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Wesley Shu
San Diego State University

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Department of IDS, San Diego State University
San Diego, CA 92182-8234
wesley.shu@sdsu.edu

Abstract

During the past thirty years, the economy of the USA, along with other industrialized countries, has experienced several noticeable trends, namely, the economic slowdown, the tremendous increase in the amount of information technology investment, and fast structural change in terms of employment. With slow economic growth and fast IT capital accumulation, the so-called "information technology (IT) productivity paradox" becomes a prevailing concept in literature. Many researchers have attempted to solve the paradox in firm-level analysis, but a macroeconomic analysis, using a nation as an analysis unit, is not common in MIS research. By considering the complex triangular relationship of the above economic trends, this paper applies econometric models and macroeconomic theories to solving the IT productivity paradox. An emphasis is placed at the impact of information technology on the structural change of employment, and at the impact of the structural change on productivity. The authors demonstrate that the structural change could unravel the IT productivity paradox and provide a prediction of the future economic growth.

Keywords

Information technology investment, employment, economic growth

Introduction

The productivity research of information technology (IT) has been perplexing MIS and economics researchers because the contribution of IT investment on the creation of business value is thus far inconclusive. Over decades, many researchers could not find positive contribution of information technology to t he productivity, for example Berndt and his colleagues have reported negative correlation between high-tech capital and labour productivity (Berndt, Morrison & Rosenblum 1992), and (Berndt & Morrison, 1995). In search of ATM's impact on productivity, Franke has reported that installation of ATMs is associated with decreased real return on equity (Franke, 1987). In addition, Loveman demonstrated no evidence of strong productivity gains from IT investments in his papers in 1988 and 1994 (Loveman 1988, Loveman 1994). The failure of positive IT productivity findings has been labeled as "IT productivity paradox," and the idea was consummated by the famous saying of Nobel Laureate Solow, "You can see the computer age everywhere but in the productivity statistics." (Solow, 1957) Since then, MIS research has been zeroing in on the long-lost information technology productivity with the hope of finding some good news. For example, (Barua and Lee 1996) reported positive IT productivity by employing econometric methodology. Along with their research, Brynjolfsson and Hitt's 1993 also exhibited positive return on IT investment. In a more recent research paper, Hitt and Brynjolfsson 1994 found that computer capital is correlated with substantial increases in net output. The positive impact of information technology on business value was further affirmed by the same authors in their 1996's paper (Hitt & Brynjolfsson 1996). They showed that computers were far from unproductive and that they were significantly more productive than any other type of investment the companies in their sample have made. Encouraged by those findings, many claimed that the IT paradox is gone (Businessweek 1993) and suggested a new paradox: how can computers be so productive (Bakos 1995)?

It is noteworthy that most of the papers with positive results were firm-level analyses, while research at macroeconomic level has shown negative IT productivity. Since macroeconomic data are defined as the aggregate data in a nation or an industry, the contradiction between macro- and micro- analyses would cast a doubt on the external validity, or generalization of the firm-level analysis. In addition to the validity problem, the positive results of firm-level analyses cannot explain the well-documented economic slowdown in the past three decades (Fischer, 1988) since if information technology contributes to large portion of the growth in productivity and the amount of information technology investment is twenty-five times as large as it was 30 years ago, the economic growth should have been accelerated rather than slowdown. Moreover, the firm-level analyses are restricted to explain the fast structural change in an economy as a result of the emergence and introduction of information technology (Freeman & Soete 1990). Therefore they are unable to delineate the relationship between the fast structural change and the continuous slow productivity growth, or to carry out an investigation of the role information technology plays in the general equilibrium of the economy. As defined by Freeman & Soete 1990 and Jonscher 1983, "fast structural change" means the dynamics between the employment of production sector and that of information sector. To be more specific, it means the change of number of workers in these two economic sectors. Fourth, by employing empirical data, firm-level analyses intrinsically tend to assume exogenous technology progress instead of endogenous.

Because of the problems ascribed to firm-level analyses, this research is conducted in macroeconomic level. We will use macroeconomic data to inquire how IT affects the structural change of the economy and how it affects the productivity. As noted above, because the productivity slowdown of the nations is coupled with increased information technology investment, the IT productivity puzzle would become more baffling if we place our focus on the national data. But also noted above, another economic trend of the past few decades is structural change. It is signified by the change of the nature of employment. Just as the post-war employment change when people moved from agricultural sector to production section, the past 30 years is the era that people moved from production sector to information sector. We suspect that the structural change complicates the causal relationship between information technology investment and productivity and we will triangulate the past economic trend and untangle the IT productivity paradox through the fast structural change.

The purpose of this paper, thus, is to explain the IT productivity paradox and the economic slowdown. To achieve this goal, we have considered the level of analysis, endogeneity of technology, and possible intermediary variables, namely the structural change in this paper. Our paper will be organized as follows. First of all, we will provide the evidence of the economic slowdown in Section Economic SlowdownEconomic Slowdown. We will denote that the slowdown is not unique to the US but also an international phenomenon. Some explanations of the slowdown will also be provided. Second, we will examine the relationship between the structural change and productivity in Section Structural Change and Productivity. We will present and discuss a model by Jonscher 1983, and examine his model by using more recent data and by doing international comparison. While his model fits into the empirical data very well, his prediction on the future trend is incorrect. Third, a time series model, developed by the authors, addressing the relationship between information technology and structural change will be presented in Section Information Technology and Structural Change. The model states that the IT investment can increase the ratio of the number of information workers to the number of total workers. Fourth, we will further provide a more complex model to understand the impact of IT and structural change on productivity in Section The Impact of IT and Structural Change on Productivity. Finally, the conclusion will be put in Section Conclusion. We have found that IT investment does have positive contribution to the economic growth while it accelerates the structural change at the same time. The structural change is the major force which pulls down the economic growth.

Economic Slowdown

Following the fast economic recovery after World War II, the economy since late 60s or early 70s was symbolized as sluggish growth. In 1960s, the U.S. labour productivity growth rate was 2.69%. It dropped to 1.03% in the early 1990s. The economic growth slowdown is not a unique phenomenon in the US, many OECD countries, including Japan, experience similar trend. The labour productivity of different countries is summarized in Table 1.

Nation[1]	1960s	1970s	1980s	1990s
Australia	1.70	0.79	-1.07	3.44
Canada	3.24	0.66	0.06	2.77
Japan	12.10	3.52	1.97	2.39
UK	2.41	1.31	3.32	2.62
USA	2.68	1.25	1.26	3.05

1. Arithmetic average, Data source: OECD, http://www.oecd.org/oecd/pages/home/displaygeneral/0,3380,EN-document-0-nodirectorate-no-1-30531-0,00.html

Table 1 Productivity Growth Rate of Selected Countries

As we can see from Table 1, productivity slowdown is an international phenomenon. Some countries suffer more than others. Among these countries, Australia bears the most serious sluggishness. Its labour productivity was 1.79 percent in 1960s which was already lower than most other industrialized countries. The productivity dropped down to -1.07 percent in the 80s. Even the fast-growing industrialized country, Japan, cannot avoid the slowdown. Its labour productivity diminished from a high of 12.1 percent to 1.97 percent in the 80s.

Productivity can be measured in multifactor or single-factor form and productivity slowdown is not only restricted to labour productivity. The labour productivity is measured by the total output divided by the number or workers or by the total hours of employment. One the other hand, total factor productivity is the output per unit of total factor inputs -- for a plant, an industry or a whole economy. The total factor productivity, also called as “multifactor” or “residual” productivity shows the efficiency of the measured entity, but it does not provide the information on how good the performance of individual input is. Labour productivity fill this gap. It shows the contribution of labour input to the output level. For the purpose of this paper, we denote productivity as labour productivity so that we can link productivity problem with employment structural change. A great deal has been written to explain the productivity slowdown in economics literature. One explanation of productivity slowdown is the structural change of the economy, namely the employment movement among different sectors, which we call ``employment dynamics". We will address this issue in-depth at Section 4, but here we would see how employment dynamics became an important economic trend during the past 30 or 40 years. Take the USA as an example. The information workers took up 42.6 percent of the total workers in 1958. In 1995, this ratio climbed up to 56.4 percent. As the economic slowdown occurred in many countries, the structural change is also an international phenomenon except Japan. It can be shown in ***Table 2 Information Workers as Percentage of Total Workers***Table 2

Nation	1960s	1970s	1980s	1990s
Australia		55.6	62.6	69.1
Canada	52.3	61.4	66.0	68.2
Japan	43.7	46.8	54.1	59.3
UK	52.7	51.3	59.6	65.4
USA	47.0	50.3	53.7	59.6

Data source: Bureau of Labour Statistics, or BLS, and Labour Force Statistics

Table 2 Information Workers as Percentage of Total Workers

Coupled with the economic slowdown, the huge increase of information technology investment has caught attention. The investment amount of information processing equipments of the USA started at a low level of 4 billion in 1959 and climbed up to 183.7 billion in 1995. The Data source is from National Income and Production Account (NIPA). The unit is constant dollar value of 1980.}. Since the opposite trends of labour productivity and IT investment, it would be easy to conclude from a simple regression with IT investment as explanatory variable and labour productivity as dependent variable that IT causes economic slowdown. However, we are not satisfied with such a simple regression not only because of its lacking of causality but because of the following reasons. First, this simple OLS model, along with other models, e.g., Matzner & Wagner 1990 assumes the amount of technology investment is determined by extraneous factors other than the economic system itself. This notion has been rejected by Romer Romer 1998. He put “... technological change arises in large part because of intentional actions taken by people who respond to market incentives." Second, we conjecture that the way information technology affects productivity is complex. It may take years to achieve its effect because of the lag of the diffusion of productivity gains of technology progress from high-tech industry to the rest of the economy Freeman & Soete 1990, and also because of the fact that IT outputs are mostly the inputs of other goods. A time series analysis, therefore, is necessary to understand their relationship. Third, an intermediary variable may be missing in a simple regression. It is shown that the employment is one of the most important intermediary variables to explain IT productivity paradox.

Because of the complex macroeconomic relationship, we propose a productivity-employment-IT research relationship. We suspect that the IT productivity paradox may be the reflection of the ignorance of information technology's potential impact on the change of employment structure. Thus, we will remark on three facets of the economy trend discussed above. First, how employment structural change affects productivity. Second, how information technology shapes the employment structure. Third, how information technology affects productivity by way of structural change and what its direct relationship with productivity is.

Structural Change and Productivity

To analyze the causal effect of structural change on productivity, Jonscher's model of 1983 provided an interesting clue. By applying general equilibrium model, he could bring the relationship of these two economic subjects into a single equation, and by inserting some assumptions, one can yield the employment ratio to be a good indicator of productivity growth. Following Jonscher's proposition, we describe the economy as the interrelation between information and production sectors. The activity of information sector is process and handle information such as “management, administration, accounting, brokerage, advertising, banking, education, research and other professional services.”. Its workers are usually referred as white-collar. The counterpart of the economy consists of factory, construction, transportation, mining and agricultural activities in which blue-collar workers are the labour force. In this sector, processing and handling material goods, including agricultural products, is the primary task. The activities they are engaged in, not the final products, differentiates the two types of workers but the equally important factor to separate the two sectors is the skill and knowledge level each sector requires. In general, the workers at information sector require higher skill level and more education and it is fair to say that the productivity of information workers should be higher than that of production workers. One significant trend during the past decades is the expansion of information sector. According to Jonscher, the value added in the production sector was doubled but that in the information sector was almost quadrupled. It is believed that this trend continues as more and more work force enters the information sector and more and more information products are required by producers and consumers. If the expansion speed is faster than the speed of new employment inflow into the information sector, it is necessary that the economy requires people from production sector to information sector. It is the primary drive of economic dynamics in the past few decades. The consequence of the dynamics is the productivity slowdown. We would like to see how Jonscher's model can delineate the relationship between the economic growth and employment change. To verify his model, we first extend the data set to 2001 and thus our data set covers 1959 to 2001 while his data only span to 1980. Second, we conduct an international comparison. We apply his model to Australia, Canada, Japan, UK as well as USA to overcome the criticism that the suitability of his model with US data is only a coincidence without rigid theoretical ground (Nightingale 1988). Extending the US data and applying his model, we find the actual ratios of information workers to the total workers almost overlap the projected ones. Jonscher's model provides a good projection of employment ratio even with the data span after his paper published. There have been several studies depicting the differences in productivity between US and other countries, and therefore an international comparison becomes necessary to show the validity of his model. Surprisingly, regardless of the countries, Jonscher's model still shows correct projection except the one of Japan.

Following Jonscher's theorentical model and empirical test, we can infer that the employment ratio (number of information workers to the number of total workers) can be an accurate indicator of productivity growth. That is, as long as the employment migration continues, the productivity slowdown will persist, and the slowdown will stop as long as the employment ratio is levelled off.

Information Technology and Structural Change

Even though Jonscher's model provides a good indication to the economic trend, and we can anticipate some “good news” of IT productivity in the very near future, it is not squeamish to say that his model still fails to recognize the endogeneity of information technology in the economic dynamics discussed above, and ignores the impact of information technology on the employment dynamics. A question would be asked that how IT shapes the economic structure. In the past few decades, the interaction of technological advances, employment rate and productivity change has been under scrutiny in the economic literature, and many models have been put forward interpreting the interaction. For example, Input-output economist Leontief has used his famous input-output table to predict the employment trend and living standard of workers from the projection of an increasing use of computers in all sectors for specific information processing and machine control tasks and their integration. He found that “by 1990 there is a progressive increase in the proportion of professionals and a steep reduction in the number and proportion of clerical workers.” (Leontief & Duchin 1986). In the model discussed here, we assume that the economy at the aggregate level keeps the optimal capital/labour combination; that is, we assume the economic expansion follows a unbiased pattern. The aggregate level is a reflection of firm behaviour -- a firm always attempts to maximize its profit by finding the optimal input factor vector. Therefore, once technology advances and IT investment rises, a firm will adjust its labour force to align with the capital input. This scenario can be expressed in a simple single equation if IT equipment operated by information workers is assumed:

$$\left(\frac{N_I}{N_T}\right)_t^* = a + b\,IT_t \qquad (1.1)$$

In this equation N_I/N_T means the ratio of the number of information workers to that of total workers. We use IT to represent the IT investment. The equation alleges that the optimal information worker size is adjusted in association with the information technology investment. An asterisk indicates the optimal situation but it would be impractical to assume that the adjustment is complete and instant. So, a partial adjustment model is introduced. In our partial adjustment model, the actual information employment ratio adjustment between two periods, *t* and *t-1* is only a proportion of the optimal adjustment:

$$\left(\frac{N_I}{N_T}\right)_t - \left(\frac{N_I}{N_T}\right)_{t-1} = (1-m)\left(\left(\frac{N_I}{N_T}\right)_t^* - \left(\frac{N_I}{N_T}\right)_{t-1}\right) + u_t, 0 \le m \le 1 \tag{1.2}$$

Combine Eq. (1.1) and Eq. (1.2), we can get the following regression:

$$\left(\frac{N_I}{N_T}\right)_t = a + b\,IT_t + m\left(\left(\frac{N_I}{N_T}\right)_{t-1} - \left(a + b\,IT_t\right)\right) + e_t,\ e_t = u_t - mu_{t-1} \tag{1.3}$$

Based on the data from NIPA and BLS, we got the parameters as follows:

α	0.4596
β	0.005698
Adjusted R^2	0.97

Both estimates are significant at 95% confidence interval. The unit for IT investment is constant billion dollars of 1980. This regression not only shows a very good fit of information technology investment to the employment ratio (a very high R^2), but also reveals the fact that for every one billion dollar investment in information technology, the information workers will posit a 0.57% increase in the total labour force.

The Impact of IT and Structural Change on Productivity

The above section demonstrated the IT impact on employment. Here in this section, we want to model the employment as well as IT impact on productivity. Jonscher's model exhibits a good indication of productivity by the employment ratio but he did not articulate the employment impact on productivity growth rate (see Nightingale's critique on Jonscher's misconception of productivity growth (Nightingale 1988). A growing productivity does not accommodate slowdown. When economists talk about "slowdown", they mean the reduction of growth rate even though the economy still undergoes positive growth. We assume the productivity of all the individuals follows a uniform distribution with a constant interval between two adjacent workers and all production workers have lower productivity than information workers do. Without confusing further reading, we list the variables in Table 3

Variables	Meaning
G_t	Average labour productivity of the whole economy
$G_{i,t}$	Information sector labour productivity
$G_{p,t}$	Production sector labour productivity

G^k_t	k'th individual's productivity
g_t	Total labour productivity growth
$g_{i,t}$	Information sector labour productivity growth
$g_{p,t}$	Production sector labour productivity growth
N_t	Total number of workers
n_t	Number of workers migrating from production to information sector
z	productivity different between two adjacent workers, a constant
G^u_t	Upper bound productivity
G^l_t	Lower bound productivity
$G^u_{pt} = G^l_{i,t}$	Upper bound productivity of production sector or lower bound productivity of information sector
IT_t	Information technology investment

Table 3 Variable Description

As noted above, the migration will cause productive reduction in both sectors. Following the model assumptions, we can simply see the reduction is equal to (n_1 - 1) ζ. After some mathematical derivation, we can get the following relationship[1]:

$$g_{t+1} = q\,\frac{n_t}{N_t}, q = \frac{1}{2}\frac{G_t^u - G_t^l}{G_t^u + G_t^l} \qquad (1.4)$$

Where n_t/N_t is the migration ratio; i.e., the number of workers moving from production to information sector/total number of workers. It is not difficult to prove that θ is a time-invariant constant parameter whose value is to be estimated. If there is no information technology investment, Equation (1.4) can be the regression to estimate the impact of employment dynamics on the growth rate. By doing this, however, we still ignore the influence from information technology investment. To incorporate IT investment into the model, we formulate that *k*'th individual increases his productivity due to the investment by $h\,(IT_t/N_t)^g$. Therefore,

$$G_{t+1}^k = \left(1 + h\left(\frac{IT_t}{N_t}\right)^g\right) G_t^k \qquad (1.5)$$

Equation (1.5) states that an individual's productivity is decided by his previous period's productivity, G^k_t , and the average personal information technology investment IT_t/N_t, with consideration of economies of scale γ and productivity per dollar of IT investment, h. And it can be easily proved that

$$G_{t+1} = \left(1 + h\left(\frac{IT_t}{N_t}\right)^g\right) G_t \qquad (1.6)$$

[1] Detailed mathematical note is available upon request.

Equation (1.6) thus is IT investment impact on productivity at aggregate level. Combining Equation (1.5) and Equation (1.6), and assuming constant return to scale, we can get

$$g_{t+1} = \eta \frac{IT_t}{N_t} + \theta \frac{n_t}{N_t} \tag{1.7}$$

Equation (1.7) thus provides the macroeconomic explanation of productivity growth under the impact of information technology investment and employment dynamics. After running an autoregressive model by using the USA data[2] and doing diagnosis checking for correct specification of order, we got the following parameter estimates:

η = 0.0014, t-statistic = 1.23008

θ = -1.1588, t-statistic -1.60935

It shows that the more workers moving from production to information sector, the slower the productivity growth will be. Whenever the employment migration ratio gains 1 percent increase, the labour productivity will lose 1.16 percent. The model also shows that the IT investment has positive contribution to the productivity growth, and whenever the dollar of IT investment for per person is made, the labour productivity will gains 0.0014 percent. It confirms our assumption that IT productivity is compounded by the structural change and it can be ascertained if the structural change comes to an equilibrium. The model is satisfactory but not perfect because η is not significant at 90% confidence level when sample size is 44 (year 1958 - 2001). Nevertheless, it disproves the IT productivity paradox that information technology investment has negative effect on productivity.

Conclusion

This paper has provided the data to show the economic slowdown of the past thirty years, and to show the structural change of the economy in the same period. Several explanations of the economic slowdown have been provided in literature, for example, the technology diffusion problem, and unsatisfactory measurement of information technology contribution. The noticeable structural change was found to be a significant cause to the economic slowdown. In this paper, we first provided the evidence of how structural change can be an indicator of and can have impact on productivity, and then we used a simple model to explain why. Jonscher's model for employment/productivity relationship is used for this purpose and we verified his model by conducting an international comparison and by extending the data set from the year of 1980 to 2001. We found his model can impressively explain the productivity growth with employment dynamics. Nevertheless, his model falsely predicted the productivity would bounce back in 1980s, in association with the equilibrium of the employment structure of the two sectors. We found that the information employment is still increasing its ratio to the total employment until now and therefore, according to Jonscher's model, the productivity would not reverse its downward trend. We also have shown that information technology investment can cause the structural change which in turns put impact

[2] In order to explain the parameters easier, we change the units of the following variables: *IT*: US dollar of 1980, *N*: person, *n/N* and *g*: percentage. All the variables come with subscript *t*.

on the productivity. Simply put, IT causes migration from production to information sector, and the migration in turns causes the reduction of productivity growth. The causal relationship of IT and structural change has been attested by our econometric model with very high level of goodness of fit. Finally, we developed a model to show how productivity growth rate can be affected by IT investment per capita IT_t/N_t and by the ratio of migratory workers to the total workers n_t/N_t. This model has confirmed negative impact of the migratory ratio on the productivity. It also derives positive IT contribution to the productivity even though the t-statistic is not significant. With IT investment and productivity growth going in opposite directions in the past thirty years, this result should be considered as good news for those who are trying to unravel the IT productivity paradox. We would expect a positive significant estimate when, first, the new technology created in high-tech industry diffuses into other industries and the growth of the industries keep balanced. Second, a measurement of productivity can be recognized to record quality improvement and added value. Third, the structural change reaches equilibrium or even leads to the opposite direction, i.e., information workers migrating to production sector.

In addition to its discovery, this paper provided contribution in terms of its analysis level. It investigated IT productivity paradox in macroeconomic level and mitigated generalization problems from traditional firm-level approach. The macroeconomic-level approach also provides a viewpoint for the structural change which has been proved as an important factor in IT paradox. We also implied endogeneity of information technology which has been ignored by previous research. In spite of this paper's contribution, the research was limited by the data set. Our future goal is to obtain IT investment data of Australia, Canada, Japan, UK as well as the USA in order to conduct test our models.

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