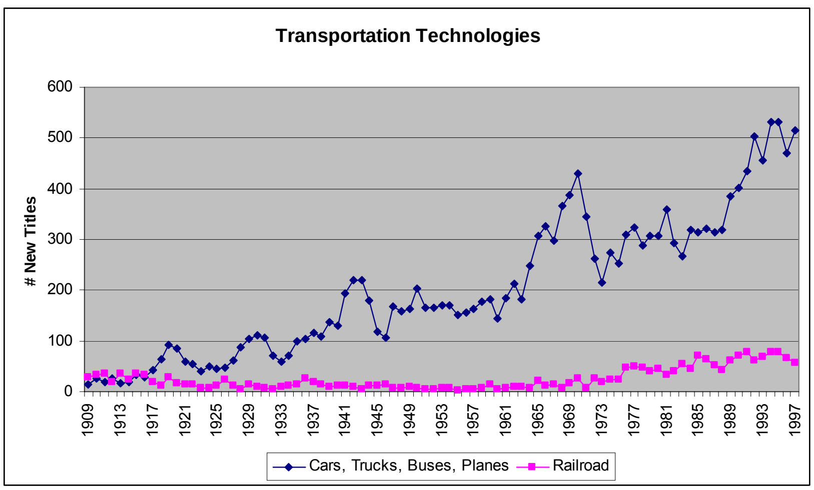
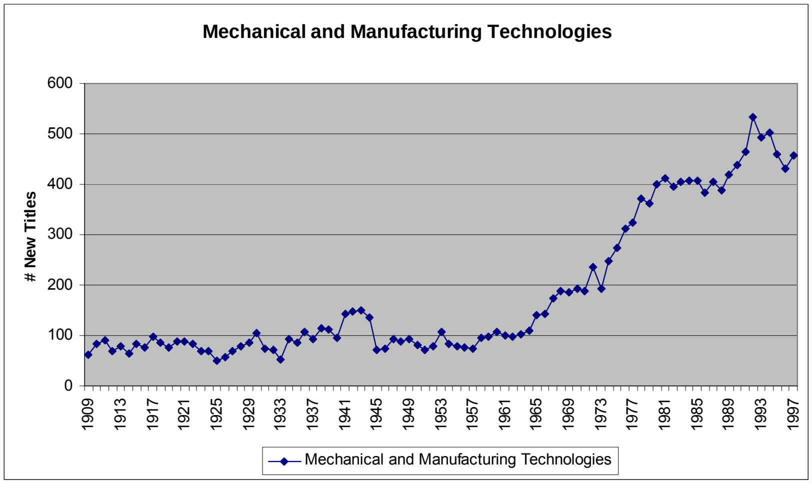
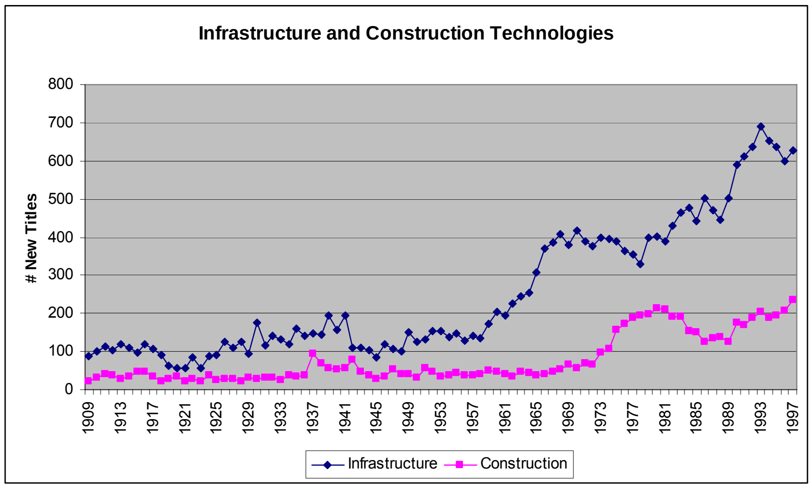


Figure 6: Graphs of Sub-group Indicators





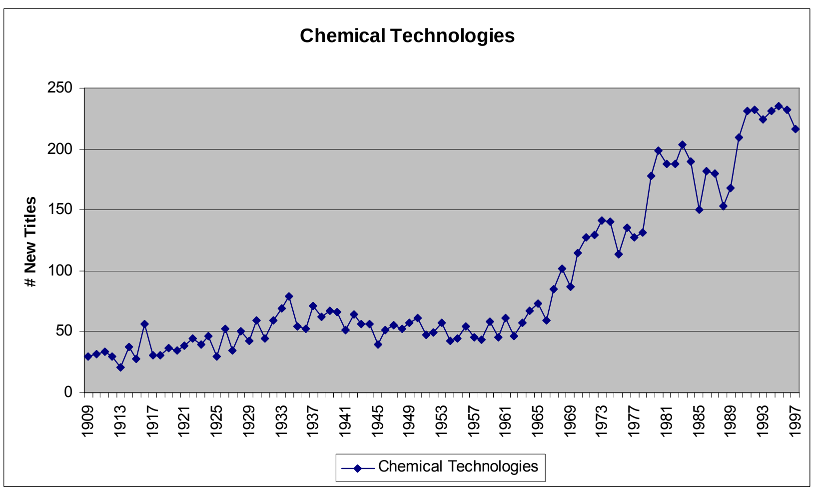
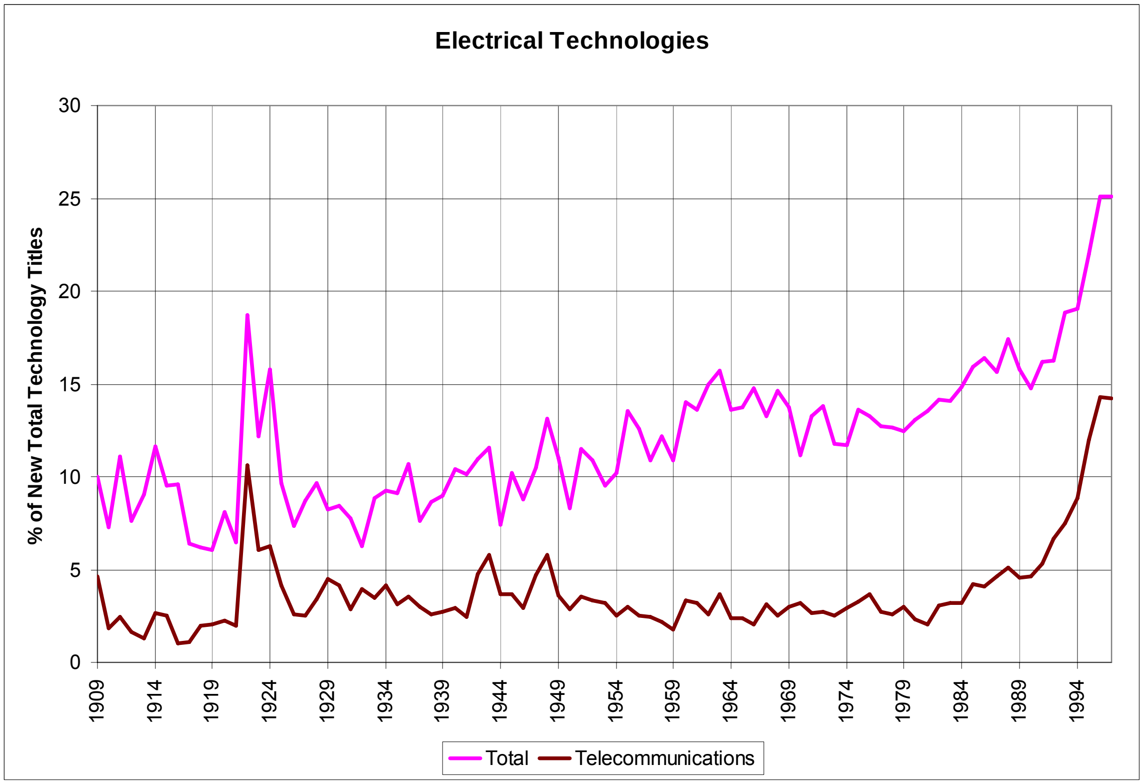


Figure 7: Waves of Innovations – Electrical and Transportation Technologies



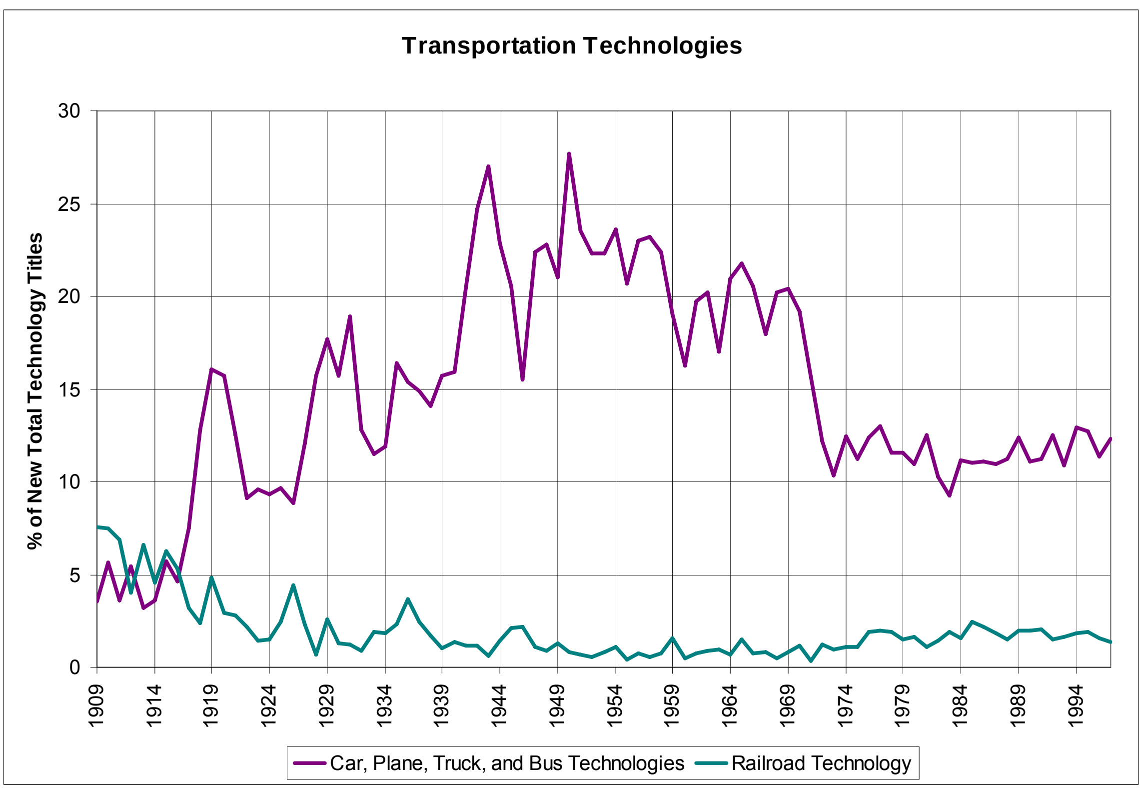
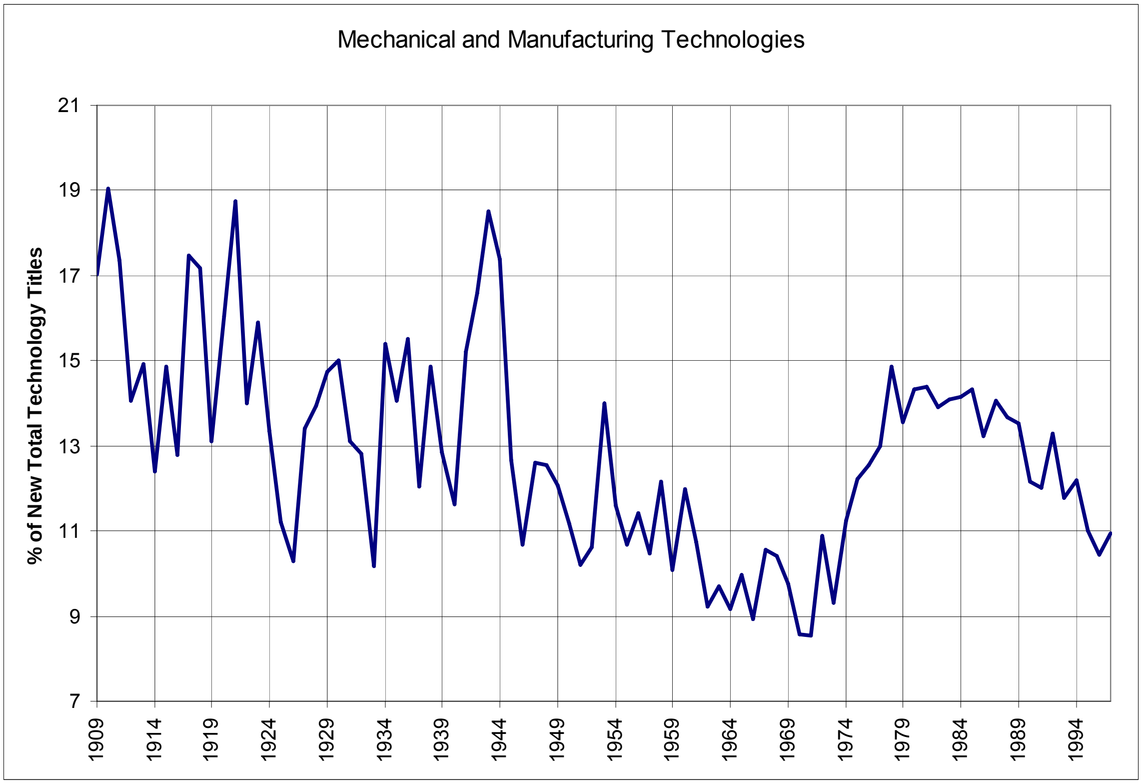


Figure 8: Waves of Innovation – Mechanical/Manufacturing and Infrastructure/Construction Technologies



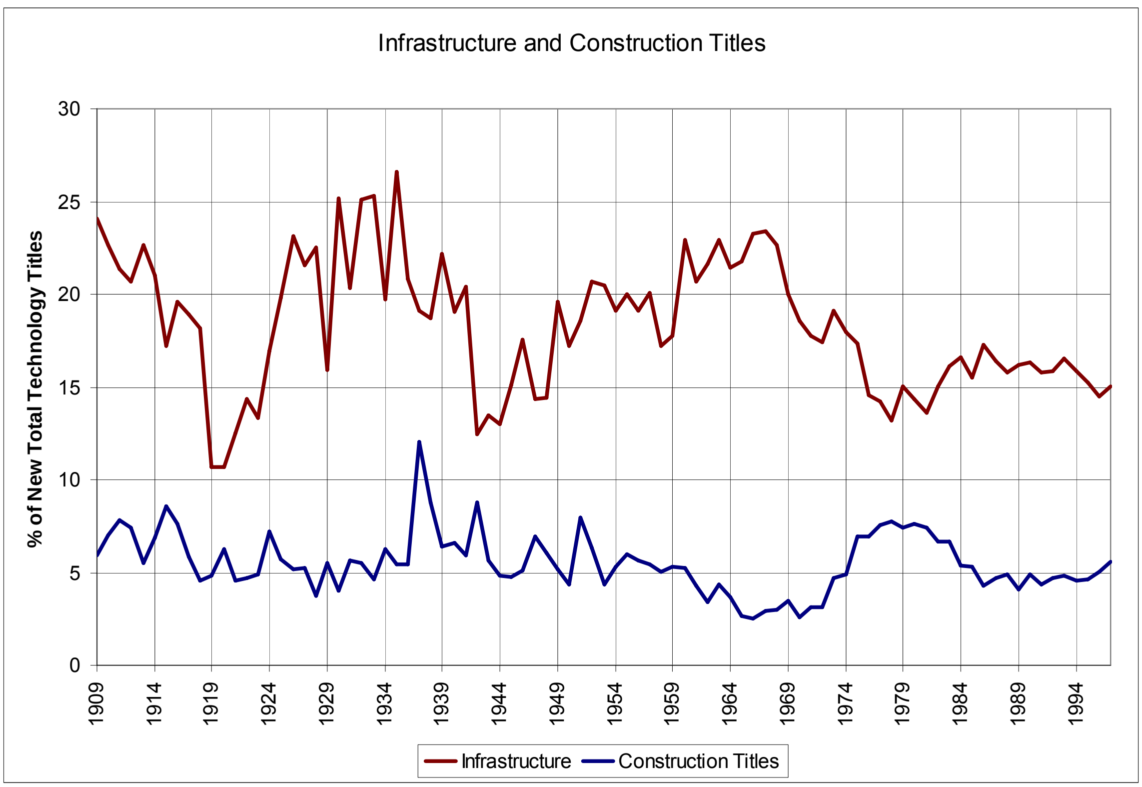
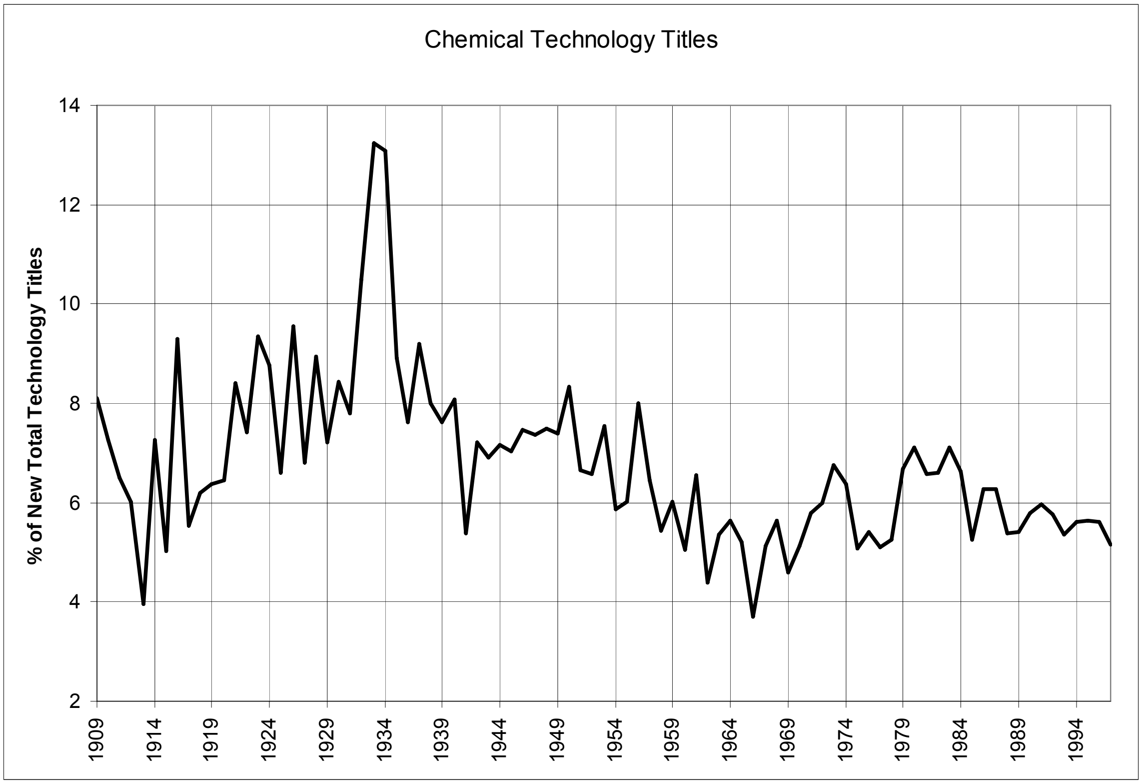


Figure 9: Waves of Innovation – Chemical and Computer Technologies



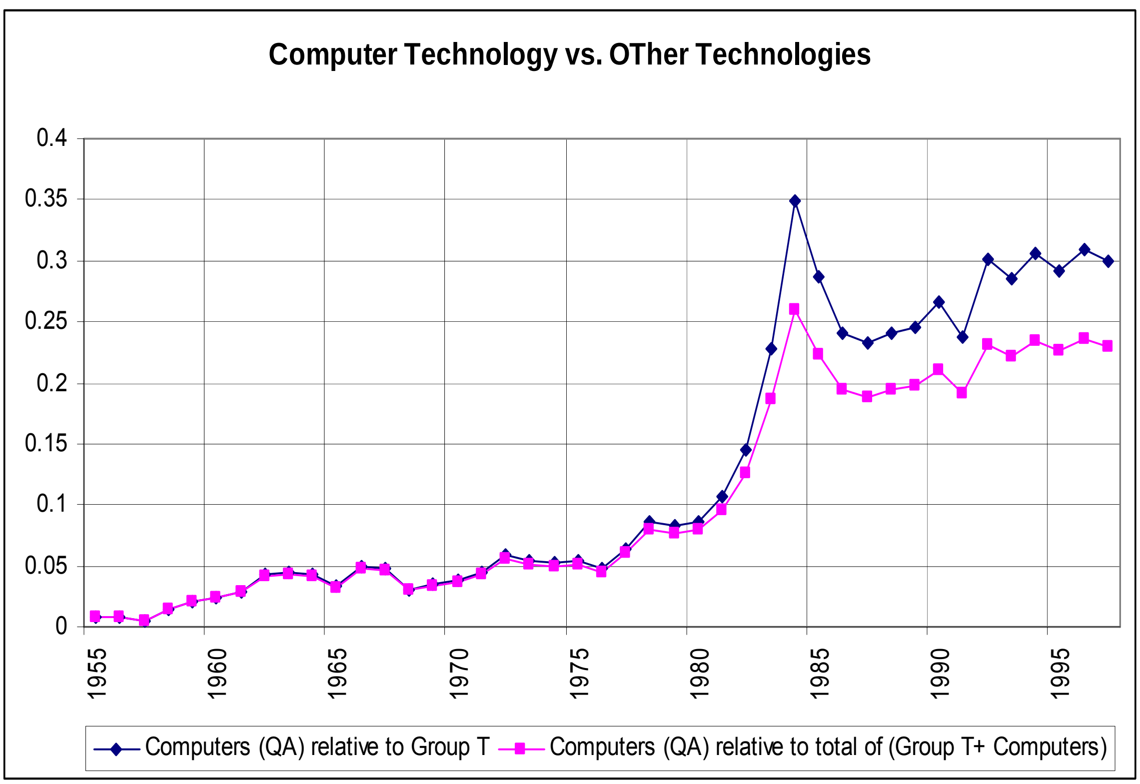
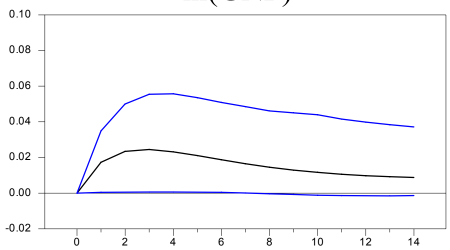


Figure 10: Impulse Responses to technology Shocks: The Solow Period

T Group Technology

ln(GNP)



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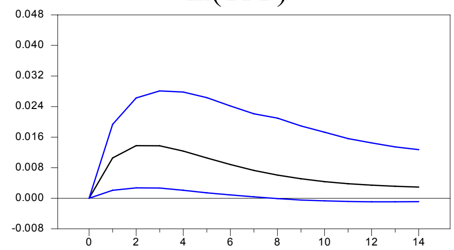
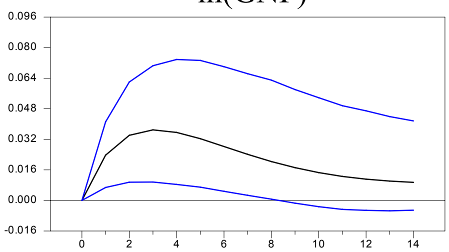


Automotive Technology

ln(GNP)



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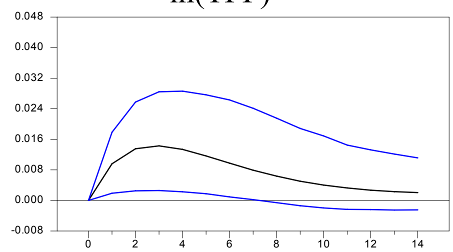
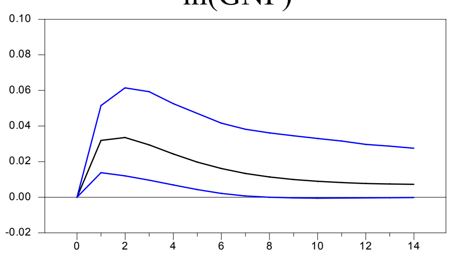


Electrical and Electronics Technology

ln(GNP)



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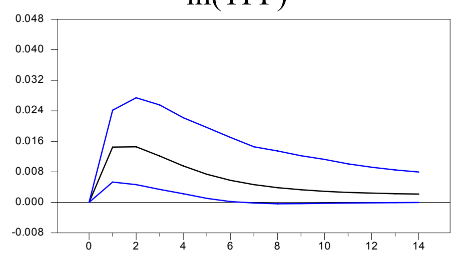
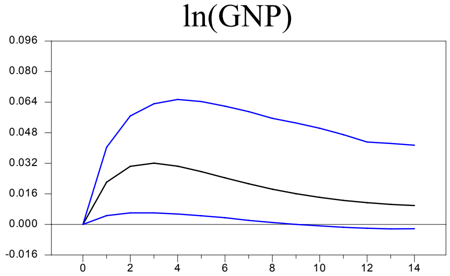


Manufacturing and Mechanical Technologies

ln(GNP)



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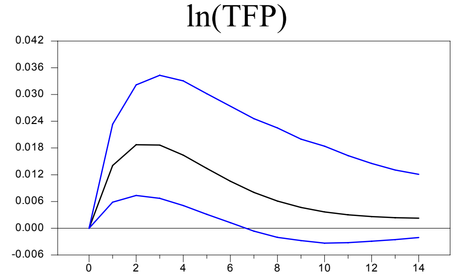
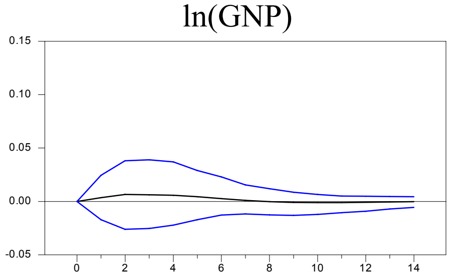


Chemical Technologies

ln(GNP)



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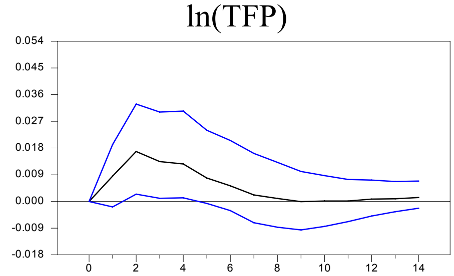
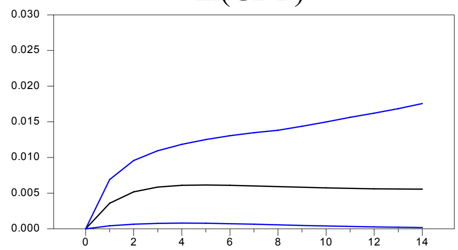


Figure 11: Impulse Responses to technology Shocks: 1950-1997

T Group Technology-LC

ln(GDP)



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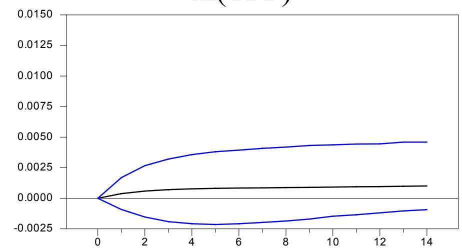
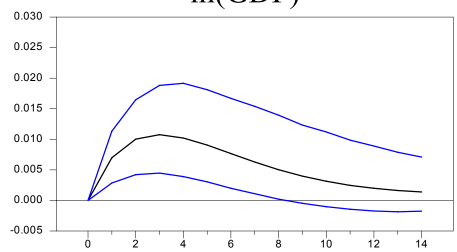


Electrical and Electronics Technology

ln(GDP)



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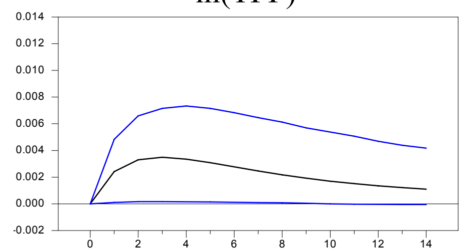
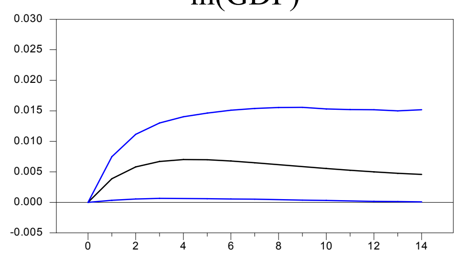
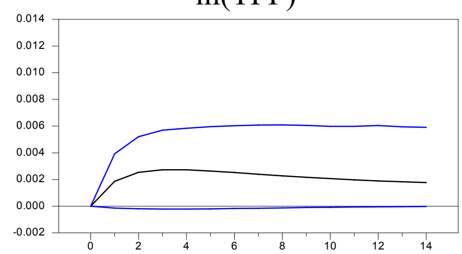


Civil Engineering and Infrastructure Technologies

ln(GDP)

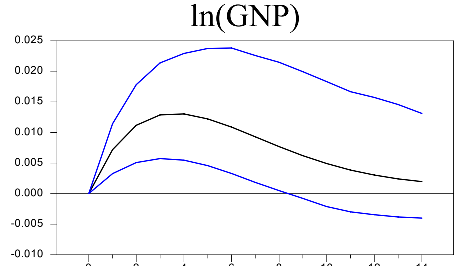


ln(TFP)

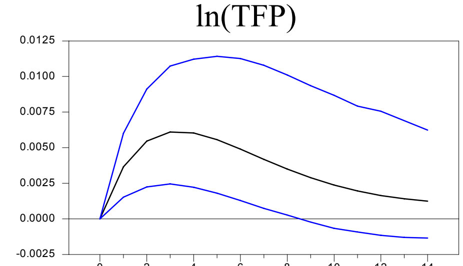


Computer Technologies (in QA Class)

ln(GNP)

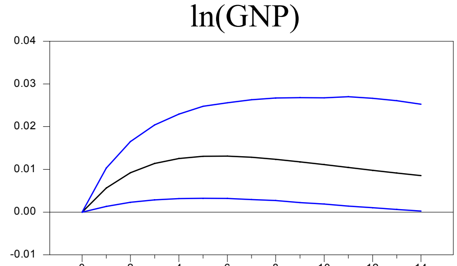


ln(TFP)



Technology titles (excluding Computers) By Major Publishers-Bowker

ln(GNP)



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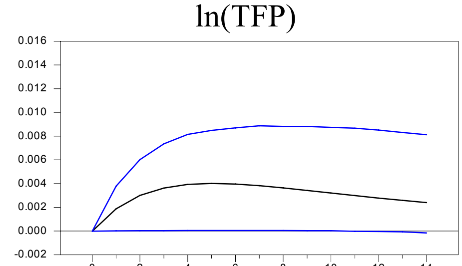


Figure 12: Impulse Response of TFP to transportation technologies (1929 to 1959)

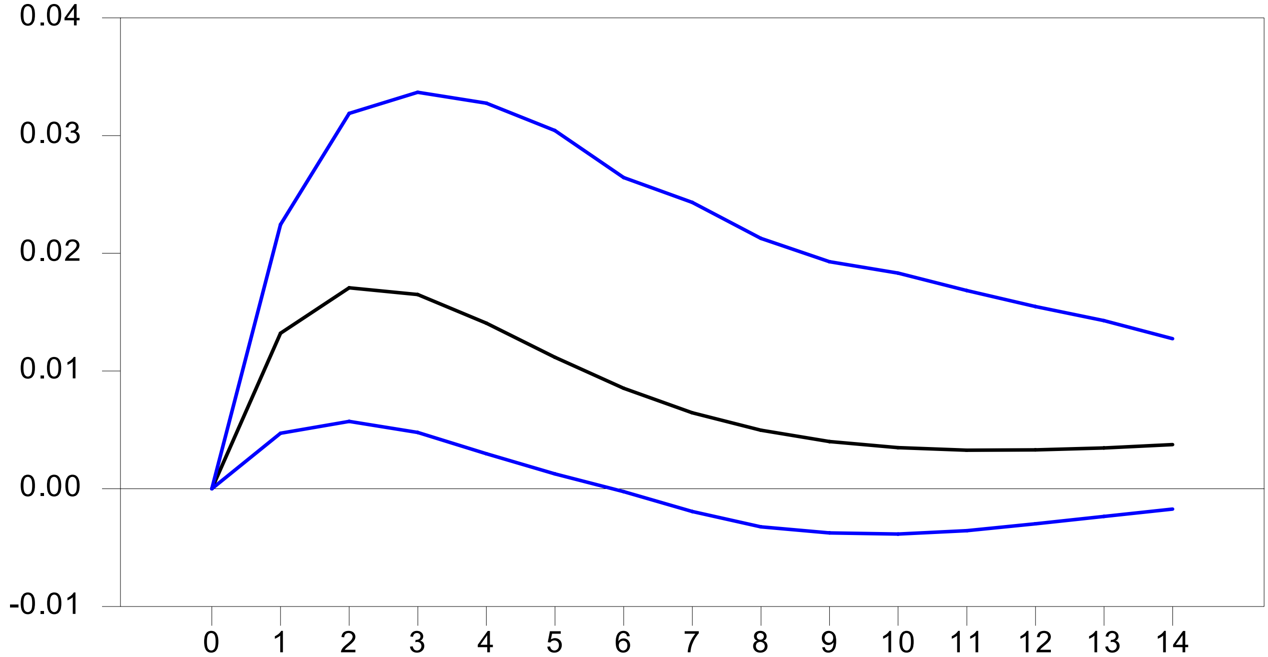
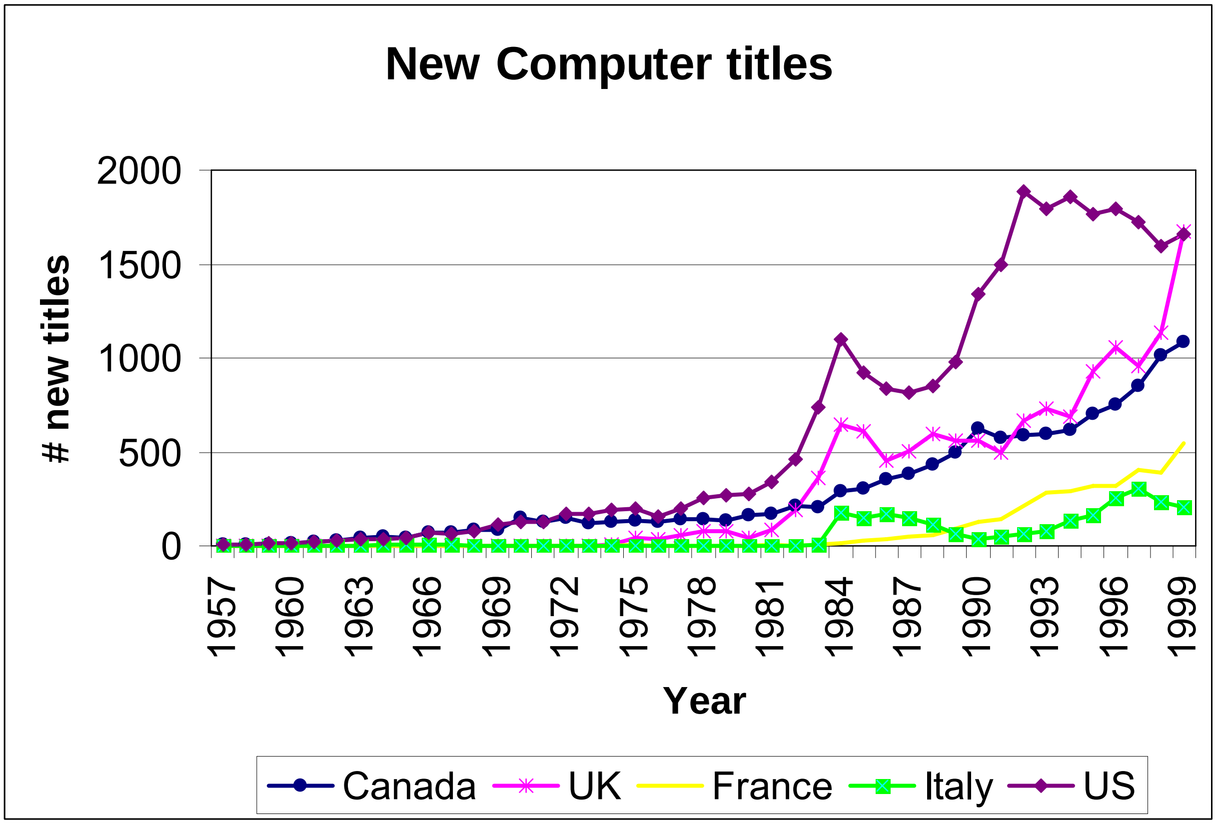


Figure 13: Cross Country Comparison (preliminary evidence)



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

Subclass QA Mathematics

- QA71-90 Instruments and machines
- QA75-76.95 Calculating machines
- QA75.5-76.95 Electronic computers. Computer science
- QA76.75-76.765 Computer software