Read All about it!! What happens following a technology shock?

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Abstract:
For decades economists have searched for the sources of business cycle fluctuations. Despite recent advances in economic modeling, there is still much debate as to the cause of recessions and expansions. In standard real business cycle models, a large component of the fluctuations is attributed to technology shocks. Unfortunately, empirical evidence examining the role of technology shocks is sparse, in part because they are notoriously difficult to measure. To identify the effect of changes in technology on the economy, I create a new indicator of technology based on the number of new books published in the field of technology, and use these indicators to examine what happens to the economy following a technology shock. My findings indicate that, in response to a positive technology shock, employment, total factor productivity and capital all significantly increase.

1. Introduction:

For decades economists have searched for the sources of business cycle fluctuations. Early business cycle research focused on trying to predict business cycles by examining which variables led and lagged the business cycle (See e.g., Burns and Mitchell (1956)). While many of these indicators are still in use today, they do not provide much insight into the sources of the fluctuations.[1]

One popular theory, embedded in the standard real business cycle models, suggests that business cycles are caused by unexpected changes in the level of technology used in the economy. Although this explanation is intuitively appealing, the problem remains that technology, and technology shocks, are difficult to measure. As a result, it has been challenging to empirically determine: (1) how important technology shocks are in explaining fluctuations over the business cycle, and (2) how the economy responds to unexpected changes in technology. In this paper, I add to the growing literature that attempts to address these issues. Specifically, I first create new measures of technological change based on new information from R.R. Bowker and the Library of Congress database. Next, I use these measures in vector autoregressions to explore how the economy responds to a technology shock.

[1] Examples include the index of consumer sentiment, the unemployment rate, and the level of business inventories.

The results of my analysis suggest that a positive technology shock (an increase in the orthogonal component of the technology indicator) causes employment, total factor productivity and capital to increase. The variance decompositions suggest that changes in technology have a relatively small effect on the number of hours worked at short run horizons. However, I find that technology (especially computer technology and telecommunications technology) significantly influences GDP by affecting total factor productivity and capital. The finding that computer and telecommunication technology is important in explaining fluctuations in GDP is consistent with the recent literature examining the effect of information and communications technologies' contribution to growth.[2]

The existing business cycle literature has proposed three ways to identify technology shocks. The first method attempts to identify technology shocks using long-run restrictions in a structural vector autoregression (VAR). This method is seen in papers such as Gali (1999, 2004), Francis and Ramey (2002), Christiano, Eichenbaum and Vigfusson (CEV (2002, 2004)), Altig, Christiano, Eichenbaum and Linde (ACEL (2003)) and Fisher (2003). The second approach, used by Basu, Fernald and Kimball (BFK (2004)), attempts to correct the Solow residual by controlling for non-technological effects such as increasing returns, imperfect competition, varying capital and labour utilization, and aggregation effects. This corrected measure is then used as the "true" measure of technology. The third approach, used by Shea (1998), attempts to measure

[2] See e.g., Wilson (2004), and the literature on telecommunications and computer technologies affect on TFP.

changes in technology in a more direct way using information on research and development expenditures (R&D) and patent activities. While each of these methodologies has strengths and weaknesses,[3] the approach I use in this paper is most closely related to work using direct measures of technological change.

The use of patents and R&D as direct indicators of technological progress has a long and distinguished history (see Griliches' (1990) survey paper). Recently, Shea (1998) used these measures to explore the impact of technology shocks on the economy. Shea (1998) argues that using direct measures of technological change (such as R&D and patents) have two main benefits. First, unlike Gali's (1998) method, his results do not rely on the assumption that only technology shocks affect productivity in the long-run (an assumption that would be violated if there is endogenous growth for example). Second, he argues that his indicators are more directly linked to technological changes than the corrected residual method used by BFK (2004), especially if the correction is incomplete.

While Shea's (1998) methodology is appealing, his results using the standard patent and R&D measures findings were mixed. For example, it appeared that changes in technology (as measured by his patent indicators) had no statistically significant impact on inputs or total factor productivity (TFP) for many of the sectors examined. For others,

[3] See Chari, Kehoe and McGratten (2004), and Christiano, Eichenbaum and Vigfusson (2004) and Gali and Rabanal (2004) for discussions on the strengths and weaknesses associated with assuming that only technology shocks affect labor productivity in the long run. See Shea (1998) and Christiano, Eichenbaum and Vigfusson (2004) for a description of the potential shortcomings of the BFK measure of technology, and see Gali (1998) and Jaffe (1998) for a discussion of the problems using patents and R&D expenditures to measure changes in technology.

he found the shock decreased TFP and increased inputs in the short run. As BFK (1999) point out, these results may have been partially driven by the long time lag between when an idea is patented and when it may be used. This may explain why my publication-based indicators of technological change, which have significantly shorter lags, provide stronger results.[4]

My approach for exploring the impact of technology shocks is closely related to the one used by Shea (1998). However, instead of using data on patents (or R&D), I create a new measure based on previously unstudied information on books titles in the field of technology used in the U.S. economy. These indicators are compiled using information from three sources: R.R. Bowker Company, the Library of Congress and Autographics/Thompson Dialog Corporation. Historically, Bowker has published many of the book lists regularly used by libraries and kept track of the new book titles that are available in the U.S. market. The files obtained from the Library of Congress' MARC21 records database (1968-1997) and the Library of Congress' REMARC database, accessible through Dialog/Autographics, provides information on most new books copyrighted within the United States from 1955-1997 in a format which can be used to create the measures of interest.[5]

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[4] Fisher (2003) has argued that investment specific technology shocks are responsible for the majority of the fluctuations seen over the business cycle. Since my indicators are closely linked to the type of machinery and capital that is used in the economy, this may also provide an explanation as to why my indicators produce stronger results.

[5] Besides being the largest library in the United States, the Library of Congress is a copyright depository for works published in the U.S. For example, the Copyright Act of 1978 established a

The rational for using this new books indicator is that, like patents, the introduction of new titles (excluding new editions) in the field of technology should capture technological progress. One potential advantage of using the book indicator is that new books on technology (e.g., manuals) are also more likely written when the idea or product is being utilized or is in the process of being implemented since books are costly to produce and publishers want to recoup these costs. Therefore, the lag between changes in technology captured by my indicator and economic activity should be much smaller than the corresponding lag when technological change is measured using patent indicators.[6,7] Indeed, the results presented in this paper suggest that, while changes in patents require a 4 year lag to affect the economy, my technology indicator appears to lead changes in TFP and GDP by approximately one year.

In addition to exploring the properties of these indicators, I use them to explore the response of the economy to a technology shock using vector autoregressions. Like Fisher (2003), Christiano, Eichenbaum and Vigfusson (2003) and Altig, Christiano,

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mandatory deposit requirement for works produced inside the U.S. boundaries within 3 months of publication in the United States.

[6] See Alexopoulos (2004) for some evidence about the lags between product discovery and introduction to market.

[7] As a result, this new measure should be more in line with the technology shock in the business cycle models where a technology shock occurs at the time at which output is affected – not at the time that the innovation process is patented.

Eichenbaum, and Linde (2003) my findings suggest that in response to a positive technology shock, real GDP, employment, total factor productivity and capital all significantly increase after one year with the peak impact occurring after 3-4 years following the shock. These findings are in partial contrast to the findings presented in Gali (1998), Francis and Ramey (2003) and Basu, Fernald and Kimball (2004). Their findings suggest a positive technology shock will increase GDP but may actually decrease the amounts of labour and capital inputs used in the first year.[8] However, my finding that the variation in employment that can be attributed to technology shocks in the short run is relatively modest is generally consistent with the findings in the other papers.[9]

The remainder of the paper is organized as follows. In section 2, I discuss the relationship between TFP and direct measures of technological change, describe the data used to create the indicators, and explore how it relates to the literature on patents and research and development. In section 3, I present results to indicate the relationship between GDP, TFP and inputs and the book indicators. Single equation estimates of the contemporaneous relationship between GDP and the indicators, and TFP measures and

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[8] CEV (2002), ACEL (2003), and Fisher (2003) have argued that: (1) Gali's (1998) and Francis and Ramey's (2002) results are driven by their assumption that hours worked is not a stationary series, and (2) if one assumes hours worked is stationary, their methodology predicts that positive technology shocks are expansionary. Moreover, see CEV (2004) and BFK (2004) for potential explanations as to why their results differ.

[9] Fisher's (2003) findings are an exception. He finds that investment specific shocks have a very large impact on labor.

the indicators are reported along with the results of the vector autoregressions when the book indicators are used to identify changes in technology. These results are then compared to those obtained when new patents applications and research and development expenditures are used as the indicator of technological change. In section 4, I conclude and offer suggests for future research.

Section 2.

Direct measures of technological change

To date there are few direct measures of technological change used in economics. The most common of these measures are based on research and development expenditures, patent statistics, and more recently, patent citation statistics.[10] As Griliches pointed out in his 1990 survey paper, patents statistics have fascinated economists for a long time. The reason is simple - patent statistics are inherently linked to changes in knowledge and may help us obtain answers to important questions such as reasons for changes in economic growth and productivity.

Figure 1 outlines the relationship between R&D, patents, technology and economic activity suggested by Griliches (1990). In this case R&D expenditures are considered inputs into the production of technology/knowledge, while patents are a

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[10] A far less common measure has been the number of trademarks issued in the U.S. (see Yorukoglu (2000)).

measure of the output of the development process. Therefore, he argues, patents should be a noisy measure of technological change. This has lead to a number of articles that examine the relationships between patents and economic activity at the firm, industry and aggregate levels.[11]

While patent statistics contain a large amount of important information, they are still subject to a number of short-comings - especially for the purpose of studying the effects of technological change in the short run (i.e., at business cycle frequencies). First, there are usually long, and variable, lags between the time that a product or idea is patented and the time that the product or process is actually put into use.[12] In extreme cases, a product idea is patented but never put into use.[13] Second, patent fluctuation in the U.S. may partially be due to changes in patent law and changes in the effect of resources of the U.S. patent officer (See Griliches (1990)). As a result, using patent statistics to measure changes in kind of technology described in business cycle models may be problematic. These problems may explain why Shea (1998) found little evidence

[11] See Griliches' (1990) survey article and Jaffe and Trajtenberg (2002) for good overviews of the patent literature.

[12] For example, while the first photocopier was developed and patented in the 1930s, the first photocopier machine was not commercially available until 1950.

[13] Geisler (2000) reports that a survey of 23 large firms indicated that over 80% of patented items never resulted in commercial products.

that technology shocks identified with data on patent applications significantly affected TFP or inputs.[14]

Given the potential problems with patent data, we would prefer an indicator of technological changes that is: (1) related to both the information available on research and development expenditures, and (2) is more closely related to technology that is actually adopted in the economy. I argue that the new indicators created from information on new titles published in the fields of technology and computer science may satisfy these criteria. The reason is simple. An indicator based on the publication of new books in the field of technology should, in principle, capture technological progress. However, unlike patents and R&D expenditures, new books on technology (e.g., manuals) are more likely written when the idea or product is first being utilized (or is in the process of being implemented) since: (1) books are costly to produce, and (2) publishers want introduce the books as early as possible to maximize the return on each new title.[15,16] As a result, the lag between the changes in technology captured by my

[14] This point was raised by Basu and others during the discussion of Shea's (1998) paper at the NBER Macroeconomic Annual Meeting.

[15] Discussions with publishers indicate that the publication lags for technology books is significantly shorter than for other book categories since technology is a rapidly changing field and delays in releasing books in technology will result in the company failing to realize maximum revenues if their competitors release a similar book faster. Therefore, they report that books on major developments in technology can be released to market within 3 months (with a 6 month average). In comparison, new books in other fields are released with a lag of 1-2 years.

measures and changes in economic activity should be much smaller than lags associated with the more traditional indicators.[17]

Creating the New Measure:

To create the new indicators, I require information on the type of books available each year, information on the book edition, and data on where the books are available. Specifically, I want to focus on the number of new titles in different fields of technology each year, and exclude books written on the history of a particular technology to identify new technologies available in the economy.

This type of information can be obtained from two sources – publishers and libraries. My indicators are created using information from three sources: R.R. Bowker company, the Library of Congress and Autographics/Thompson Dialog Corporation.

R.R. Bowker is a private company that has published many of the book catalogues used by American libraries and has kept track of the new book titles by major

[16] In addition to the books produced by major publishers, companies like IBM, Microsoft and Goodyear also release manuals along with the new technology.

[17] In addition, technology shocks identified using the new measure should be more in line with the technology shocks modeled in the business cycle models where a technology shock occurs at the time at which output is affected – not at the time that the innovation process is patented.

subject fields that are available within the U.S. market. Their information, on American Book Production, is reported on a yearly basis in Bowker's Annual Yearbook.

From 1955-1997 Bowker reported estimates of how many new titles were available in the American market in different subject groups (e.g., Technology, Science, History, Home economics, etc) during the year. In the early years, their estimates are based on information collected using surveys of the major book publishers in the U.S. Later it was based on information obtained from the Library of Congress's Cataloguing in Publication Program.[18] The technology indicators created from this data source is graphed in Figure 2.

While Bowker's estimates represent a general pattern of books in technology marketed by major book sellers in the U.S., the statistics suffer from two potential drawbacks. First, they do not cover all books produced and sold in the U.S. (e.g., manuals printed by a company like Microsoft may be missed). Second, their measure of technology does not include books on computer technology. Instead, books on computer technology are grouped together with dictionaries and encyclopedias.[19] As a result, to

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[18] The Cataloguing in Press Program collects information from major publishers about books published in English for the American Market that are likely to be mass marketed and carried by a large number of libraries.

[19] This occurred because the Bowker's categories are based on the Dewey Decimal Book Classification which classifies computer books as a type of general knowledge along with bibliographies and reference books, like encyclopedias and dictionaries.

investigate computer technology and telecommunications technologies, I also create indicators from records in the Library of Congress' database.

The Library of Congress distributes database files in MARC21 format (See Figure 3 for a sample of a Marc record and the corresponding database file). These files are used by the Library of Congress to run their online book search program, and are distributed to other libraries to be used for cataloguing purposes. The Library of Congress' collection contains information on a larger number of publications than R.R. Bowker's data since it is the copyright depository for the U.S., and the largest library in the U.S.[20] As a result, the Library's MARC21 records database (1968-1997) and their REMARC database, accessible through Dialog/Autographics, provides information on new books copyrighted within the United States from 1955-1997 in many subject fields and information on books imported from other countries.

The Marc21 records are in machine readable form, and contain information that identifies the type of book (e.g., new title or edition), the country of publication, the language of publication, the Library of Congress' Classification Code, and a list of major subjects covered in the book. The information in the first three fields allows me to identify books in English, published in the US, that are new titles. The library of congress classification code is what the librarians use to group books on similar topics

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[20] The Library of Congress' collections include more than 29 million books and other printed materials.

together (e.g., science books, technology books, economics books, etc).[21] For the purpose of this investigation we will be primarily looking at books listed in the main subgroup T (which identifies the book as being in the field of Technology)[22], the subgroup of T that identifies traditional telecommunications technologies and QA75-76 (which identifies books in Computer software and hardware). The information contained in the subject fields in the MARC21 record, along with the title field, allow me to remove books from these groups that list history as a major topic.[23] Figure 4 presents the aggregate indicators on technology and computer science based on the information from the Library of Congress' records.

The relationship between books, patents and R&D

Books on technology and computers are usually published when the new technology has commercial value and will be implemented. As a result, we might expect that R&D expenditures should be leading indicators of the number of new technology titles. The linkage between books and R&D can be described by Figure 5 where, once

[21] See Appendix A for a listing of the major groupings and sub-groupings in T and Q.

[22] A number of the books in Subgroups TT (Handicrafts) and TX (Home Economics) are excluded to focus on new technologies in use in the market economy.

[23] Books with history in the title or indicated as a major subject are removed to exclude books that have no real link to current technology (e.g., a book on the Life of Alexander Graham Bell published on the 20th anniversary of his death will not tell us much about the current state of technology in the communications industry).

again R&D can be viewed as an input. In addition to R&D leading to new technology, increases in scientific knowledge, or patents, may also lead to more books in the field of technology.

To investigate the relationships between these different measures of innovative activity, I explore whether changes in patents, science books, or R&D expenditures Granger-cause changes in the number of new titles in technology.[24] The numbers reported in Table 1 provides some support for the relationship between R&D, science and technology.[25] When changes in new titles in Science is used as a measure of changes in scientific knowledge and R&D intensity is proxied by R&D expenditures, we find some evidence that both Science and R&D granger-cause changes in New books on technology and computer science. However, there is little evidence that patents Granger-cause books on technology.

Although these results help strengthen the argument that the new book measure of technological change is an output of innovative activity, it is still necessary to examine whether the date of the first book(s) on a subject appear to coincide with what we know about the introduction of new products to the market. Because of the number of different technological advancements, it would be virtually impossible to do this for every

[24] The data on the number of patent applications by year can be obtained from the U.S. Patent Office and statistics on R&D expenditures are available from the National Science Foundation. The expenditures were converted to real R&D expenditures using the GDP deflator.

[25]The results are similar if the Stock of R&D (as defined in papers such as Loch (1995)) is used instead of the flow.

category. However, the timeline and graph for Computer hardware, found in Figure 6, demonstrates that the book measure appears to capture major technological advances in the area – especially the introduction of the personal computers in the early 1980s.[26,27] For example, the period 1980-84 saw the introduction of the first portable computer, the first IBM personal computer, the first IBM clone, the first Macintosh computer, the first laptop computer and large changes in the power of computer chip.

Just a Measure of Diffusion?

Although it appears that the new indicators may be correlated with the introduction of new technologies, it remains important to ask if the new indicators are only capturing technological diffusion. There are a number of reasons to believe that diffusion alone does not explain the patterns seen in the indicators. First, as mentioned before, companies publish their instruction manuals at the time that the product is

[26] Alexopoulos (2004) also provides an example based on books on penicillin. Although the healing properties of penicillin were discovered in the 1920s, books on penicillin did not appear in the Library of Congress until approximately 1940 when the drug companies published manuals for doctors on how to treat patients with penicillin. The reason for the long lag (between discovery and publication) again demonstrates the usefulness of the new measure in certain fields. The history of penicillin confirms that it was impossible to produce commercial grade penicillin until the early 1940s because addition technology needed to be developed.

[27] A similar patter for the 1980s appears if we graph new titles in both hardware and software. However, when software is included, there is a larger increase in books seen in the 1990s which corresponds to the introduction of the internet.

introduced to market (not afterwards)[28], and book publishers are likely to introduce books on the subject shortly afterward given their incentive to maximize profits. This suggests that the majority of manuals/new book titles should precede the technological diffusion. Second, the data on the share of computer expenditures in durable expenditures does not have the same pattern as the computer indicators based on publications (See Figure 6B). Specifically, there is no peak in the share of expenditures in 1984, and no decline between 1985 and 1990. Instead, the data would suggest that computer technology began diffusing in the late 1970s and has not yet stopped. This measure of diffusion is consistent with the data on the share of computer and periphery equipment in the total net stock of non residential capital reported in Oliner and Sichel (1994), which suggests that, between 1970 and 1993, the peak in the ratio occurs in 1989 (not in 1984 as my computer indicators suggest). Together, the evidence suggests that the new book indicators are not solely picking up the diffusion of technology.

Section 3:

The relationship between direct measures of technology and changes in GDP

While, there is some evidence that suggests that the books indicator is related to changes in the level of technology available in the economy, it remains to be seen if there is a relationship between the books indicator and changes in GDP. Figure 7 graphs

[28] For example, the marc record displayed in Figure 3 is the manual that was shipped with C++ when it was first introduced to the market.

changes in the technological indicator obtained from the Bowker's information and changes in real GDP. The graph shows that there are significant changes in the number of new titles in the field of technology before almost all recessions and expansions.[29]

A more formal analysis confirms that the new technology indicators generally do not have a contemporaneous relationship with changes in real GDP (See Table 2). However, using a two variable VAR, where $Y_t = \alpha + \gamma t + \rho Y_{t-1} + \varepsilon_t$ and $Y_t = [\ln(GDP_t), \ln(X_t)]'$, I find evidence that the technology shocks identified by the indicators do have a significant impact on GDP.[30] Similar to Shea (1998), I assume that the technology shock only affects GDP with a lag.[31] Figures 8 to 10 display the impulse responses of GDP to a technology shock for each of the indicators used along with 1.65 Monte Carlo standard error bands. These figures illustrate that GDP rises in response to a positive technology shock with the peak response occurring 2-4 years after the shock.

While the relationship between Patents and GDP is weak, the results in Table 3 suggest that changes in new technology indicators Granger-cause GDP. However, the

[29] In fact, there are also changes in the number of new books prior to the growth slowdowns discussed by Zarnowitz (1992).

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

[31] To determine if the ordering had a significant impact on my results, I also ran VARs with the Technology indicator entering before the ln(GDP). I found little evidence to suggest that the results from the bi-variate VAR were sensitive to the ordering of the variables.

reverse is not true. The tests indicate that GDP does not Granger-cause the level of the technology indicators.

Table 4 displays the variance decomposition implied by the VARs at the 3, 6 and 9 year horizons. Three patterns emerge in this table. First, the percent of variation in ln(GDP) due to technology at a 3 year horizon is approximately 10-20% with this effect doubling over the next 3 years. Second, the computer and telecommunications indicators explain more of the variance that the general technology indicators. Third, the results suggest that the new indicators are better able to explain the variation in GDP than the more traditional indicators (i.e., patents and R&D expenditures).[32]

Just Trends in the Publishing Industry?

In general there may be some concern that the changes in the number of technology books may simply capture trends in the publishing industry as a whole. To illustrate that this is not the case, I explore how changes in the number of new technology books differ from changes in the number of new titles in history. While both of these series should be influenced by changes in the publishing industry, if they have different properties, and if changes in the number of history titles do not have the same relationship to R&D or patents, this will help bolster the case that changes in technology titles are related to changes in the technology used in the economy. However, I find no

[32] Similar results emerge for the computer and telecommunications indicators when the first difference of ln(GDP) is used instead of the level.

indication that the number of new history titles is related to either R&D expenditures or patents. Furthermore, Figures 7 and 10, along with the results reported in Tables 2 and 3, suggests that an indicator based only on the number of new history books does not have the same relationship with changes in GDP.[33] Therefore, it does not appear that the relationship between GDP and the new technology indicators can be simply explained by changes in the publishing industry as a whole.

While these results about the relationship between the new indicators and GDP may be information, it is important to explore how technology shocks affect TFP, capital and labor. The methodology used for this analysis is similar to the one used by Shea (1998). However, I use the new indicators of technological change in my regressions and consider multiple measures of total factor productivity growth.

Measures of Total Factor Productivity

There are many ways that economists measure total factor productivity. For the purpose of my analysis, I use three of the most common measures. The first measure is the basic uncorrected Solow residual typically used in macroeconomics, namely:

$$\ln(TFP_t)= \ln(Y_t) - \alpha\ln(K_t) - (1-\alpha)\ln L_t \text{ where } \alpha=1/3.$$

[33] Similar results are obtained using new titles in other fields (e.g., new titles in music, drama and poetry) that: (1) are unlikely to be correlated with changes in technology that could have an impact on economic activity, and (2) would be affected by changes in the publishing industry.

Here, K is measured using data on the fixed reproducible tangible assets for the United States, Y is real GDP and L is the number of employment hours.[34] The second measure I use is the Tornqvist Measure of TFP:

$$\text{Tornqvist Measure} = \Delta\ln(Y_t) - 0.5(\alpha_t + \alpha_{t-1})\Delta\ln(K_t) - (1-0.5(\alpha_t + \alpha_{t-1}))\Delta\ln L_t$$

This measure still maintains the assumption that firms are perfectly competitive. However, now the elasticity of output with respect to capital and labor are allowed to vary over time. To compute this measure, I use the same data as above for the measures of K, Y and L. However, now I also use data on labor's share of income in the economy each year to compute α_t. The third measure is the state of the art cleansed Solow residual created by Basu, Fernald and Kimball (2004). Their purified measure of the Solow residual takes the aggregation issue seriously and attempts to correct for changes in utilization, imperfect competition and non-constant returns to scale.

Table 5 examines the contemporaneous relationship between changes in the TFP measures and changes in the book indicators. Similar to the findings for GDP growth, the results demonstrate that there is very little evidence to support a contemporaneous relationship between changes in the TFP measures, and changes in the indicators. However, as the VAR evidence indicates positive shocks to technology – as measured by increases in the orthogonal component of my technology indicator – significantly increase TFP in the short run.

[34] The data for the first two measures are based on the National Accounts Data obtained from the Bureau of Economic Analysis.

Four Variable VARs

In the VAR, I assume that the level of In this section we expand the number of variables in the VAR to include changes in Capital, labor and TFP. Specifically, I assume that $Y_t = \alpha+\gamma t+\rho Y_{t-1} +\varepsilon_t$ where $Y_t = [\Delta\ln(K_t), \ln(N_t), \ln(TFP_t), \ln(X_t)]'$.[35] Again, I follow the convention in Shea (1998) and place the technology measure last in the ordering to reflect the assumption that shocks to this variable only affect TFP, hours and the change in capital with a lag.

Tables 6 – 8 report that Granger-causality tests for the VARs using the different measures of TFP. These results show that the new technology measures tend to Granger-cause TFP and changes in capital – especially when the computer and telecommunications indicators are used. However, only the telecommunications indicator appears to Granger-cause labor at the 5% level. The tables also show that labor, and TFP Granger-cause changes in the telecommunications and Bowker's Technology indicator when the first and second TFP measures are used in the regression. However, this relationship vanishes when the corrected solow residual is used (i.e., TFP measure 3).

Tables 9-11 report the percent of variation due to technology in the four variable VARs for the different TFP measures. A comparison of these tables illustrates that the

[35] For the BFK measure of TFP I consider the case where and $Y_t = [\Delta\ln(K_t), \Delta\ln(N_t), \ln(TFP_t), \ln(X_t)]'$

computer indicators and the telecommunications indicators explain the most variation in TFP, employment and capital.[36]

Figures 11-19 illustrate the impulse response functions for the new technology indicators and the different measures of TFP. In general they show that a positive technology shock increases TFP and capital one period after the shock with a peak response usually occurring two periods after the shock. The TFP and capital responses are significant for approximately 5-7 years following a shock to computer technology, and 2-3 years following a shock to telecommunications technology. The effects on labor are somewhat weaker and depend on the type of technology considered and the measure of TFP used.

Conclusion:

The answer to the question what happens following a technology shock is an important one. First, this information helps us determine if technology shocks are an important source of business cycle fluctuations. Second, the answer to this question can help us determine which type of model is most consistent with the data (e.g., sticky prices vs. the standard real business cycle mode).

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[36] While patent appear to do a relatively good job at explaining variation in labor and TFP, similar to Shea (1998) I find little evidence that patents Granger-cause TFP or changes in capital and only weak evidence (a p-vale of approximately 0.1) that patents Granger-cause labor. Moreover, the corresponding impulse response functions show that a shock to patents had no significant impact on TFP, labor or capital at any horizon.

In this paper, I add to the literature exploring the importance of business cycle shocks in two ways. First, I create a new measure of technological change using previously unstudied information on new book titles in the field of technology from R.R. Bowker and the Library of Congress. Second, I use these new measures in a vector autoregression to explore what happens following a technology shock.

My analysis is closest in spirit to Shea's (1998) study that uses the number of patent applications and R&D expenditures as direct indicators of technological change. However, I find that my new indicators are better able to capture movements in TFP, capital and labor than the more traditional patent and R&D indicators. In response to a positive technology shock, I find that GDP, TFP, Labor and Capital increase. These results are consistent with the predictions of the standard real business cycle models and stick price models where the monetary authority accommodates a technology shock by increasing the money supply.

While my results are consistent with this class of models, I do not find overwhelming evidence that technology shocks are able to account for the variation of labor seen at business cycle frequencies. In particular, only telecommunications technology appeared to have a significant impact on hours in the short run. The short run fluctuations in GDP from technology shocks appear to be caused by changes in TFP and capital, with the largest affects being driven by computer and telecommunications technology.

Given that the results suggest that new book indicators may provide good proxies for technological change in some areas, future work should concentrate on: (1) examining other subgroups of technology in an attempt to determine which other types of innovations may that have an impact on economic activity, (2) exploring if these results hold for other countries, and (3) redoing this analysis using industry panel data to determine which sectors are most influenced by the type of technological changes captured by the new indicators.

References:

Altig, D., Christiano, L., Eichenbaum, M. and J. Linde, "Technology Shocks and Aggregate Fluctuations." Manuscript, Northwestern University, 2003.

Basu, S., J. Fernald, and M. Kimball, "Are technology improvements contractionary?" NBER Working Paper #10592, 2004.

The Bowker Annual, R.R. Bowker Company, New York, Various Years.

Burns, Arthur F., and Wesley C. Mitchell, *Measuring Business Cycles,* National Bureau of Economic Research, Cambridge, Mass. 1946.

Chari, V.V, P. Kehoe and E. McGratten, "Are Structural VARs Useful Guides for Developing Business Cycle Theories" Working Paper, Federal Reserve Bank of Minneapolis.

Christiano, L., M. Eichenbaum and R. Vigfusson. What Happens After a Technology Shock?, Manuscript, Northwestern University, 2002.

Christiano, L., M. Eichenbaum and R. Vigfusson. "The Response of Hours to a Technology Shock: Evidence Based on Direct Measures of Technology." National Bureau of Economic Research, Inc, NBER Working Papers: 10254, 2004

Jaffe, A and M. Trajtenberg . “Patents, Citations and Innovations: A Window on the Knowledge Economy.” MIT Press, Cambridge (2002).

Fisher, J. “Technology Shocks Matter.” Working Paper, Federal Reserve Bank of Chicago, 2003-06-01

Francis, N. and V. Ramey, “Is the Technology-Driven Real Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revisited,” UCSD working paper.

Gali, Jordi, “Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?” *American Economic Review* 89 (March 1999), 249-271.

Gali, Jordi, "Discussion of *What Do Technology Shocks Do*?" 1998 NBER Macroeconomics Annual, Cambridge, MA.

Gali, Jordi and P. Rabanal “Technology Shocks and Aggregate Fluctuations: How Well Does the RBS Model Fit Postwar U.S. Data?” NBER Working Paper 10636, 2004

Geisler E., “The metrics of science and technology.” Westport, Conn. : Quorum Books, 2000.

Griliches, Z. “Patent Statistics as Economic Indicators: A Survey.” *Journal of Economic Literature* 28 (December 1990), 1661-1708.

Jaffe, A. "Discussion of *What Do Technology Shocks Do*?" 1998 NBER Macroeconomics Annual, Cambridge, MA.

Kortum S. and J. Putnam. “Assigning Patents to Industries: Tests of the Yale Technology Concordance”. Economic Systems Research, 9 (2), 1997, 161-175.

Library of Congress Classification. A-Z, Library of Congress, Cataloguing Distribution Services, Washington, D.C. Various years

Oliner, S. and D. Sichel, “Computers and Output Growth Revisited: How Big is the Puzzle?” *Brookings Papers on Economic Activity* 1994 (2), 1994, 273-317.

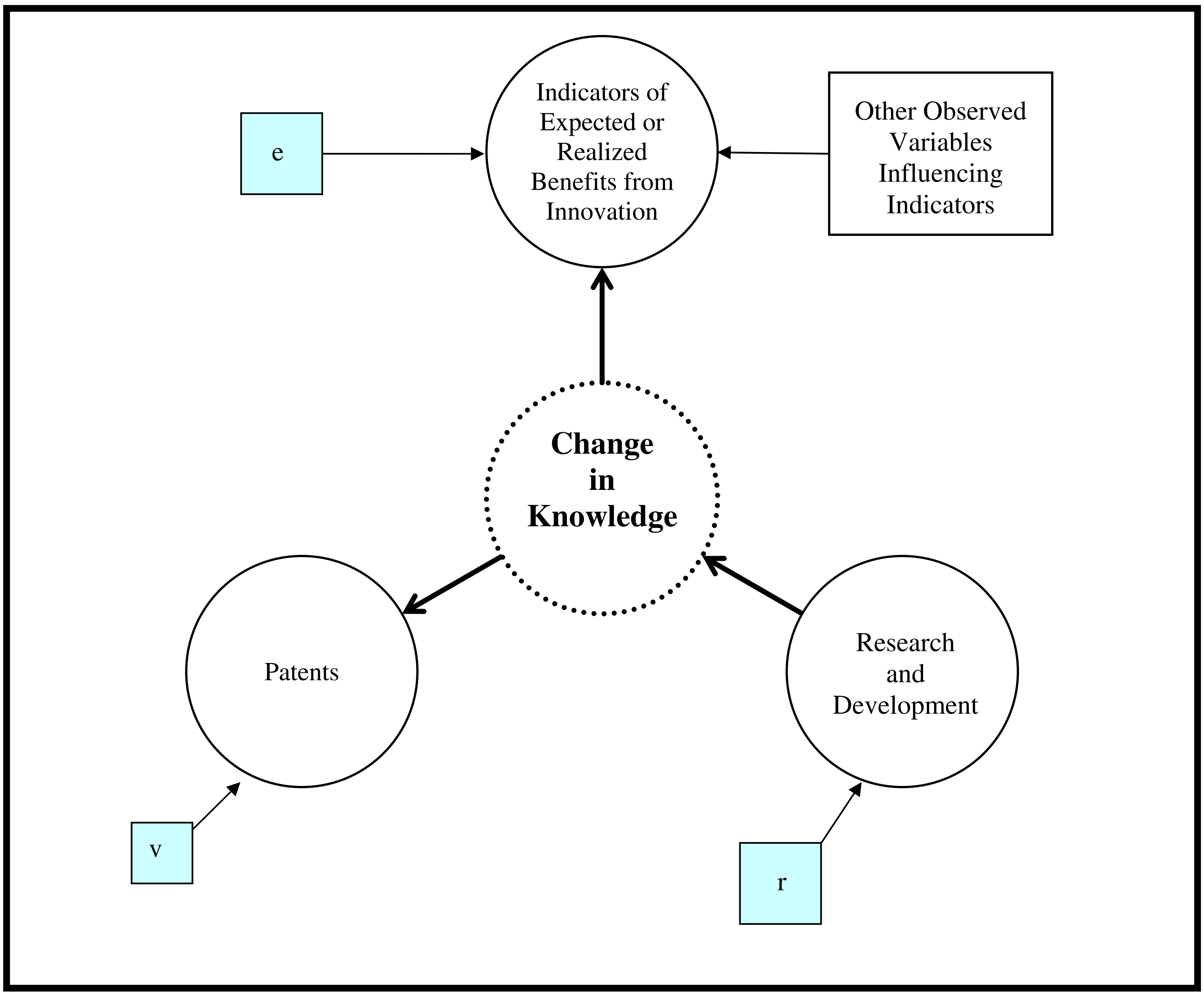
Shea, John. "*What Do Technology Shocks Do*?" 1998 NBER Macroeconomics Annual, Cambridge, MA.

Wilson, D. “IT and Beyond: The Contribution of Heterogeneous Capital to Productivity” Manuscript Federal Reserve Bank of San Francisco, 2004.

Yorukoglu, M. “Product vs. Process Innovations and Economic Fluctuations” Carnegie-Rochester Conference Series on Public Policy, vol. 52, no. 0, June 2000, pp. 137-63.

Zarnowitz, V. “Business cycles: Theory, history, indicators, and forecasting”, NBER Studies in Business Cycles, vol. 27. Chicago and London: University of Chicago Press, 1992

Figure 1. The Knowledge Production Function (Griliches)
A Simplified Path Analysis Diagram



Here v, r, and e represent shocks to patents, research and development and measures of economic activity like GDP respectively.

Figure 2.

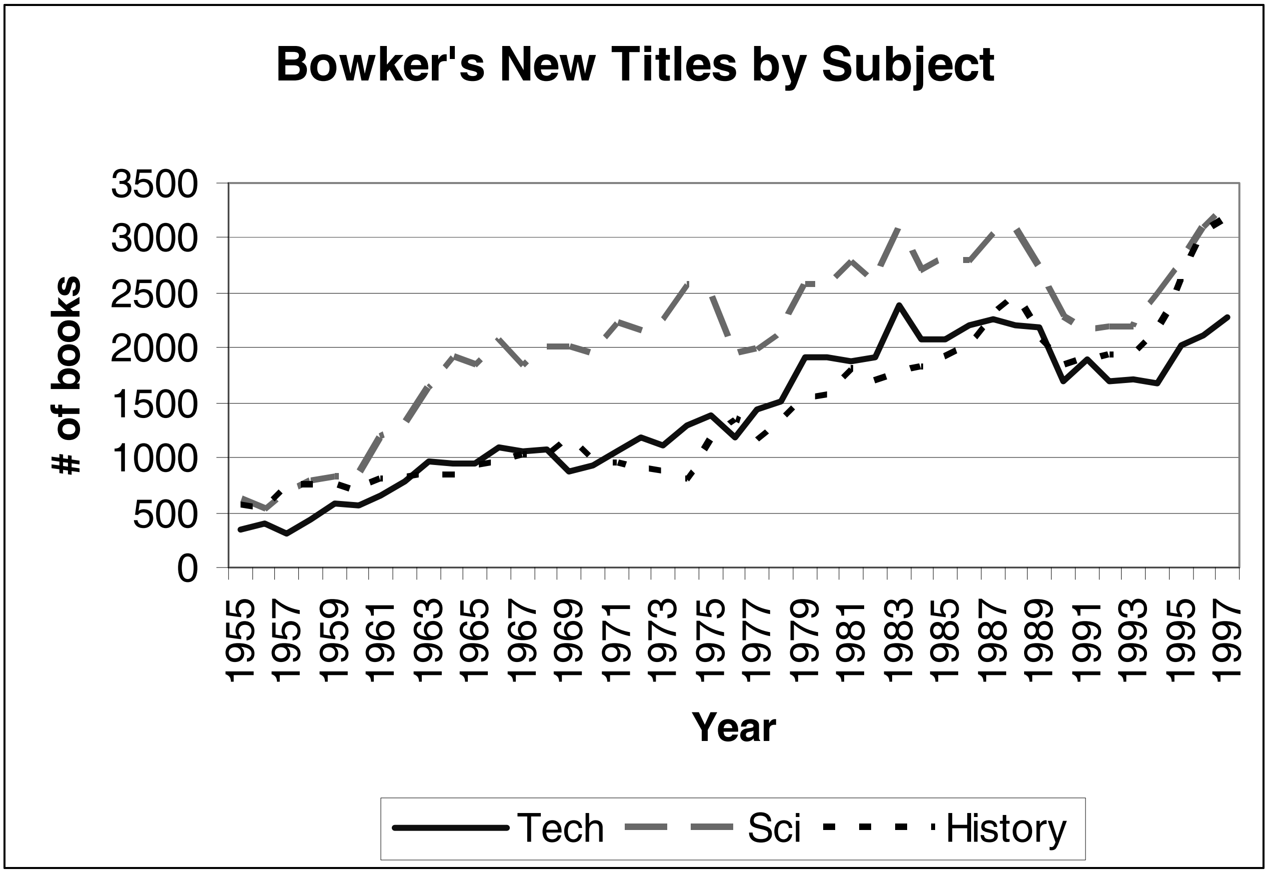

Bowker's New Titles by Subject
3500
3000
2500
2000
1500
1000
500
0
# of books
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
Year
Tech
Sci
History

Figure 3. Sample Marc Record and Associated online display

<u>Marc Record:</u>

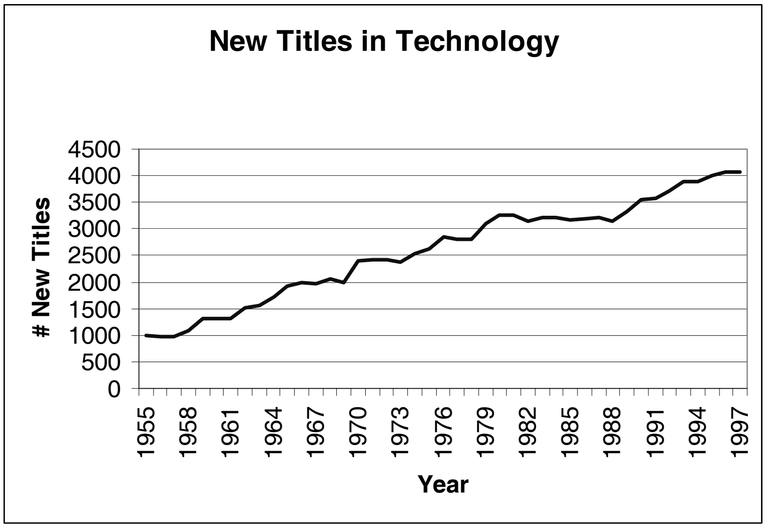

```
00971cam  2200277 a
4500001000800000005001700008008004100025035002100066906004500087010001700132020003900149040001800188050002700206082001700233100002400250245005500274260004600329300002700375440004600402504002500448500002000473650003600493740003800529952006000567991006600627-2860358-20000328102341.0-85
0830s1986    mau      b    001 0 eng  -  9(DLC)   85020087-  a7bcbc-
corignewd1eocipf19gy-gencatlg-  a   85020087 -  a020112078X (pbk.) :-
c$21.95 (est.)-  aDLCcDLCdDLC-00aQA76.73.C153bS77 1986-00a005.13/3219-1
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-GenCollhQA76.73.C153iS77 1986p0003475293AtCopy 1-
wBOOKS-
```

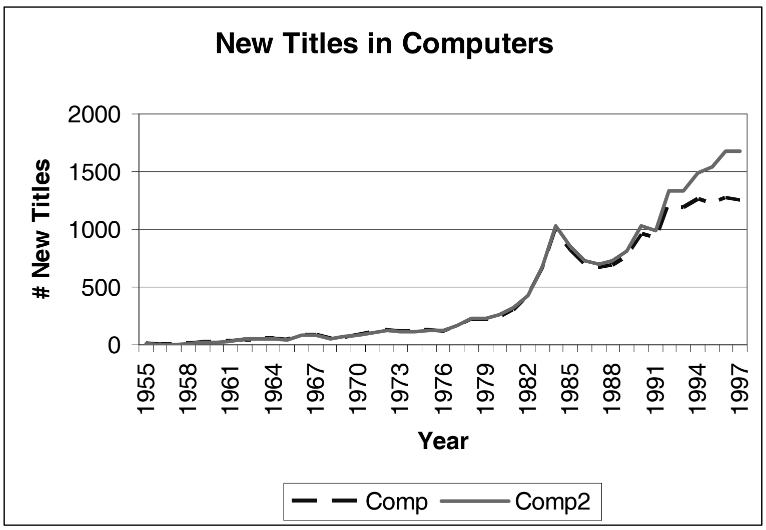

<u>Online display of information in Marc Record:</u>

The C++ programming language / Bjarne Stroustrup.

LC Control Number:	85020087
Type of Material:	Text (Book, Microform, Electronic, etc.)
Personal Name:	<u>Stroustrup, Bjarne.</u>
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:	<u>C++ (Computer program language)</u>
Series:	<u>Addison-Wesley series in computer science</u>
LC Classification:	QA76.73.C153 S77 1986
Dewey Class No.:	005.13/3 19

Figure 4. LOC Graph of Indicators





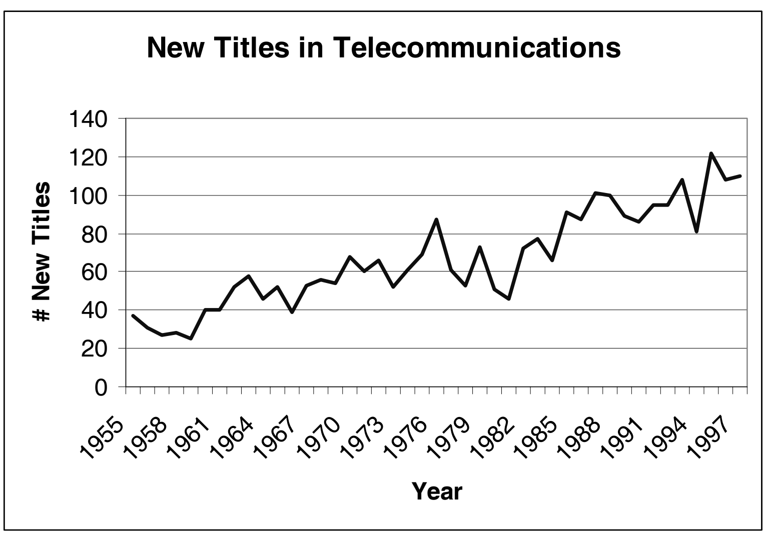


Figure 5. The Augmented Knowledge Production Function
A Simplified Path Analysis Diagram

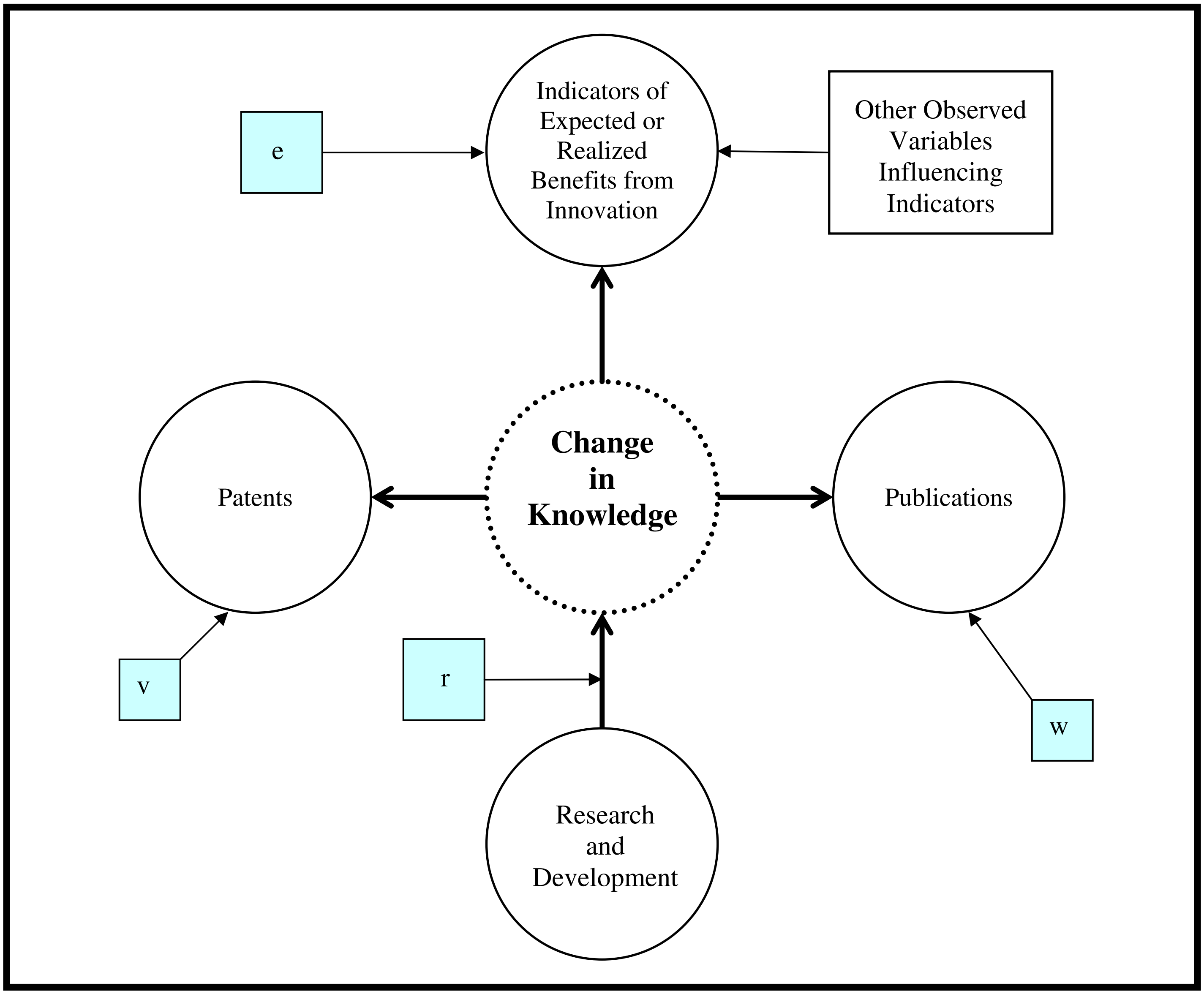
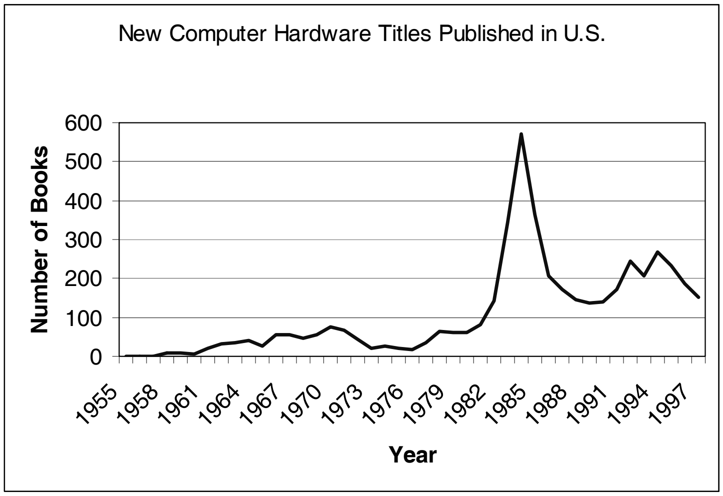


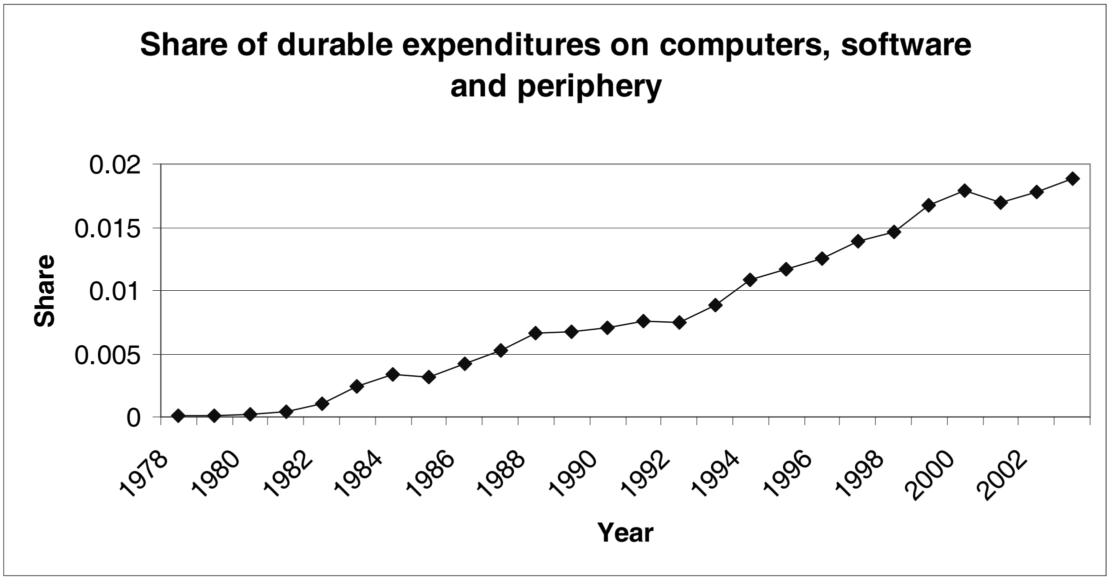
Figure 6. New Hardware Titles and Timeline



Timeline with Major dates

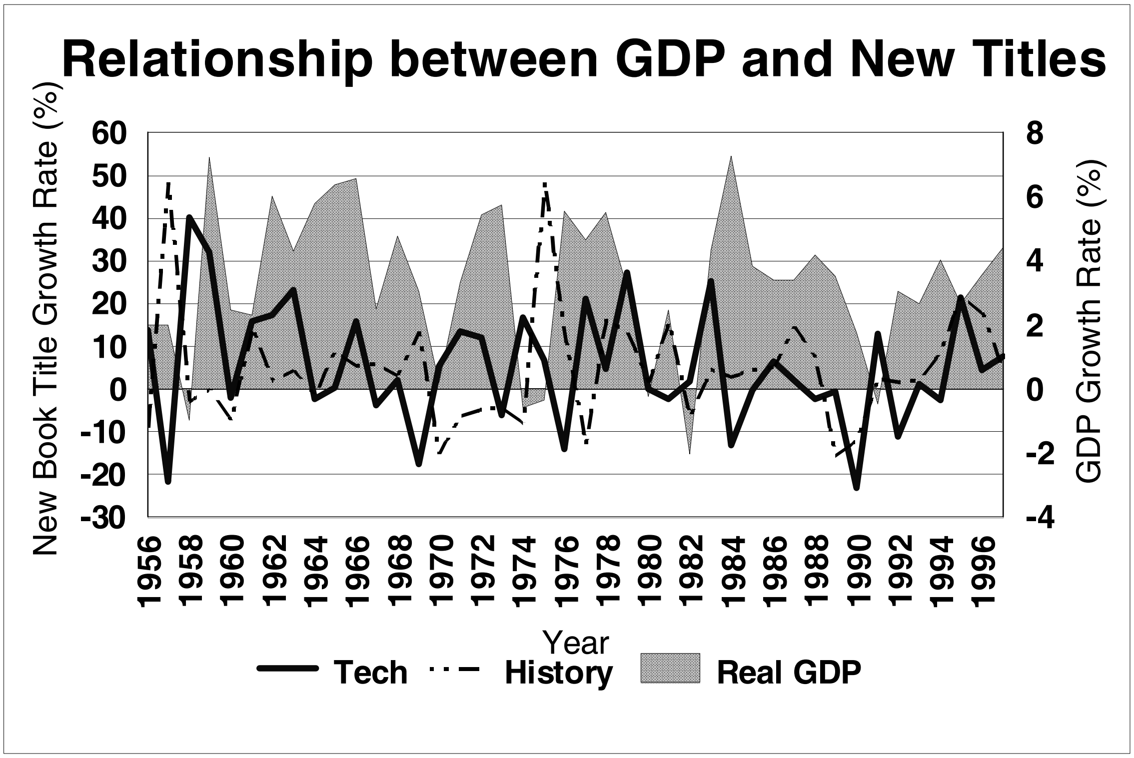
1955	Computers introduced: IBM702, Norc, Monorobot III
1956	IBM builds 1st hard drive cost: $1,000,000
1957	IBM introduces RAMAC Storage system
1958	Commercial Transistor Computers make first appearance
1959	Beginning of second generation of computers
1960	IBM releases IBM360 computer & DEC introduces computer with keyboard and monitor ($120,000) and first mini-computer ($20,000)
1961	First commercially integrated circuit introduced & IBM 7030 marketed
1962	Magnetic storage tape introduced & input output system using punch-tape terminal
1964	First Super computer introduced (CRAY)
1965	DEC introduces new mini-computer ($18,500)
1966	IBM introduces fist disk storage system
1967	floppy disk invented
1969	Intel announces first 1KB Ram chip
1970	First Floppy disk Available & Daisy wheel printer
1971	First Mass produced Microprocessor (Intel 4004), First mini-computer kit and Intel introduces DRAM
1972	Intel 8008 processor released, hand held calculators become popular, and liquid crystal display introduced
1973	
1974	The Intel 8080 processor is introduced and becomes the basis for the first personal computers
1975	Altair computer introduced for $397 and becomes overnight success and IMSAI introduced as business computer
1977	Apple II computer is introduced at trade show along with TRS-80 and Commodore computers
1978	Office Automation is marketed by Wang and Intel introduces 8086 and 8088 chips
1979	Motorola introduces chip that will be used for Macintosh computers later
1980	First Portable computer introduced
1981	First IBM PC introduced, cost of RAM dropping rapidly, Intel develops much faster 80286
1982	First IBM clones introduced
1983	First laptop computer, IBM launches IBM/XT and IBM/AT, Apple launches Lisa computer
1984	Apple introduces Macintosh computer, commodore introduces AMIGA and Intel ships 80286 chips
1985	Intel 80386 chip introduced
1986	First computer using new 80386 chip sold
1988	Nextcube computer introduced
1989	First 80486 computer chip by Intel
1990	New Cray super computers introduced and new chips developed by Motorola
1991	Archie telnet data retrieval system introduced
1992	World Wide Web launched
1993	Power PC introduced and Intel develops Pentium chip
1995	Pentium Pro chip introduced

Figure 6B.



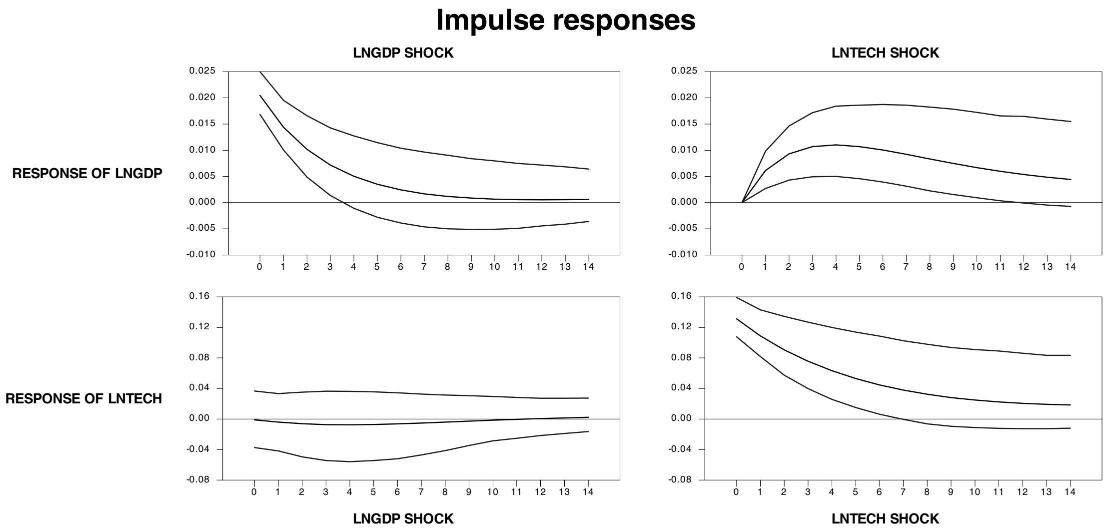
Share of durable expenditures on computers, software and periphery
0.02
0.015
0.01
0.005
0
Share
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Year

Figure 7.



Relationship between GDP and New Titles
New Book Title Growth Rate (%)
60
50
40
30
20
10
0
-10
-20
-30
8
6
4
2
0
-2
-4
GDP Growth Rate (%)
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Year
Tech
History
Real GDP

Figure 8. Impulse Response Functions for Tech and Tech2 Indicators



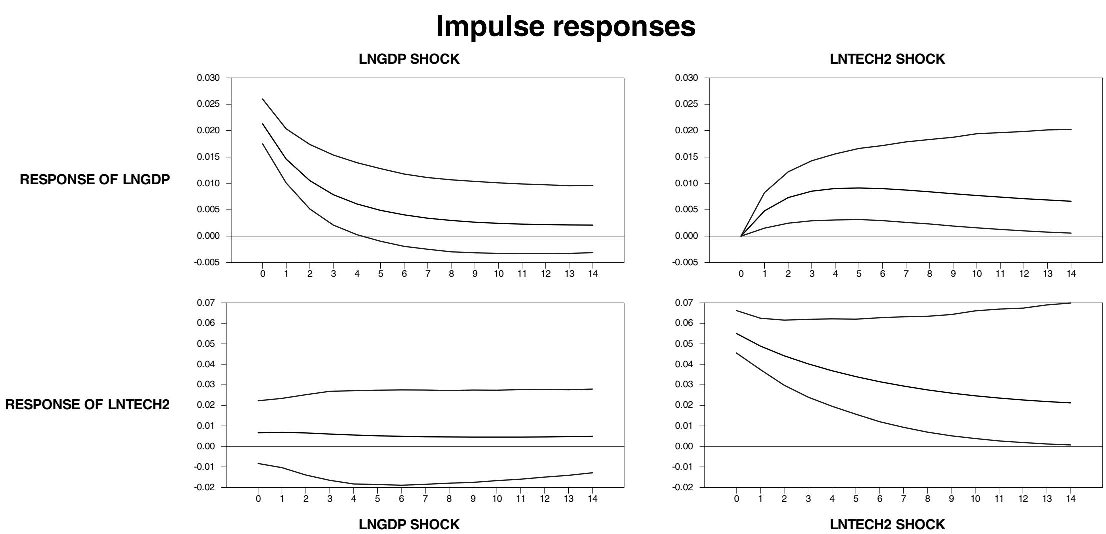
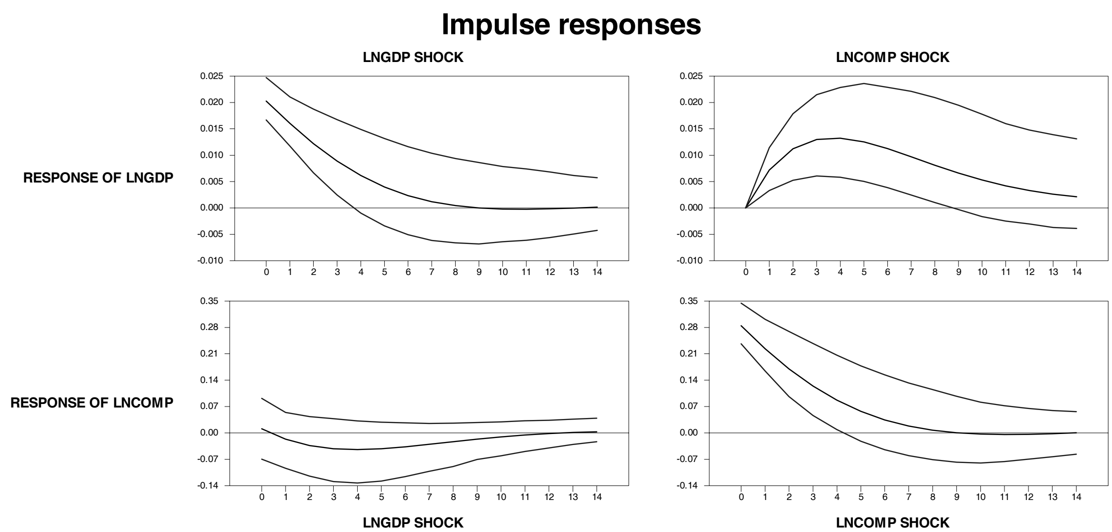


Figure 9. Impulse Response Functions for Comp and Comp2 indicators



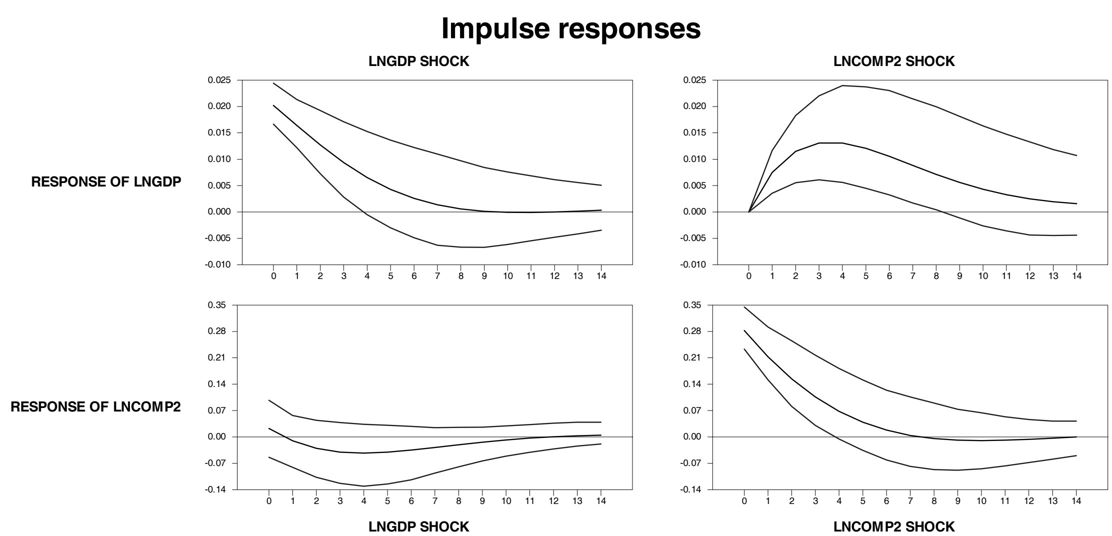
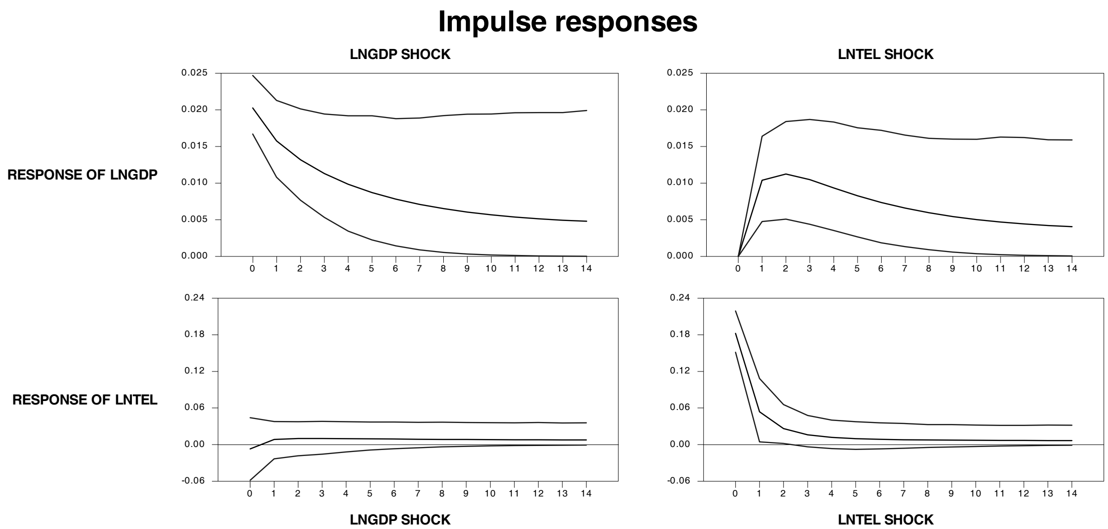


Figure 10. Impulse Response functions for Telecommunications and History



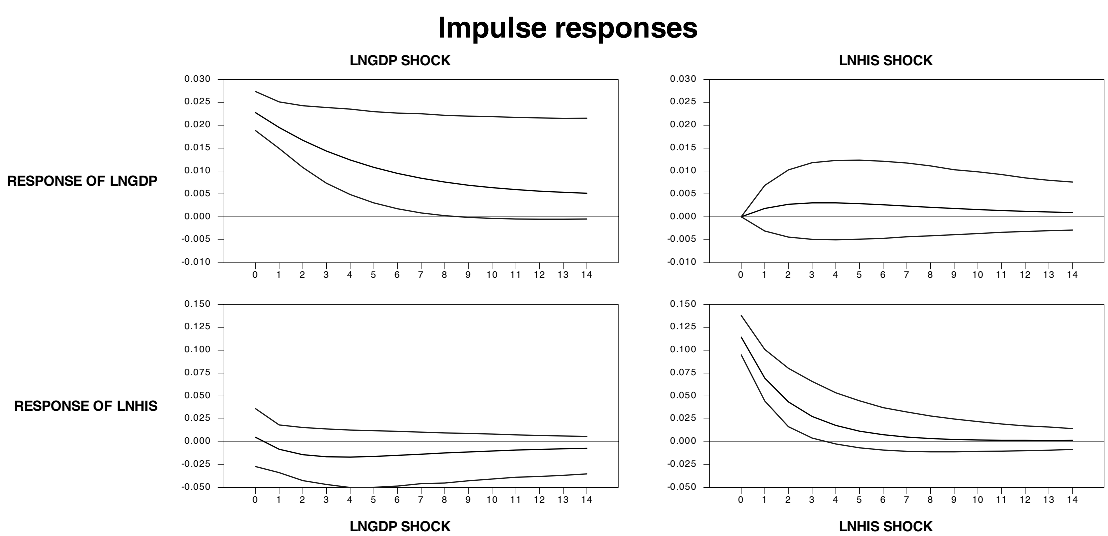
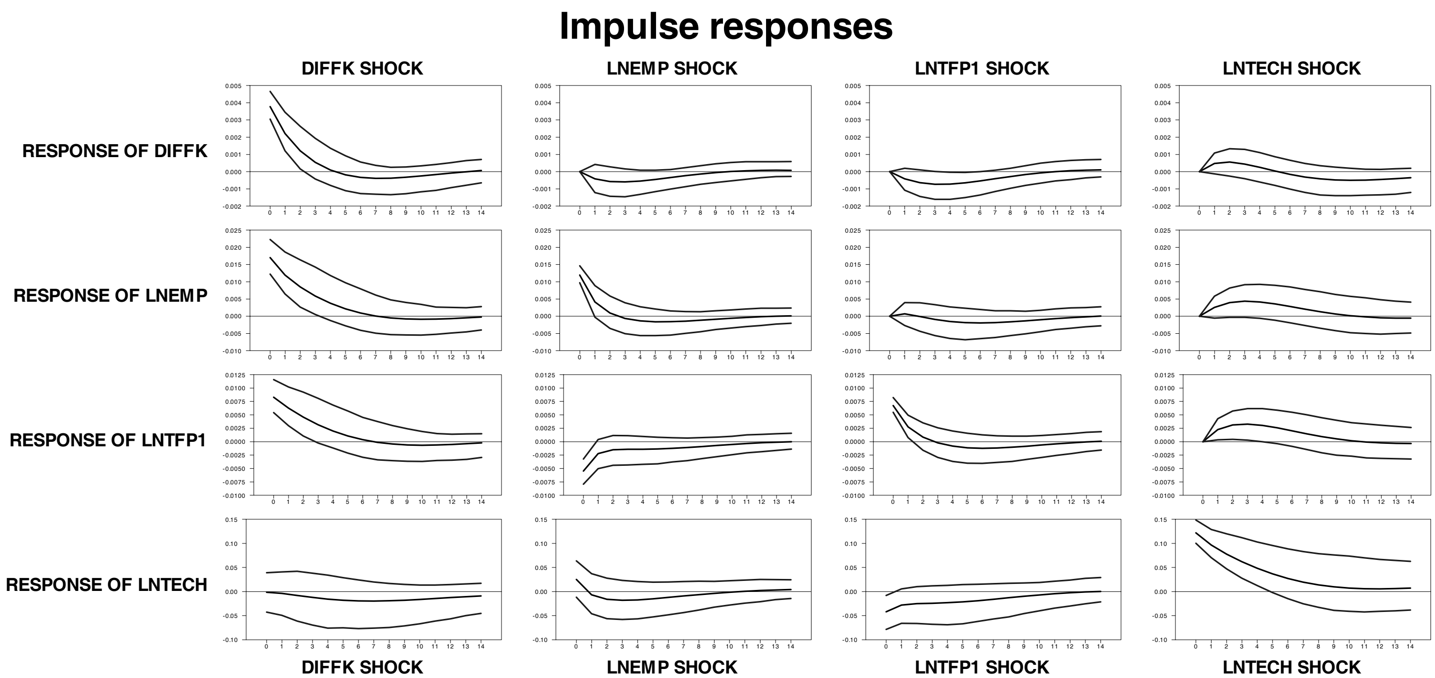


Figure 11. Impulse Responses for Tech and Tech2 Indicators



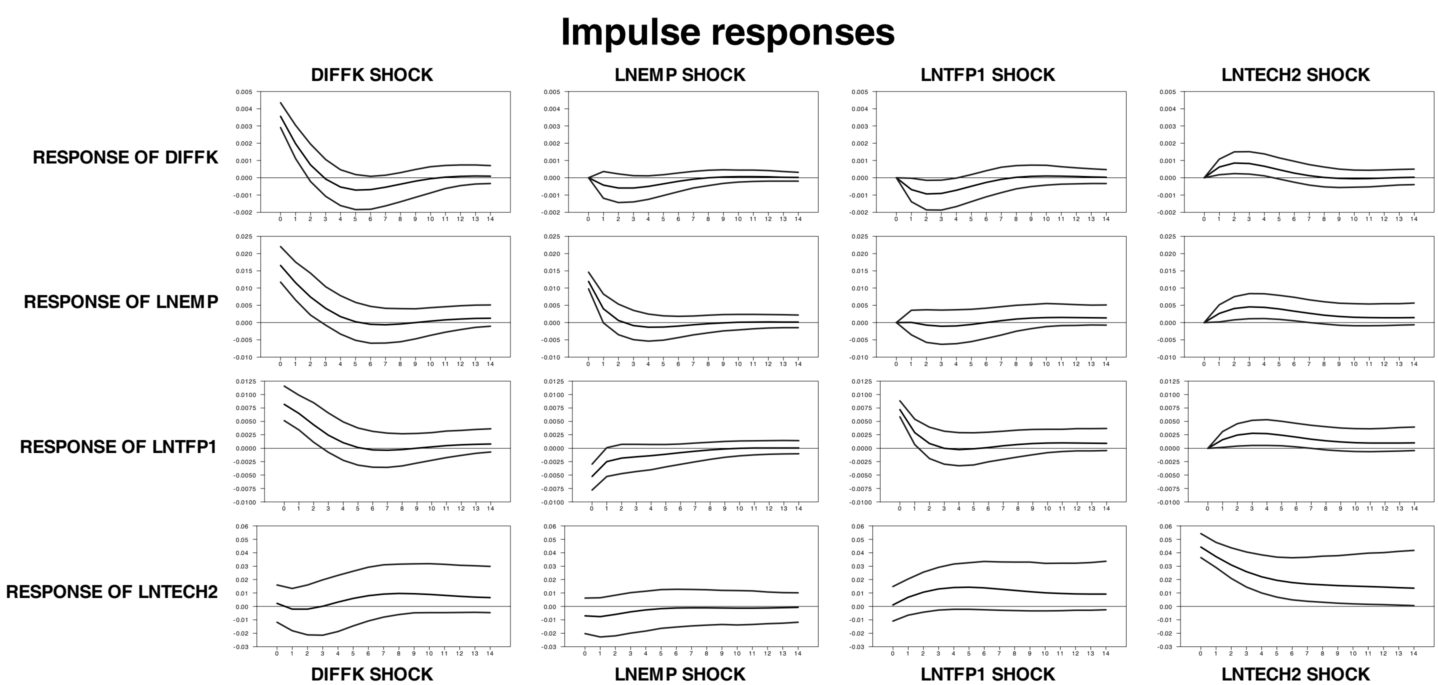
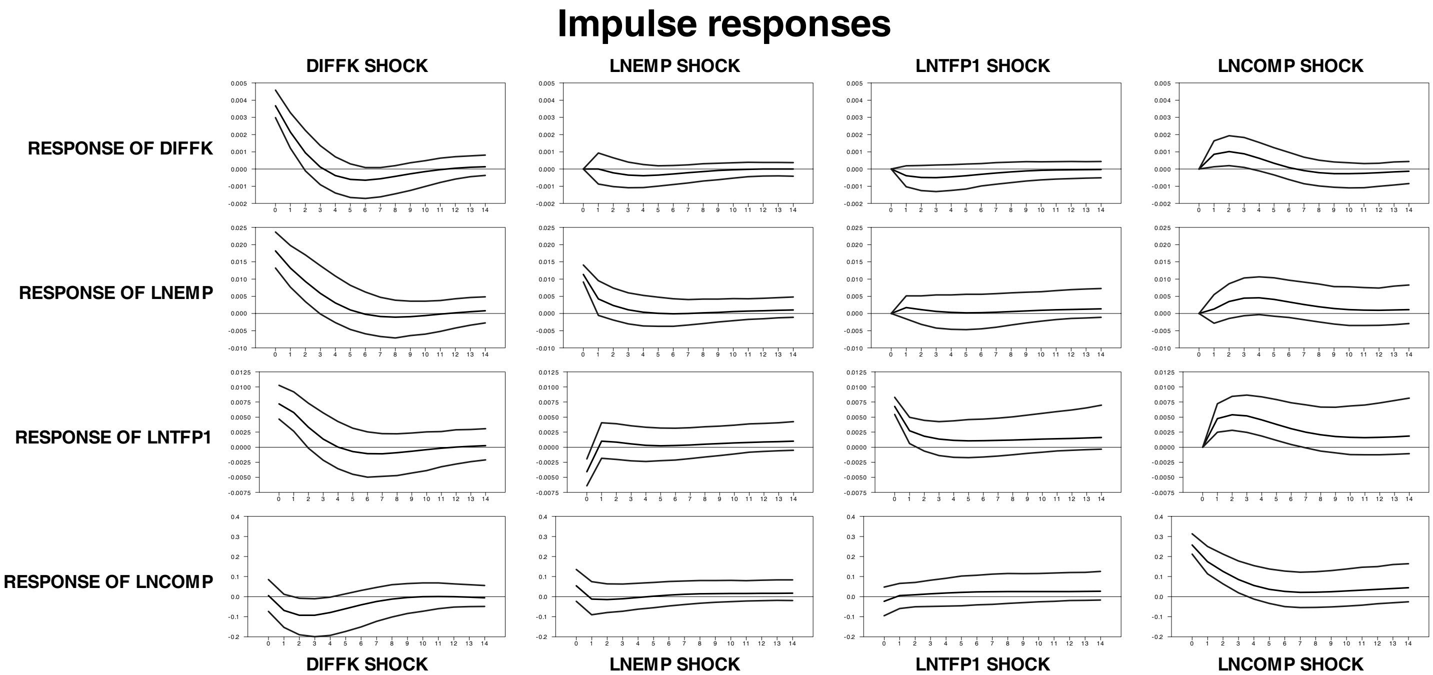


Figure 12. Impulse Responses for Computer Indicators



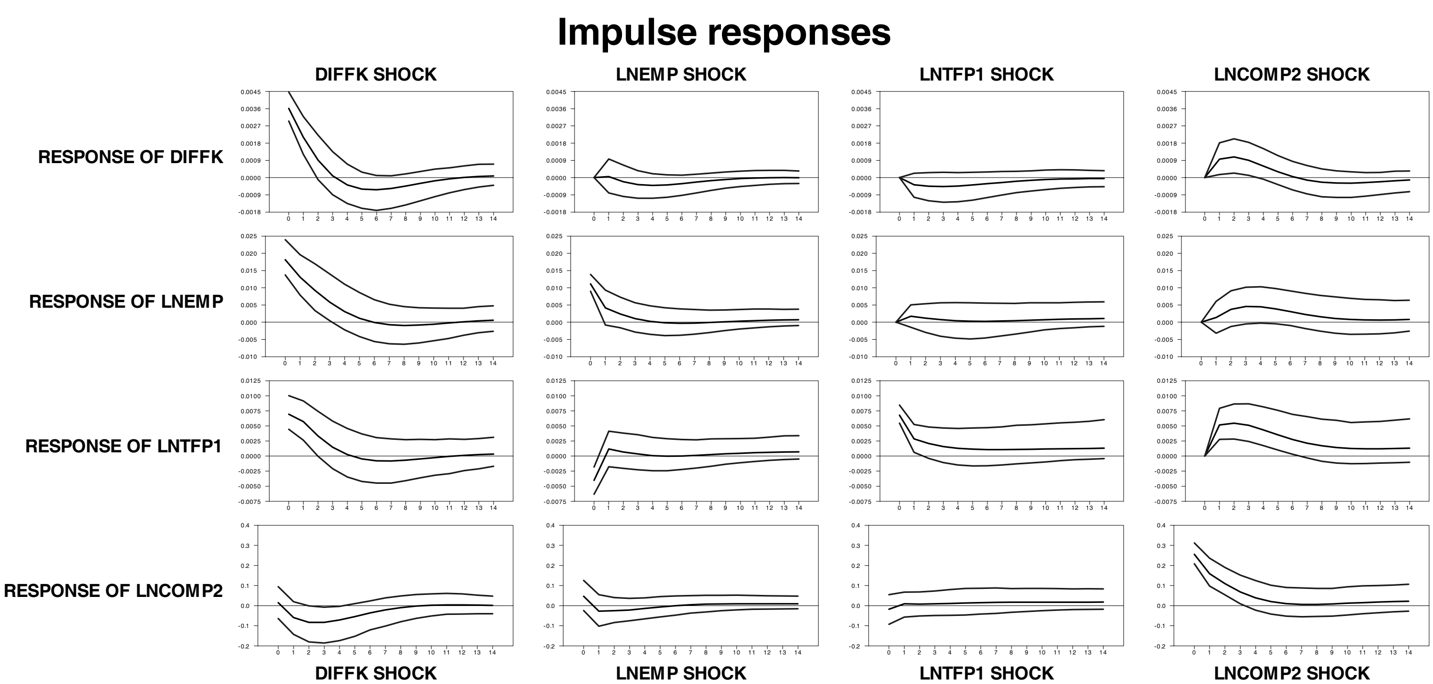


Figure 13. Impulse Response Functions for Telecommunications indicator

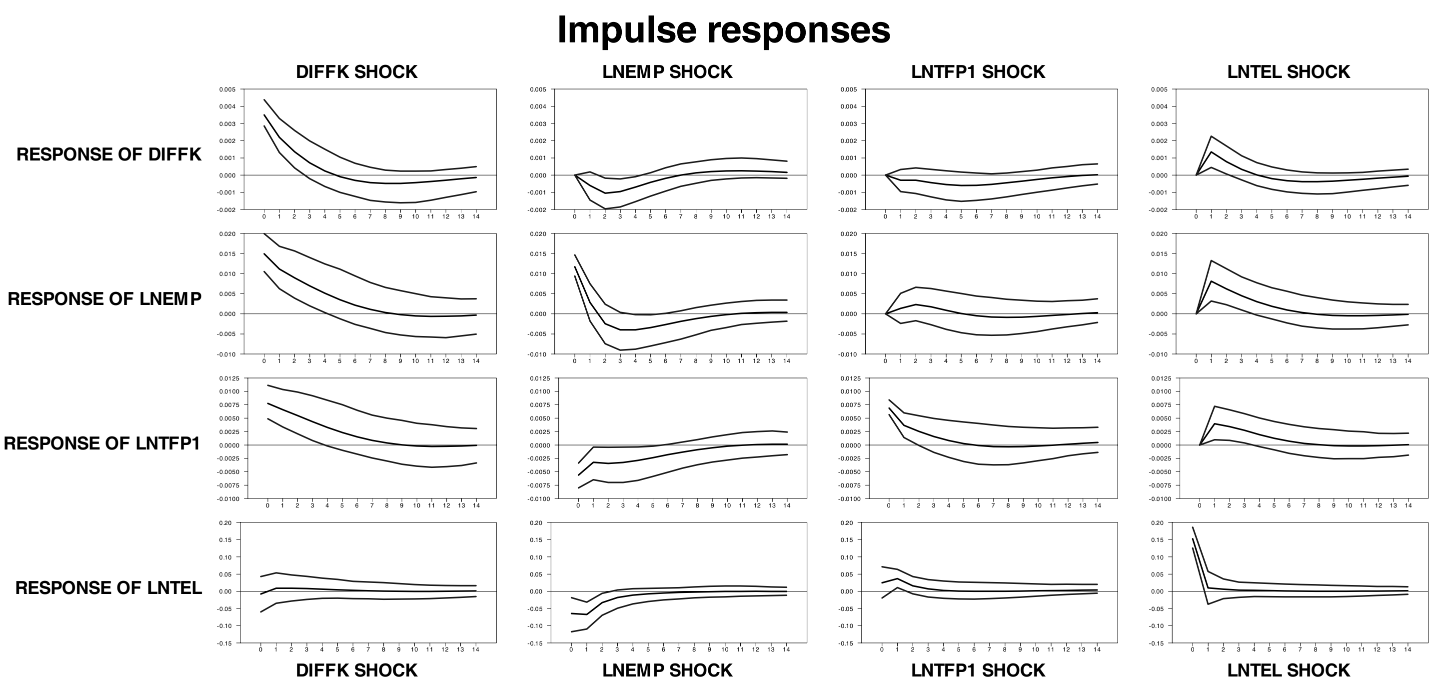
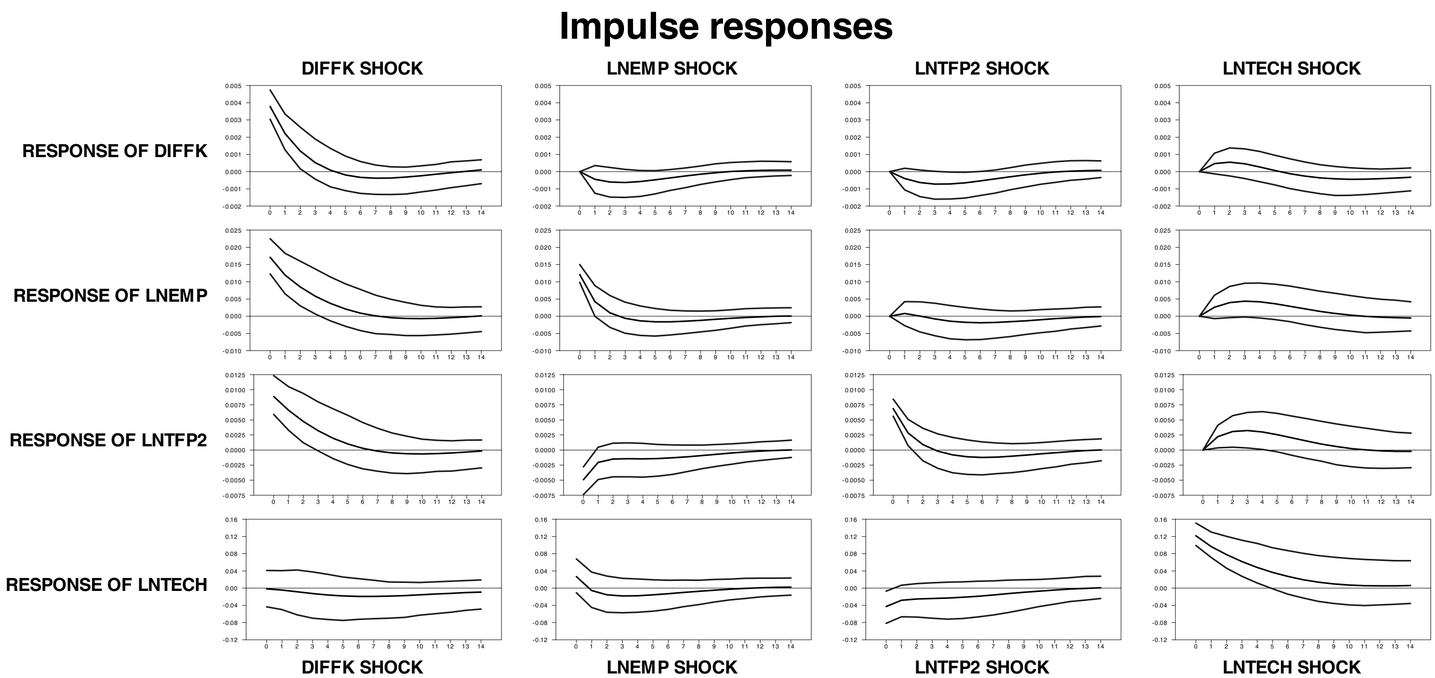


Figure 14. Impulse Response Functions for Tech and Tech2 Indicators



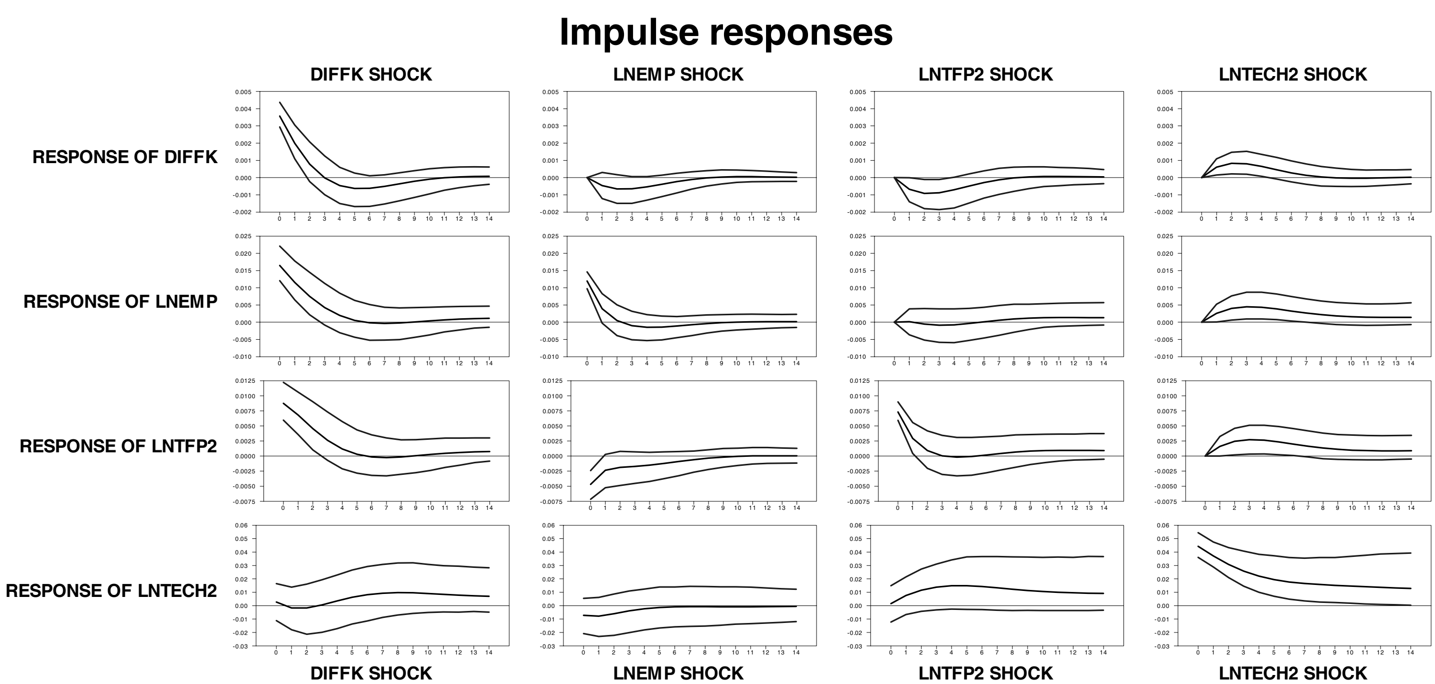
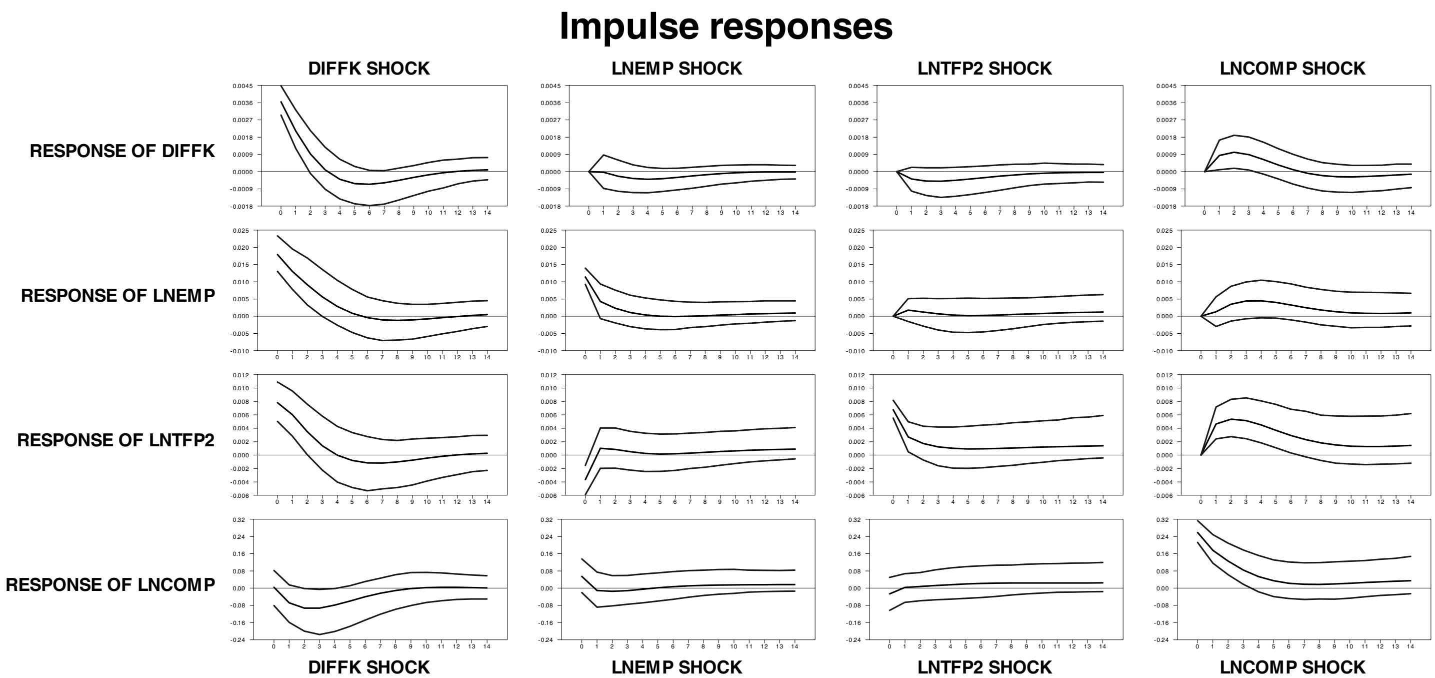


Figure 15. Impulse Response Functions for Computer Indicators



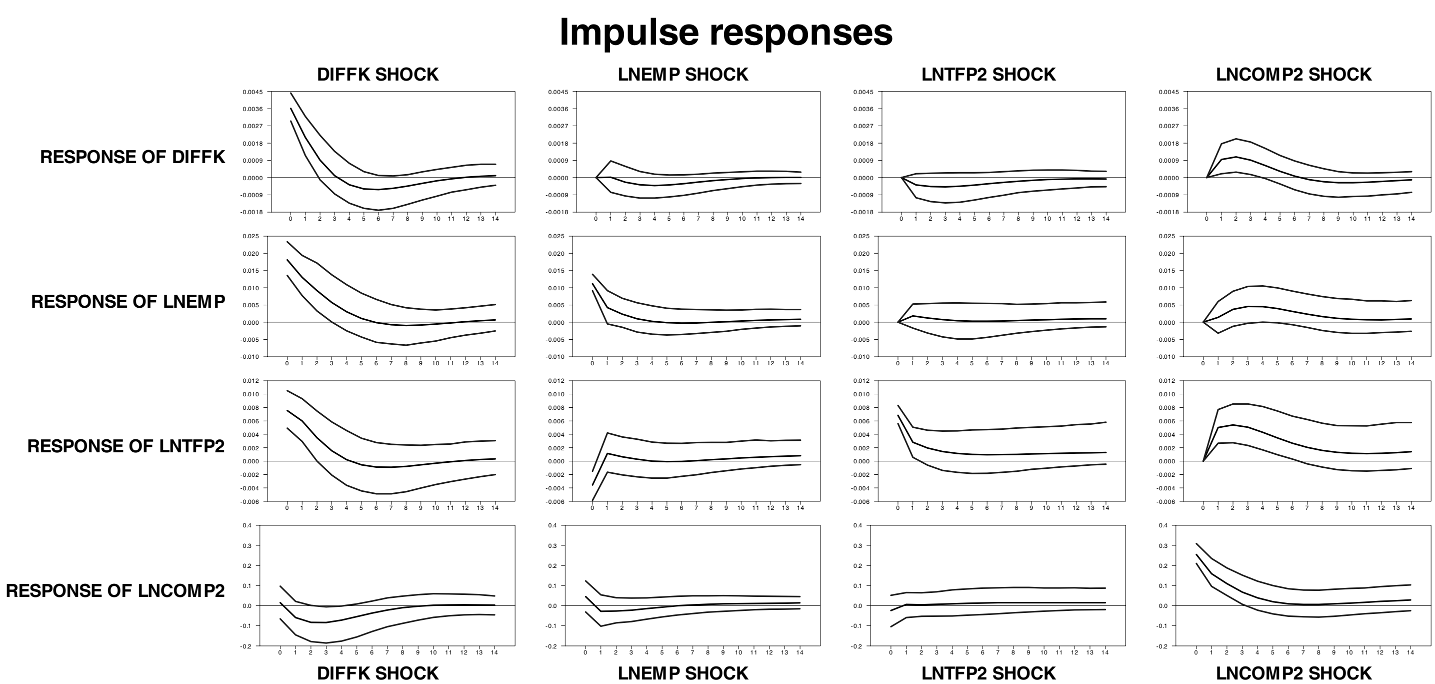


Figure 16. Impulse Response Functions for Telecommunications

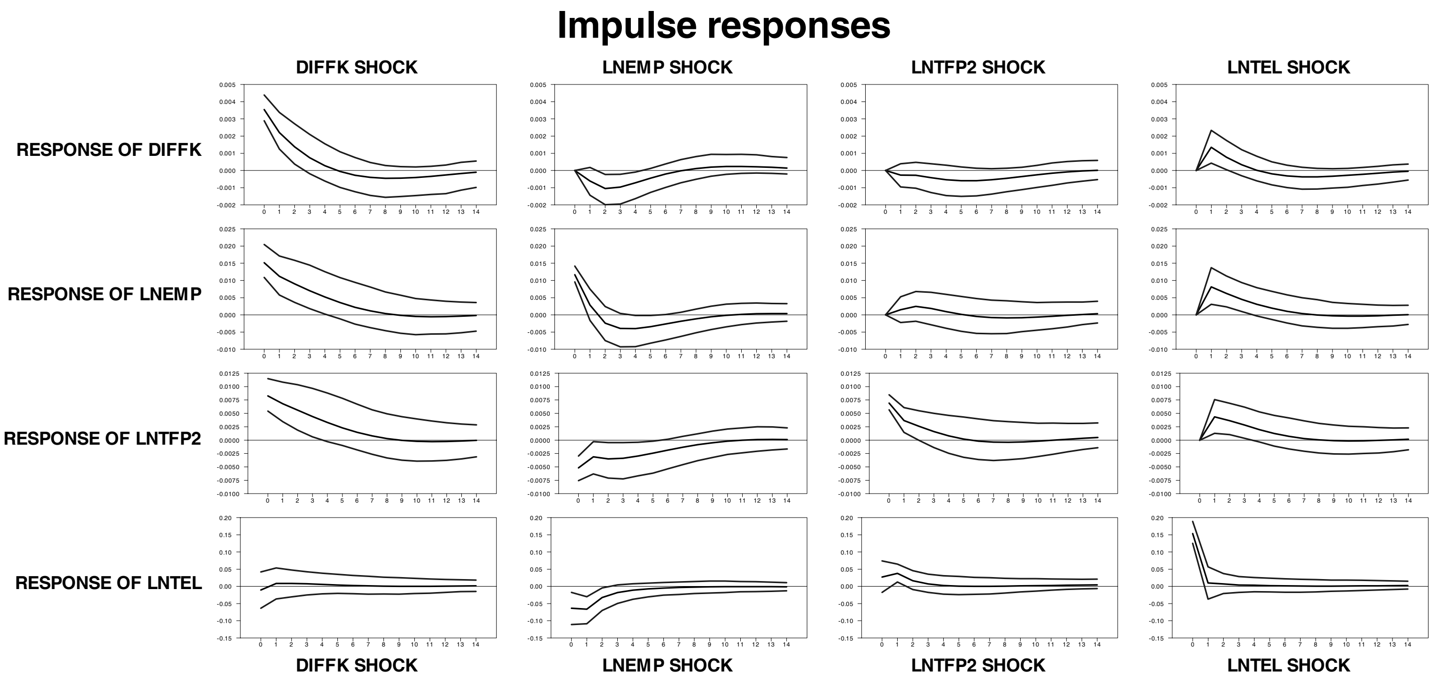
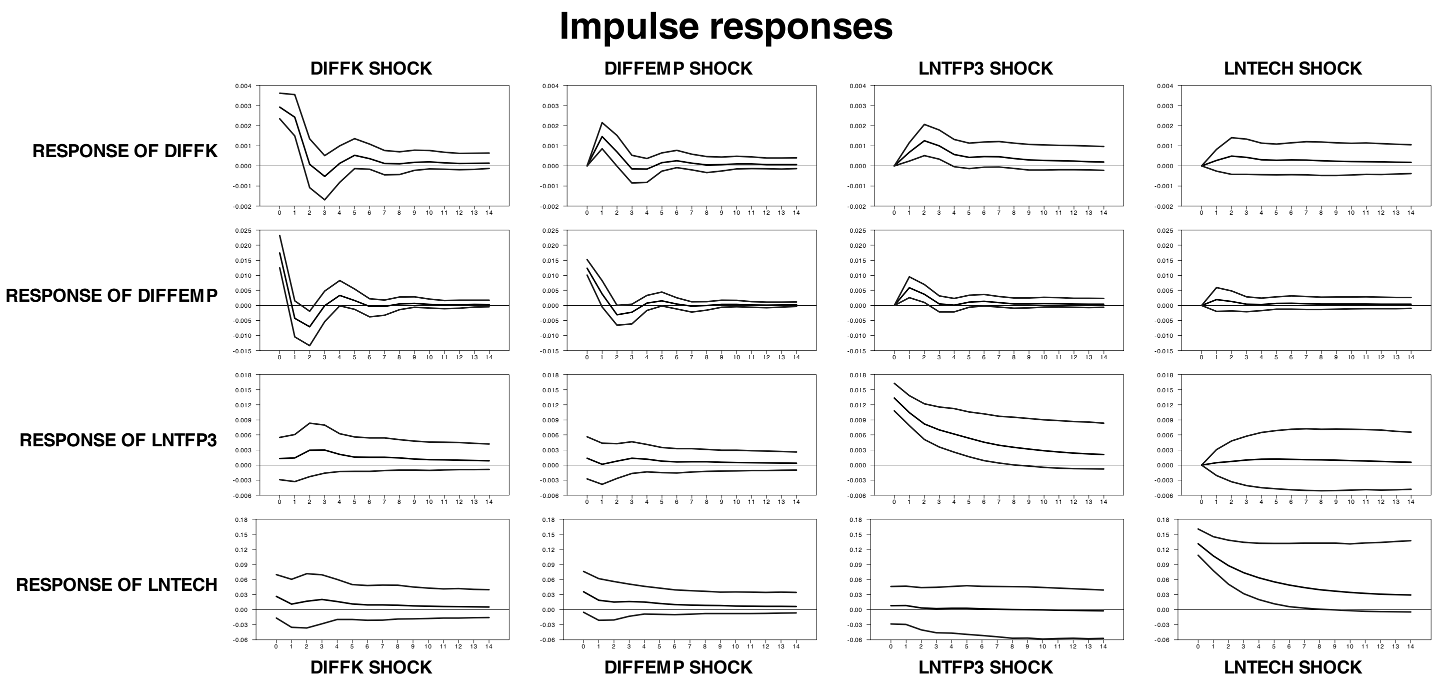


Figure 17. Impulse Response Functions for Tech and Tech2 Indicators



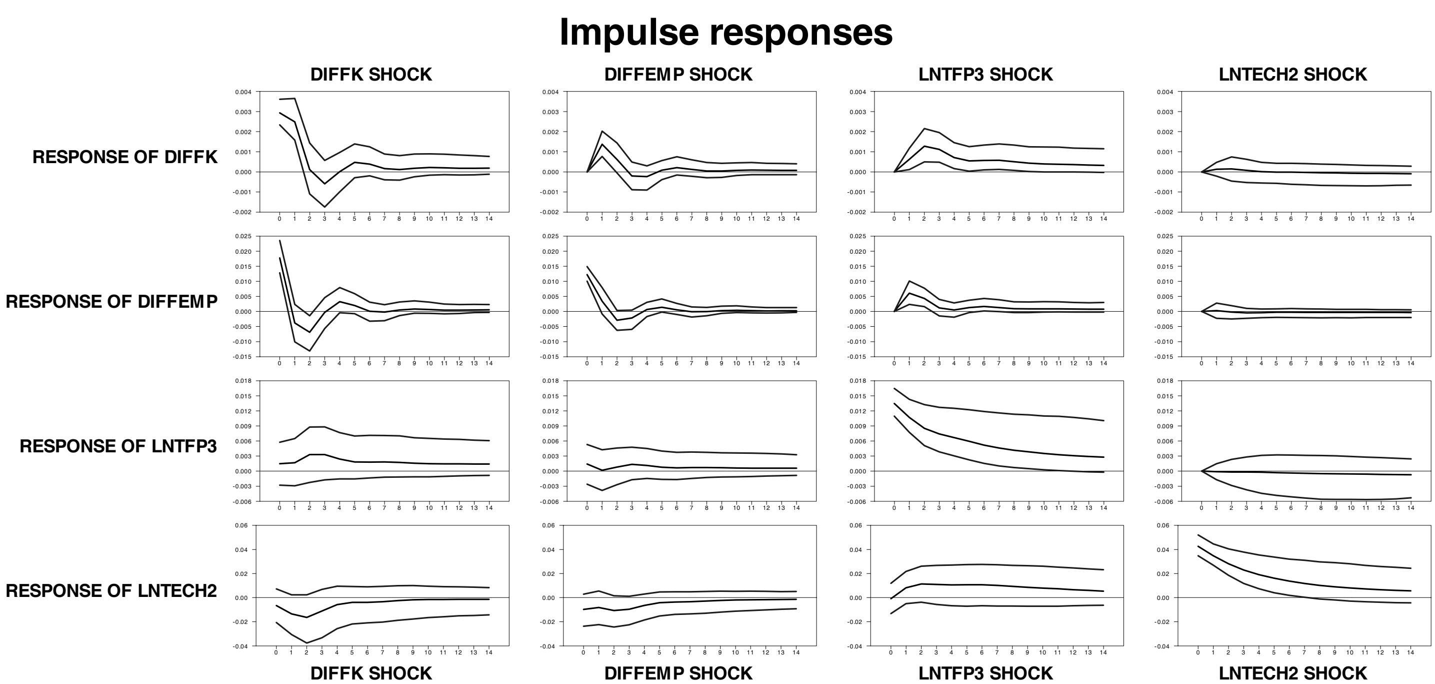


Figure 18. Impulse Response functions for Computer Indicators

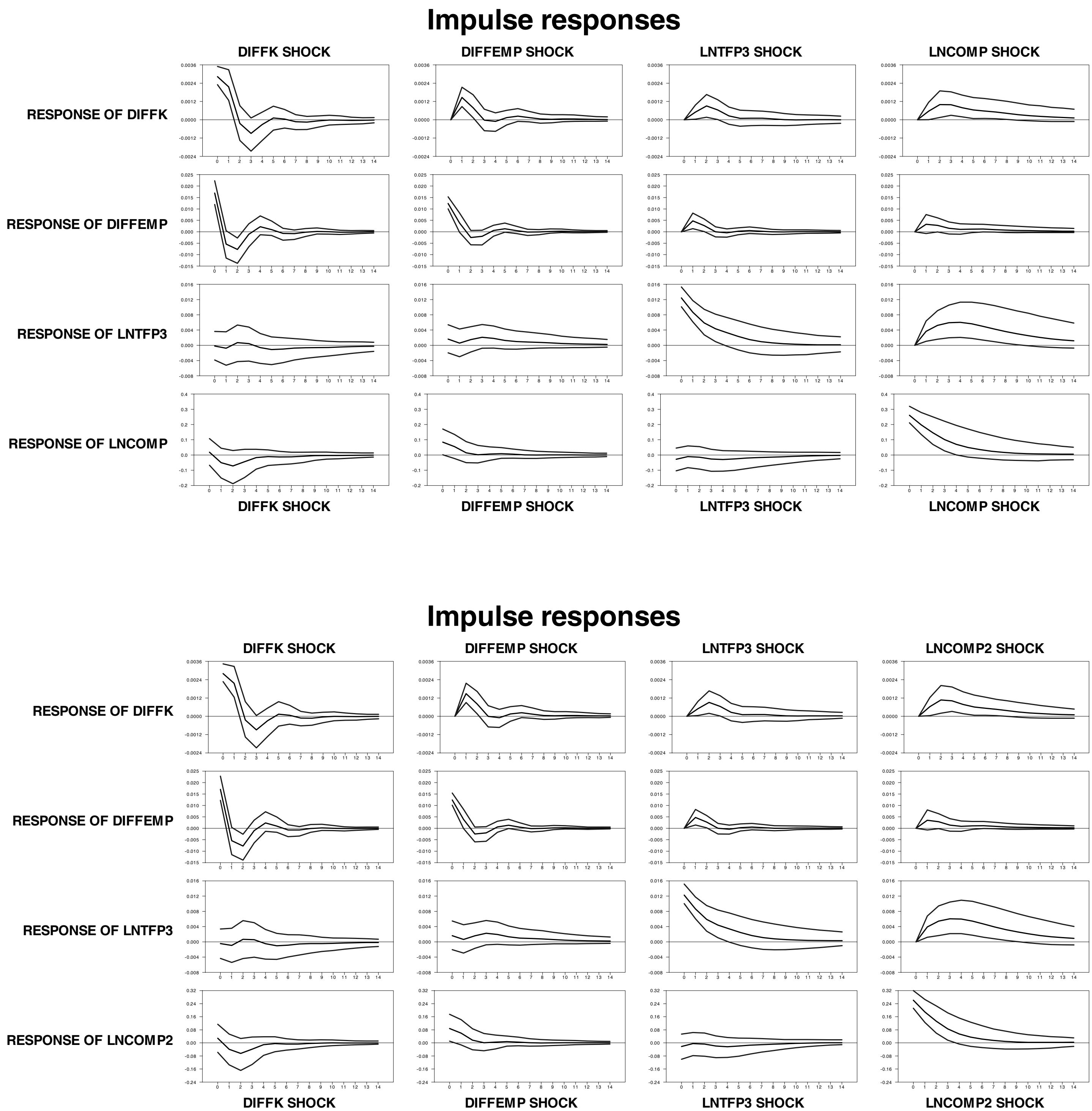


Figure 19. Impulse Response Functions for Telecommunications

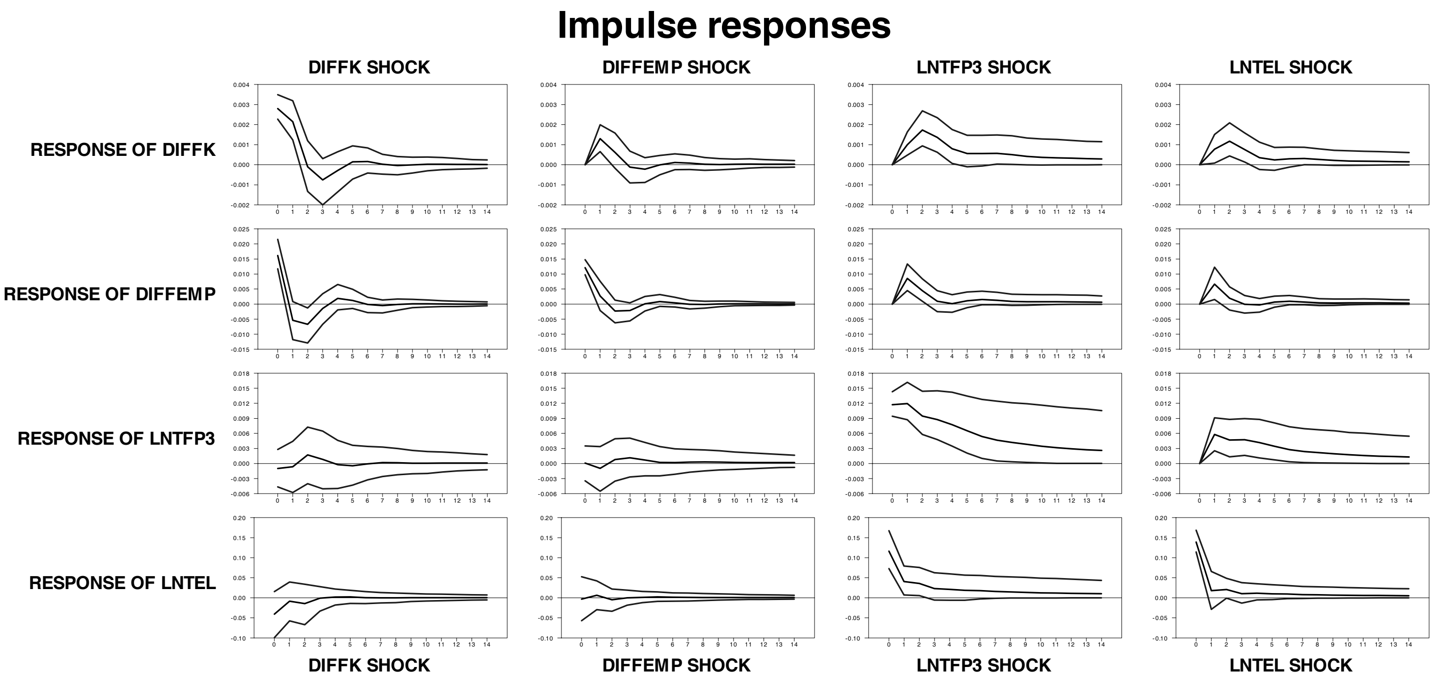


Table 1. Relationship between Science and Technology

Indicator	Does Science Granger-cause Technology?		Does R&D Granger-cause Technology?		Does Patents Granger-cause Technology?	
	P-Value	Lag Length	P-Value	Lag Length	P-Value	Lag Length
Bowker's New Tech Books	0.049	1	0.230	2	0.221	1
Comp1	0.022	2	0.074	1	0.126	3
Comp2	0.012	2	0.058	1	0.188	2
Telecommunications	0.038	1	0.016	1	0.702	2
LOC New Tech Books	0.016	1	0.023	2	0.327	2

Table 2: Relationship Between GDP and Technology Growth Rates in the Short Run

X	Estimate	Std. Error
Bowker's New Tech Books	-0.0077	0.0262
Computer Software and Hardware Books	-0.0011	0.0119
Computer Software, Hardware and Network Books	-0.0005	0.0119
Library of Congress New Tech Books	0.0362	0.0629
Telecommunications*	-0.0304	0.0158
Patents	0.0077	0.0781
R&D	0.0802	0.0698
Bowker's new Science Books	0.0091	0.0291
Bowker's new History Books	0.0039	0.0291

Regression is: $\Delta\ln(TFP_t)=\alpha+\beta\Delta\ln(X_t)+\varepsilon_t$
* Significant at 10% level

Table 3: Granger-Causality Tests: P-Values

Technology Indicator	Does Technology Granger-Cause GDP?	Does GDP Granger-Cause Technology?
Bowker's New Tech Books (TECH)	0.004	0.805
Computer Software & Hardware Books (COMP)	0.002	0.282
Computer Software, Hardwares and Networks (COMP2)	0.002	0.237
Library of Congress New Tech Books (TECH2)	0.015	0.872
Telecommunications (Tel)	0.002	0.467
Patents (PAT)	0.570	0.588
R&D	0.863	0.318
Bowker's New Science Books (SCI)	0.002	0.931
Bowker's new History Books (HIS)	0.528	0.275

Table 4. Variance Decomposition

Percent of Variation Due to Technology in Two Variable VAR

	Years	ln(Gdp)
Bowker's New Tech Books	3	15.02
	6	37.59
	9	46.68
Computer Software & Hardware Books	3	18.41
	6	42.25
	9	49.55
Computer Software, Hardware & Networks Books	3	18.84
	6	40.99
	9	47.02
Library of Congress New Tech Books	3	9.42
	6	27.43
	9	37.67
Telecommunications	3	22.61
	6	30.73
	9	32.67
Patents	3	5.53
4 lags	6	5.03
	9	5.06
R&D	3	0.39
4 lags	6	0.83
	9	2.55
Bowker's new Science Books	3	8.07
	6	35.86
	9	41.05

Table 5: Relationship Between TFP and Technology Growth Rates in the Short Run

X	Measure 1 Estimate	Measure 1 Std. Error	Measure 2 Estimate	Measure 2 Std. Error	Measure 3 Estimate	Measure 3 Std. Error
Bowker's New Tech Books	-0.0256*	0.0147	-0.0248	0.0149	0.0160	0.0163
Computer Software and Hardware Books	-0.0057	0.0068	-0.0053	0.0069	0.0004	0.0075
Computer Software, Hardware and Network Books	-0.0056	0.0068	-0.0051	0.0069	-0.0003	0.0075
Library of Congress New Tech Books	0.0419	0.0359	0.0413	0.0364	0.0001	0.0398
Telecommunications	-0.0029	0.0096	-0.0043	0.0097	0.0132	0.0102
Patents	0.0214	0.0451	0.0207	0.0456	-0.0223	0.0506
R&D	0.0518	0.0403	0.0525	0.0407	0.0245	0.0444
Bowker's new Science Books	-0.0051	0.0169	-0.0038	0.0170	0.0216	0.0180
Bowker's new History Books	-0.0043	0.0169	-0.0032	0.0170	0.0014	0.0183

Regression is: $\Delta\ln(TFP_t)=\alpha+\beta\Delta\ln(X_t)+\varepsilon_t$

Table 6: Granger-Causality Tests for four variable VAR using TFP Measure 1: P-Values

Technology Indicator	Does Technology Granger-Cause		
	$\Delta\ln(K)$	$\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books (TECH)	0.160309	0.1691934	0.0005758
Computer Books (COMP)	0.048485	0.6016272	0.0004814
Computer Books (COMP2)	0.033355	0.5948115	0.0002896
Library of Congress New Tech Books (TECH2)	0.01675	0.0728686	0.0713859
Telecommunications	0.011069	0.0054031	0.0274826
Do Inputs and TFP Granger -Cause Technology?			
	$\Delta\ln(K)$	$\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books (TECH)	0.446477	0.084766	0.6220172
Computer Books (COMP)	0.549181	0.1893126	0.3318428
Computer Books (COMP2)	0.778854	0.1042605	0.3485315
Library of Congress New Tech Books (TECH2)	0.154281	0.5789154	0.222206
Telecommunications	0.690292	0.0448554	0.0248394

Table 7: Granger-Causality Tests for four variable VAR using TFP Measure 2: P-Values

Technology Indicator	Does Technology Granger-Cause		
	$\Delta \ln(K)$	$\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books (TECH)	0.167365	0.1650787	0.0478333
Computer Books (COMP)	0.051692	0.5945819	0.0008848
Computer Books (COMP2)	0.035428	0.5886882	0.0005353
Library of Congress New Tech Books (TECH2)	0.019408	0.0748937	0.0712334
Telecommunications (TEL)	0.011893	0.0055373	0.0173103

Do Inputs and TFP Granger -Cause Technology?			
	$\Delta \ln(K)$	$\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books (TECH)	0.46981	0.0825315	0.6054422
Computer Books (COMP)	0.541366	0.1853408	0.3406448
Computer Books (COMP2)	0.76507	0.1018703	0.354252
Library of Congress New Tech Books (TECH2)	0.14103	0.5997812	0.2005319
Telecommunications (TEL)	0.740147	0.040019	0.040019

Table 8: Granger-Causality Tests for four variable VAR using TFP Measure 3: P-Values

Technology Indicator	Does Technology Granger-Cause		
	Δln(K)	ln(L)	ln(TFP)
Bowker's New Tech Books (TECH)	0.351333	0.3685633	0.7311666
Computer Books (COMP)	0.084019	0.1777909	0.0159831
Computer Books (COMP2)	0.061811	0.157853	0.012507
Library of Congress New Tech Books (TECH2)	0.497808	0.8548658	0.9114137
Telecommunications (TEL)	0.055674	0.0250764	0.0017349
Do Inputs and TFP Granger -Cause Technology?			
	Δln(K)	ln(L)	ln(TFP)
Bowker's New Tech Books (TECH)	0.824111	0.4462502	0.8867868
Computer Books (COMP)	0.17188	0.7150676	0.6262223
Computer Books (COMP2)	0.156181	0.8324339	0.5933751
Library of Congress New Tech Books (TECH2)	0.207418	0.7948127	0.0511131
Telecommunications (TEL)	0.687414	0.7211116	0.1371739

Table 9.

Variation Due to Technology
Four Variable VAR with TFP Measure 1

	Years	$\Delta\ln(K)$	$\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books	3	2.779	3.592	7.128
	6	3.82	10.235	16.921
	9	4.712	11.546	18.536
Computer Software & Hardware Books	3	9.393	2.012	25.32
	6	13.881	9.229	40.876
	9	13.43	11.085	42.814
Computer Software, Hardware & Networks	3	11.073	2.24	26.933
	6	15.25	9.279	40.446
	9	14.782	10.758	41.883
Library of Congress New Tech Books	3	6.177	4.095	4.107
	6	10.89	12.171	12.432
	9	10.686	14.66	15.049
Telecommunications	3	11.673	16.463	10.566
	6	10.98	17.169	11.868
	9	12.027	16.939	11.736
Patents	3	2.657	9.118	1.611
4 lags	6	6.076	7.013	9.925
	9	5.968	7.672	9.747

Table 10.

Variation Due to Technology
Four Variable VAR with TFP Measure 2

	Years	Δln(K)	ln(L)	ln(TFP)
Bowker's New Tech Books	3	2.66	3.59	6.51
	6	3.70	10.17	15.49
	9	4.41	11.52	16.92
Computer Software & Hardware Books	3	9.219	1.998	23.247
	6	13.937	9.159	38.512
	9	13.435	11.041	40.344
Computer Software, Hardware & Networks	3	10.932	2.225	24.938
	6	15.337	9.205	38.249
	9	14.81	10.702	39.574
Library of Congress New Tech Books	3	5.798	3.957	3.992
	6	10.407	11.766	11.93
	9	10.274	14.252	14.381
Telecommunications	3	11.332	16.366	11.741
	6	10.65	17.104	12.775
	9	11.755	16.87	12.627
Patents	3	2.64	9.18	1.34
4 lags	6	6.03	7.07	9.64
	9	5.98	7.81	9.57

Table 11.

Variation Due to Technology
Four Variable VAR with TFP Measure 3

	Years	$\Delta\ln(K)$	$\Delta\ln(L)$	$\ln(TFP)$
Bowker's New Tech Books	3	1.778	0.989	0.227
	6	3.285	1.033	1.206
	9	4.038	1.156	2.108
Computer Software & Hardware Books	3	8.113	3.378	13.931
	6	16.478	3.958	32.515
	9	18.724	4.266	38.336
Computer Software, Hardware & Networks	3	9.209	3.644	14.931
	6	17.022	4.064	32.608
	9	18.813	4.313	37.522
Library of Congress New Tech Books	3	0.228	0.016	0.005
	6	0.255	0.046	0.004
	9	0.267	0.047	0.004
Telecommunications	3	10.338	8.024	12.959
	6	11.216	7.965	15.754
	9	11.541	8.073	16.131
Patents	3	1.131	5.996	10.92
4 lags	6	2.506	12.796	11.209
	9	3.231	13.796	11.314

Appendix A. Library of Congress Classification Overview

LIBRARY OF CONGRESS CLASSIFICATION OUTLINE CLASS T - TECHNOLOGY

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

LIBRARY OF CONGRESS CLASSIFICATION OUTLINE CLASS Q - SCIENCE

Subclass Q Science (General)

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

Subclass QB Astronomy

Subclass QC Physics

Subclass QD Chemistry

Subclass QE Geology

Subclass QH Natural history - Biology

Subclass QK Botany

Subclass QL Zoology

Subclass QM Human anatomy

Subclass QP Physiology

Subclass QR Microbiology