

Healthier and More Educated Society Improves Multifactor Productivity: Time Varying Relationships

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Abstract

This study analyzes the influence of externalities generated by human capital on multifactor productivity (MFP). Education and health are two components of human capital that improvements in either of them influence the MFP. Scientific knowledge generated through published articles, and doctorates awarded by the US universities are considered as education components. Life expectancy at birth is an indicator of healthy nation. Explanators of MFP for the US private business sector for the last century are analyzed using Flexible Least Squares that enables an analyst to diagnose the magnitude of coefficient variation and detect which particular coefficients are changing. Results show that indicated variables have significant externalities and positively affect the MFP.

Keywords: Multifactor Productivity, Time Varying relationships, Human Capital, Flexible Least Squares

JEL Classification Codes: C30, O47, O51

Sağlıklı ve Daha Eğitimli Toplum Çoklu Faktör Verimliliğini Arttırır: Zamanla Değişen İlişkiler

Bu çalışma, beşeri sermaye tarafından oluşturulan dışsallıkların çoklu-faktör verimliliği (ÇFV) üzerindeki etkilerini analiz etmektedir. Eğitim ve sağlık beşeri sermayenin bileşenlerindedir ki bunlardaki gelişmeler ÇFV'ni etkiler. Yayımlanmış makaleler yoluyla üretilen bilimsel bilgi ve ABD üniversiteleri tarafından verilen doktoralar eğitim bileşenleri olarak düşünüldü. Doğumda beklenen yaşam süreside sağlıklı milletin bir göstergesidir. ABD'nin özel sektör ÇFV'sini açıklayan etkenleri Esnek EKK kullanarak analiz edildi ki bu yöntem analizcinin hangi katsayıların değiştiğini ve değişimin büyüklüğünü belirlemesine imkân

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sağlar. Sonuçlar belirtilen değişkenlerin dışsallıklara sahip olduğunu ve ÇFV'ni pozitif etkilediğini göstermektedir.

Anahtar Kelimeler: Çoklu Faktör Verimliliği, Zamanla Değişen İlişkiler, Beşeri Sermaye, Esnek En Küçük Kareler

JEL Sınıflandırma Kodları: C30, O47, O51

1. INTRODUCTION

The economies of western world have grown at a pace that greatly exceeds anything previously known in the long sweep of human history for more than two centuries now. In the last few decades, we have experienced what have come to be called the “information age” and the “knowledge economy”. These labels, in fact, do reflect a very real transformation that it is now “knowledge” —not labor, machines, land or natural resources— that is the key economic asset that drives long-run economic performance.

Recent changes in the global environment and the new generation of “information age” force economists to generate new theories that try to figure out what happens to our understanding of economics if the large numbers of economy’s labor force are employed to create ideas, solve problems, and sell services rather than to produce any tangible goods. Furthermore, traditional production factors land, labor, and capital are losing their significance in a boundless global environment because in such global environment where land in the form of office space or manufacturing infrastructure is no longer important. Labor can also be employed wherever it is most cost-effective worldwide.

At the heart of this phenomenon lies a complex, multifaceted process of continuous, widespread and far-reaching innovation and technical change. Yet, “knowledge”, “innovation”, and “technical change” are elusive notions, difficult to conceptualize and even harder to measure in a consistent, systematic way. Therefore, while economists from Adam Smith on have recognized their crucial role in shaping the process of economic growth, until the last several decades have seen a number of pioneering efforts to overcome these measurement problems and gather data that can be used for the systematic empirical analysis of technological knowledge. Most of the attention is given to the business firms and entrepreneurs, operating in a market setting, who are the central actors in developing and introducing new products and processes. In addition, it is generally accepted that invention was stimulated and guided by the power of the market, and the strength of the science base drives the innovation¹. Publicly funded

1 See Richard R. Nelson, *National Innovation Systems: A Comparative Analysis*, (Oxford: Oxford University Press, 1993), and David C. Mowery and Richard R. Nelson, *The Sources of Industrial Leadership*, (Cambridge, MA: Cambridge University Press, 1999).

research largely produces this science, and the knowledge produced by that research is largely open and available for potential innovators to use. In other words, publicly supported scientific commons initiates the market part of the Capitalist engine.

Capitalism and market economy guarantees, via the protection of intellectual property, private ownership over creations of the human mind while encouraging inventiveness and innovation². Moreover, without any market intervention, the market automatically assigns rewards after establishing clear intellectual property rights³. However, human knowledge and creativity cannot be limited within the geographical boundaries of the Western industrial society and its globalizing market. Protecting intellectual property might prevent economic progress in the less-developed areas and disadvantaged sections of a nation⁴. One can argue that using protected property rights in sharing and distributing benefits is a suitable tool for recognizing the information or knowledge's total value such as economic, environmental, social, cultural and spiritual.

The reasons mentioned above in fact raises arguments against the capitalist system economist have been using since the Adam Smith's book, better known simply as *The Wealth of Nations*⁵. At the center of Smith's thinking was the belief that the primary engine for building a better society is the market—that is, the production and exchange of goods for profit through commercial transactions. He believed the forces of the market would counter selfishness through competition. As he said that the "invisible hand of the market" would ensure that the public isn't cheated and that living standards rise. However, the gains from capitalism are not equally distributed over the large part of the population in societies. As stock markets rose, corporate profits soared, and CEO salaries reached astronomic sums, reports of the United Nations showed that conditions were deteriorating for the most nations. For instance, the United Nations, in 2005 Human Development Report, wrote that one of the major factors in the creation of poverty was the globalization of an unregulated market

2 Kenneth Carlaw, Les Oxley, Paul Walker, David Thorns and Michael Nuth, "Beyond the Hype: Intellectual Property and the Knowledge Society/Knowledge Economy", *Journal of Economic Surveys*, Vol. 20 No. 4, 2006, pp. 633-690.

3 Amitrajeet A. Batabyal ve Hamid Beladi, "On the Optimal Management of a Class of Aquatic Ecological-Economic Systems", *European Journal of Operational Research*, Vol. 132, No. 3, 2001, pp. 561-568.

4 Debra Harry, "Biopiracy and Globalization: Indigenous Peoples Face a New Wave of Colonialism", *SplICE*, Vol. 7, No. 2&3, 2001: www.ipcb.org/publications/other_art/globalization.html, accesses 15 March 2012.

5 Adam Smith, *The Wealth of Nations*, first published in 1776. Modern Library Edition, (New York, NY: Random House Inc., 1994).

system. In addition, infant and maternal deaths were increasing in some societies. Finally, one-fifth of children were living in poor conditions in the prosperous United States⁶.

The idea of “Caring Economy” is raised by its proponents with the idea that main investment is in caring for people and nature. In this system, the value of caring work is taught starting in childhood. Girls and boys are learned how to care for self, others, and natures in schools. Value of caregiving is really important in this system. As it is more recognized, men do more of it, women and men participate equally in the formal labor force and have the same opportunities and responsibilities at home. As the general quality of human capital rises, more capable, educated, skilled and caring workers contribute to a more productive economy. This in turn makes more funding available for government and business policies that support caring and caregiving. Finally all this improves the quality of life. The proponents of Caring Economics also argue that there is increasing evidence about what the conventional development theories report. For example, it is expected that countries with similar income level should also have similar measures of development such indicators as infant mortality, maternal mortality, and life expectancy. Thus, the United Nations use life expectancy at birth as an indicator of long and healthy life while calculating human development indices⁷.

Long lived global crises raised an argument that conventional economic theories should take into considerations such as value of caregiving. In this paper, next section is concerned with the endogenous growth models’ take on this issue. The role of knowledge and health on total factor productivity is explained considering different theories of endogenous growth theory. Methodology and FLS estimation technique explained and results discussed in the third section. Finally the last section concludes the paper’s findings.

2. LITERATURE REVIEW

2.1. Roots of Economic Growth

The most basic proposition of growth theory is that in order to sustain a positive growth rate of output per capita in the long run, there must be

6 United Nations (2005), Human Development Report.

7 United Nations (2011), Human Development Report.

continual advances in technological knowledge in the form of new goods, new markets, or new processes⁸. Since the times of David Ricardo, economists emphasized the significance of physical capital formation, and thus increasing investment, for economic growth. It is argued that differences in capital stocks of countries mainly created the differences in long-term economic growth between nations. As a result, economic policies were characterized by an emphasis on large-scale industrialization. A number of influential articles on balanced growth and the inferior role of the agricultural sector provided the theoretical support to this idea. The significance of a minimum volume of the investment program, also known as the Big Push⁹, and the significance of balanced development of the different sectors of the economy¹⁰ are the main points of the theory of the balanced economic growth. The literature on the inferior role of the agricultural sector in the process of economic growth points that the agricultural sector is less productive than the industrial sector and has fewer linkages to other sectors¹¹. Both types of literature emphasize the important role of capital accumulation and government interventions for economic growth. Underlying these theories, a Harrod-Domar production function was assumed in which total output is proportional to the capital stock of the nation, and thus total output growth directly relates to the investment share, through savings.

The neoclassical economists challenged the assumed significance of physical capital accumulation for economic growth by showing that investment does not affect the long-run equilibrium growth rate. According to the neoclassical growth model, only labor-augmenting technological progress, which is assumed to be exogenous, affects the long-run per capita growth rate. The model is sometimes referred to by the term *exogenous growth model* because only exogenous variables influence the long-run economic growth. The effect of physical capital accumulation on economic growth is restricted to the adjustment period to the long-run equilibrium of the economy (the *steady state*). In summary, the neoclassical economists

8 The appearances of the Robert M. Solow, "A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics*, Vol. 70, No. 1, 1956, pp. 65-94, and Trevor W. Swan, "Economic Growth and Capital Accumulation", *Economic Record*, Vol. 32, 1956, pp. 334-361 models had great importance for the theory of economic growth and the economic policy.

9 Paul N. Rosenstein-Rodan, "Problems of Industrialization in Eastern and Southeastern Europe", *Economic Journal*, Vol. 53, No. 210/211, 1943, pp. 202-211.

10 Ragnar Nurkse, *Problems of Capital Formation in Underdeveloped Countries*, 9th impr., (Oxford: Basil Blackwell, 1964).

11 William Arthur Lewis, "Economic Development with Unlimited Supplies of Labour", *Manchester School of Economic and Social Studies*, Vol. 22, No. 2, 1954, pp. 139-191.

by referring to the advantages of free markets reject the idea that government interventions by means of large-scale industrialization would stimulate economic growth.

2.2. The Endogenous Growth Models

Mechanism that makes economic growth endogenous is the elimination of the neoclassical assumption of diminishing returns to capital in the long run. In the endogenous growth theory, this has been done either by including human capital or by discovering new ideas by universities (mostly by publishing articles) or profit-driven entrepreneurs (R&D type models). In this study, we deal with human capital, and the new ideas that discovered by universities and openly shared.

The accumulation of human capital can be brought about by on-the-job-training—in other words by *learning by doing*¹² or by education. Development theory has always considered education as a significant engine for economic growth. Traditionally, studies concerning the importance of human capital especially relate to the micro level. The human capital theory makes a cost-benefit analysis of investments in human capital and calculates rates of return of investments in education¹³. These studies come up with some important results for economic policy. Most of them conclude that the rate of return of investments in human capital is higher than that of investments in physical capital.

The Solow neoclassical model is reformulated by taking human capital into account¹⁴. In their model, human capital is an additional production factor in the standard neoclassical production function. The main contribution of Mankiw, Romer, and Weil is that they firmly challenge the idea of most endogenous growth theorists that the neoclassical model along the lines of Solow cannot explain cross-county differences in economic growth. Point estimates with respect to the original Solow model shows at a much too high-implied value for the capital share in total output. However, the value of the capital share becomes reasonable when human capital is included in the capital measure. Thus, Mankiw, Romer, and Weil argue that a simple extension of the Solow growth model with human capital does

12 Kenneth J. Arrow, "The economic implications of learning by doing", *Review of Economic Studies*, Vol. 29, No. 3, 1962, pp. 155-173.

13 Theodore W. Schultz, "Investment in human capital", *The American Economic Review*, Vol. 51, No. 1, 1961, pp. 1-17.

14 N. Gregory Mankiw, David Romer, and David N. Weil, "A contribution to the empirics of economic growth", *Quarterly Journal of Economics*, Vol. 107, No. 2, 1992, pp. 407-437.

a good job in explaining cross-country economic growth differences. This certainty confirms the significance of human capital in explaining growth.

The endogenous growth literature has always paid much attention to the role of education in stimulating economic growth. Aghion and Howitt (1998) distinguish two types of endogenous growth models in which the relationship between education and growth is considered¹⁵. According to first approach, similar to Mankiw, Romer, and Weil model, human capital is considered as an input in the production function and stresses the significance of the *accumulation* of human capital for economic growth. These models explain the differences in economic growth as a result of differences in the *growth rates* of human capital accumulation. An unrealistic implication of these models is that education, and therefore the change in human capital, will always have a positive impact on economic growth, even when the technology is stagnant. In the other types of models, which are based upon a Schumpeterian analysis, this is not the case. These models lay emphasis on countries with a higher stock of human capital is better able to create new products and technologies and thus innovate. In addition, a nation with a higher stock of human capital is better able to adapt to new technologies and hence to improve the diffusion of technology throughout the economy¹⁶. Thus, these models suggest that differences in growth rates can better be explained by differences in the stock of human capital than by differences in its growth rates.

In addition to conventional approach, there are features of human capital that can give it a much more important role in economic growth. This is especially true when we consider disembodied human capital. Disembodied human capital is the realm of knowledge and ideas that do not live and die with their inventors but can be transmitted freely between people and carried forward over generations. A significant feature of disembodied human capital is that ideas are both non-rival and cumulative. Non-rivalry implies that one person's use of the idea does not prevent another person from using it at the same time. Moreover ideas are cumulative: one idea could lead to another use of the same idea that may in turn lead to yet further ideas. Analysis of these attributes of non-rivalry and cumulative feedback has led growth theorists to speculate that investment in the generation of ideas can be the engine of long-run growth.

15 Philippe Aghion and Peter Howitt, *Endogenous Growth Theory*, (Cambridge, MA: MIT Press, 1998).

16 *Ibid.*

2.3. Re-thinking Economic Growth: the Role of knowledge

Knowledge is fundamental to economic growth. If we were to suffer collective amnesia—not remembering how to read and write—our material standard of living would be reduced to unrecognizable levels. All economic activities depend on institutions that encourage the preservation, transmission and development of knowledge. Even though this is obvious, an approach that ignored the role of knowledge dominated the economic analysis of growth for several recent decades. Concentration on the accumulation of objects rather than the accumulation of ideas was the main approach of economists to explain economic growth.

This way of thinking about the economic growth was challenged in a series of papers, starting with Paul Romer, recognized as “the new growth theory” or “endogenous growth theory”¹⁷. An important feature of this new wave of economic models is that policy intervention and the nature of institutions can influence the long-run growth rate of the economy. There are various technical features of these models that make it feasible for the long-run growth rate to be determined endogenously, i.e. determined by economic behavior. One possibility arises where the degree of substitutability between capital and labor is sufficiently high that returns to the accumulation of capital do not diminish to zero. In addition, complementarity, dynamic feedback and non-rivalry in investment are the properties that distinguish the accumulation of ideas and skills from that of objects. It is important to understand each of them in turn.

2.3.1 Complementarity of investment

Complementarity arises when someone’s investment increases the return (monetary and/or psychological) to others’ investment. This may happen when we invest in activities that exhibit network externalities. Even though complementarity is not exclusive to investment on human capital, complementarity is probably more pervasive in the accumulation of skills than in the accumulation of objects.

In some theories, only a portion of human capital is used in the production of goods¹⁸. The accumulation of human capital takes place because

17 Paul M. Romer, “Increasing Returns and Long-Run Growth”, *Journal of Political Economy*, Vol. 94, 1986, pp. 1002-1037.

18 See Hirofumi Uzawa, “Optimal Technical Change in an Aggregative Model of Economic Growth”, *International Economic Review*, Vol. 6, No. 1, 1965, pp18-31, and Robert E. Lucas Jr., “On the Mechanics of Development Planning”, *Journal of Monetary Economics*, Vol. 22, No. 1, 1988, pp. 3-42.

the part of human capital not used for current production goes to school and becomes educated. A special feature of the model is the existence of an externality, which is taken into account by spillover effects of human capital accumulation. The idea is that individual workers, given their own skill level, are more productive when other workers have more human capital. The introduction of externalities is a common approach in endogenous growth models to avoid the diminishing returns to capital assumption from the traditional neoclassical model and hence to obtain a model which reproduces a process of endogenous growth.

Barro and Sala-i-Martin provide some interesting analyses related to the behavior of the Lucas model during the adjustment process¹⁹. Authors, especially, consider what would happen if the ratio between human and physical capital is not at its optimal level. It appears that a sort of a neoclassical convergence process starts when the initial human capital, physical capital ratio is above its optimal level. In that case, the growth rate will increase with the amount of imbalance. On the other hand, if there is too little human capital, growth rates will decrease with the amount of the imbalance. This implies that a country would have much more difficulties to recover when she has a shortage of human capital than when she has a shortage of physical capital. Therefore, a brain drain will do much more harm for economic growth than a war, which destroys only physical capital.

2.3.2 Dynamic feedback

In Lucas' model, because of diminishing returns to the accumulation of both physical and human capital these education externalities are not sufficient in themselves to drive long-run growth²⁰. He uses another feature of education "dynamic feedback" to endogenize growth. It is obvious that as we learn more, it becomes easier to acquire further knowledge and skills.

Dynamic feedback²¹ explained by a function expressing the change in the level of human capital in some representative household as a function of the amount of total labor time, $L_{h,t}$, that is devoted to education and the current level of human capital per person, h_t .

19 Robert J. Barro and Xavier Sala-i-Martin, *Economic Growth*, (New York: McGraw-Hill, 1995).

20 Robert E. Lucas Jr., "On the Mechanics of Development Planning", *Journal of Monetary Economics*, Vol. 22, No. 1, 1988, pp. 3-42.

21 Steve Dowrick, "Ideas and Education: Level or Growth Effects?", NBER Working Paper Series, no. 9709, May 2003.

$$\frac{dh_t}{dt} = \phi L_h h_t^\gamma \quad (1)$$

In this formulation the extent of dynamic feedback is captured by the value of the exponential parameter (γ). A value of zero implies that there is no feedback. Aggregate output per person, y , depends on both physical and human capital per person:

$$y_t = A(k_t)^\alpha (h_t)^\beta \quad (2)$$

where the diminishing returns assumption is maintained by restricting $\alpha, \beta < 1$.

In this model, existence of positive feedback in the second sector of the economy, the education sector, makes the endogenous growth feasible. To show this, one should take logarithms of equation (2), differentiate with respect to time and substitute equation (1) to drive the growth rate of output per worker:

$$\frac{dy_t}{dt} \frac{1}{y_t} = \alpha \frac{dk_t}{dt} \frac{1}{k_t} + \beta \frac{dh_t}{dt} \frac{1}{h_t} = \alpha \frac{dk_t}{dt} \frac{1}{k_t} + \beta \frac{\phi L_h}{h_t^{1-\gamma}} \quad (3)$$

Equation (3) demonstrates whether or not the accumulation of human capital can drive long run growth is determined by the final term in this equation. With no positive feedback, i.e. if $\gamma=0$, final term of the equation approaches to zero as the level of human capital, h_t , increases over time. This is exactly what happens to the physical capital term, as a given investment rate leads to slower and slower proportional growth in the stock. However, if there is sufficiently high feedback in human capital accumulation, i.e. if $\gamma=1$, the final term in equation (3) is a positive constant. That is to say, the long run growth rate is positive.

To overcome the problem of limits to human capabilities, Romer emphasizes the difference between the skills and abilities that are embodied in individuals, and disembodied knowledge²². He focuses on the properties of the latter category, the world of ideas and research, supposing that there is sufficient dynamic feedback in the research sector to generate endogenous growth and that the scope for developing new ideas is limitless. In Romer's model, it is the number of people engaged in research and development that drives long-run growth.

22 Paul M. Romer, "Endogenous Technological Change", *Journal of Political Economy*, Vol. 98, 1990, pp. S71-S102.

2.4. Health and Economic Growth

The studies that searched relationship between health and economic growth have shown that improvements in health can accumulate human capital²³. In this context, it is argued that there exist a positive relationship between other component of human capital, health, and economic development. Only those that have better health can be a source of economic development in terms of human capital accumulation, knowledge generation, etc. For instance, generating new ideas requires healthy bodies, as much as well-educated researchers. In the literature, indicators of health status like life expectancy at birth and the infant mortality rate have been used rarely in convergence studies²⁴. These indicators were also introduced to growth literature by augmenting the Mankiw, Romer, and Weil's model by controlling for health and education components of human capital separately²⁵. They estimated this relationship in a Solovian growth framework and found the positive relationship between health and output²⁶.

In addition, health has also important implications on labor supply²⁷. Cuddington *et al.* studied long term growth in the presence of a communicable disease, such as AIDS, under the assumption of exogenous health expenditures²⁸. They conclude that epidemic disease has significant effects for size, structure, and productivity of labor, and thus for the growth performance of a nation. Furthermore, van Zon and Muysken introduced health into the Lucas' endogenous growth framework²⁹. In their model, healthy labor is not only used in the production of goods and knowledge, but it is also necessary to maintain health. As a consequence the characteristics of the health sector that have a clear impact on economic growth and optimal health expenditures are analyzed.

23 Theodore W. Schultz, "Investment in human capital", *The American Economic Review*, Vol. 51, No. 1, 1961, pp. 1-17, and Selma J. Mushkin, "Health as an Investment", *Journal of Political Economy*, Vol. 70, No. 5, Part 2: Investment in Human Beings (Oct., 1962), pp. 129-157.

24 See Robert J. Barro and Xavier Sala-i-Martin, *Economic Growth*, (New York: McGraw-Hill, 1995).

25 Stephen Knowles and Dorian P. Owen, "Health Capital and Cross-Country Variation in Per Capita in the Mankiw-Romer-Weil Model", *Economic Letters*, Vol. 48, 1995, pp. 99-106.

26 Stephen Knowles and Dorian P. Owen, "Education and Health in an Effective-Labour Empirical Growth Model", *Economic Record*, Vol. 73, 1997, pp. 314-328.

27 Selma J. Mushkin, "Health as an Investment", *Journal of Political Economy*, Vol. 70, No. 5, Part 2: Investment in Human Beings (Oct., 1962), pp. 129-157.

28 John T. Cuddington, John D. Hancock, Carol Ann Rogers, "A Dynamic Aggregative Model of the AIDS Epidemic with Possible Policy Interventions", *Journals of Policy Modeling*, Vol. 16, No. 5, 1994, pp. 473-496.

29 Adriaan van Zon and Joan Muysken, "Health and Endogenous Growth", *Journal of Health Economics*, Vol. 20, No. 2, March 2001, pp. 169-185.

1. METHODOLOGY AND DATA

I estimated the impact of the creation of scientific knowledge through ideas generated by published articles and number of doctorates to productivity growth for the United States economy between 1900 and 2006 using Shazam 10 econometric software program. The following system of equation is generally referred in order to evaluate the contribution of these factors to output growth:

$$Y = MFP \cdot F(H, K) \quad (4)$$

$$MFP = G(P, PhD, O) \quad (5)$$

$$P_t = \sum w_p N_{t-1}^P \quad (6)$$

$$PhD_t = \sum w_{PhD} N_{t-1}^{PhD} \quad (7)$$

where Y is the output, H is the stock of private labor measured in hours worked, K is the stock of private capital, MFP states the current state of technological or scientific knowledge (multi-factor productivity), P stands for the measure of accumulated number of published articles (as a proxy for the knowledge *stocks* generated by domestic firms, public research institutions and foreign institutions), PhD stands for the measure of accumulated number of doctorates earned, and O is the other factors affecting multi-factor productivity. N^P represents the number of published articles in time t , and w_p connects the level of past research to the current state of knowledge. For estimation purposes, a production function of a country i 's explicit structure is generally of the Cobb-Douglas type, which has a log-additive form, and an exponential trend (t) approximates O .

$$Y_i = \exp[\phi_i t + u_i] H_i^{\alpha_1} K_i^{\alpha_2} P_i^{\beta_1} PhD_i^{\beta_2} \quad i = 1, 2, \dots, N \quad (8)$$

where u is random term, ϕ is the rate of disembodied technical change and α_1 , α_2 , β_1 and β_2 are the output elasticities of labor, capital, stock of published articles, and stock of PhD earned, respectively. The estimation of these parameters may be calculated by taking the natural logarithm of equation (8), as follows:

$$\ln Y_i = \phi_i t + \alpha_1 \ln H_i + \alpha_2 \ln K_i + \beta_1 \ln P_i + \beta_2 \ln PhD_i + u_i \quad (9)$$

It is common to drive an index of multi-factor productivity h MFP from equation (9):

$$\ln MFP_i = \ln Y_i - \hat{\alpha}_1 \ln H_i - (1 - \hat{\alpha}_1) \ln K_i = \phi_i t + \beta_1 \ln P_i + \beta_2 \ln PhD_i + u_i \quad (10)$$

the assumption of constant returns to scale with respect to labor and

capital and payments of these traditional inputs are required for this analysis. In other words, the output elasticities with respect to labor (capital) are assumed to be equal to the labor (capital) cost share in total output and α_2 is equal to $(1 - \alpha_1)$.

Given the theoretical and empirical discussions of previous section the following equation is eventually estimated:

$$\ln MFP_t = \phi + \beta_1 \ln P_t + \beta_2 \ln PhD_t + \beta_3 \ln Life_t + \beta_4 \ln U_t + \varepsilon_t \quad (11)$$

where, *MFP* is an index of multi-factor productivity of private economy. *MFP* is computed as the ratio of the domestic product of industry to the weighted sum of the quantity of labor and fixed capital stock, the weights being the annual labor cost share and the capital cost share, respectively as given in equation (11). The data for the multifactor productivity are taken from two different sources. For the 1889-1947 period, total factor productivity series for private domestic economy were taken from Kendrick³⁰. The data between 1948 and 2006 is taken from the US Bureau of Labor Statistics³¹. Finally, Levy and Terleckyj generated unified *MFP* series and showed that this unified *MFP* data can be used in studies such that looking for the determinants of productivity³².

P denotes the source of knowledge generated by counting number of published articles from ten different field of sciences for the past century. Table 1 gives the field of sciences, availability of periods for the publications and the sources that the number of published articles were counted.

30 John W. Kendrick, *Productivity Trends in the United States*, (Princeton: Princeton University Press, 1961).

31 United States Bureau of Labor Statistics. www.bls.org accesses 01 March 2012

32 David M. Levy and Nestor E. Terleckyj, "Government Science and the US Economy: Approaching the Puzzle", (Unpublished manuscript, 2008).

Table 1: Sources of Published Articles

Field of Science	Time Period	Source Index
Biology	1918-	Biological Abstracts
Chemistry	1907-	Chemical Abstracts
Computer science	1957-	Computer Abstracts
Mathematics and Statistics	1868-	Two different sources
	1868-1942	1-Jahrbuch uber die Fortschritte der Mathematik
	1943-	2-Mathematical Reviews
Physics	1896-	Physics Abstracts
Engineering and Technology	1884-	Engineering Index
Clinical Medicine	1879-	Index Medicus
Earth Sciences	1933-	GeoRef
Nuclear Science	1948-	Nuclear Science Abstracts & Inis Atomindex
Space Science	1961-	International Aerospace Abstracts

PhD represents the number of doctorates received from the US universities. It is a proxy for the stock of human capital. Even though multifactor productivity index is already measured taking account of share of human capital, this variable is added to measure positive externalities of the higher education. Data are received from the Bureau of Labor Statistics.

Life is the life expectancy at birth. In general, life expectancy is a proxy for good health and desirable performance of nations. Barro and Sala Sala-i-Martin state that “higher life expectancy may go along with better work habits and higher levels of skills”³³. Thus, changes in life expectancy may affect multifactor productivity. Data are received from National Vital Statistics Reports for the United States.

Finally, a control variable that is added to model is the number of unemployed. Since the people that out of work lose their skills and abilities, productivity will be negatively influenced. It is also a stylized fact that unemployment is countercyclical. Data for this variable are received from the Historical Statistics of the US and Bureau of Labor Statistics.

1. ESTIMATION TECHNIQUES

First concern working with time-series data is the problem of stationary. The variables used in this study like number of published articles and number of doctorates earned, both summed values, are growing over time since beginning of the century. This brings concerns about the results of

33 Robert J. Barro and Xavier Sala-i-Martin, *Economic Growth*, (New York: McGraw-Hill, 1995), p. 432.

the ordinary least squares (OLS) estimates because the mean of the series tends to increase over time. As a result, Augmented Dickey-Fuller (ADF) unit-root test applied to model given in equation (11)³⁴. ADF unit root test statistics is estimated by the following equation:

$$\Delta Y_t = \mu + \beta t + \gamma Y_{t-1} + \sum_{j=1}^p \delta_j \Delta Y_{t-j} + \varepsilon_t \quad (12)$$

Where Y is the variableⁱ⁼¹ that we are searching whether it has a unit-root or not. μ is constant, β is the coefficient on a time trend and p the lag order of the autoregressive process. In equation (12), the coefficient of interest is γ ; if $\gamma = 0$, the equation is entirely in first differences and so has a unit root and series are not stationary. Thus, if the estimated test statistics are higher than critical levels at 10% significance level, we are not able to reject $\gamma = 0$ hypothesis.

Table 2 gives the test statistics for constant and trend and related significance values at 10 percent level.

Table 2. Dickey-Fuller Unit-Root Test Results for the Series

Explanatory variables	Test Statistics with constant and trend	Critical values at the 10% level
Multifactor Productivity	-1.2718	-3.13
Total number of published articles	-2.6543	-3.13
Total number of doctorates earned	-0.0239	-3.13
Life expectancy	-0.9545	-3.13
Number of unemployed	-3.2084	-3.13

Since test statistics for all variables other than unemployed exceed the critical value of -3.13 , the conclusion is that the null hypothesis of a unit root cannot be rejected for the variables given in the Table 2. This generally requires first differencing of series. On the other hand, it is suggested that if the regressed variables are co-integrated there is no need for differencing of time series³⁵. Thus, Dickey-Fuller test on the residuals of co-integrating regression applied to equation (11). The estimates show that

34 David A. Dickey and Wayne A. Fuller, "Distribution of the Estimators for Autoregressive Time Series With a Unit Root", Journal of the American Statistical Association, Vol. 74, No. 366, June 1979, pp. 427-431.

35 Anindya Banarjee, Juan J. Dolado, John W. Galbraith and David F. Hendry., Co-Integration, Error-Correction, and the Econometric Analysis of Non-Stationary Data, New York: Oxford University Press, 1993).

while the estimated test statistic is -3.68 , the critical value at the 10 percent is -4.43 . Then, one can conclude that the null hypothesis of non-stationary cannot be rejected. In other words, the variables in our regression are not co-integrated. As a result, first differences of log values are used for the regression analysis.

1.1. Ordinary Least Square Estimates and Time-Varying Relationships

Stationarity—constancy of the parameters like the mean, variance and trend over time—is the main assumption of applied time series analysis. However, this assumption is questionable and one can ask what happens if the parameters change over time.

Even though we check for stationarity in the previous part, it is straightforward that some of or all the regression coefficients could be different in subsets of the data. Especially, considering the data we use for the last century, and two world wars could influence the variables used. Moreover, one could find results using the ordinary least squares technique (OLS) estimates with unexpected signs. The estimated coefficients and standard errors using the OLS for the explanatory variables reported in table 3.

Table 3. Estimates of the Variables on Multifactor Productivity: 1901-2006

Explanatory Variables	Estimated coefficients	Estimated Standard Errors
Constant	0.0123	0.0038
Total number of published articles	-0.2492***	0.1398
Total number of doctorates earned	0.2986**	0.1621
Life expectancy	0.077	0.0566
Number of unemployed	-0.0388***	0.0072
R ²	0.3027	
Durbin-Watson	2.3362	

*Indicates the significance level at 10 percent

**Indicates the significance level at 5 percent

***Indicates the significance level at 1 percent or better

Results show that we don't have the expected sign for the estimated coefficient of the total number of published articles, plus the estimated coefficients is statistically significant at 10 percent significance level. It is not really logical to say total number of published articles did not contribute

to multifactor productivity for the last century. Especially considering the significant effect of creation of scientific knowledge on multifactor productivity through scientific articles. In addition, effect of life expectancy on multifactor productivity is not significant. As expected, the total number of doctorates earned, which is proxy for highly educated human capital, has the largest effect on the multifactor productivity of the U.S. economy. However, a question could be raised about the wrong sign of published papers and the accuracy of the estimates of the OLS. Thus, data should be analyzed for the structural change or coefficient variation problem.

The classical test for structural change is typically attributed to Chow³⁶. His famous testing procedure splits the sample into two sub-periods, estimates the parameters for each sub-period, and then tests the equality of the two sets of parameters using a classic F statistics. This test was popular for many years and was extended to cover most econometric models of interest. Similarly, the Goldfeld-Quandt³⁷ (G-Q) statistics provides a test for different error variance between two subsets of observations. For the G-Q test, error variances would be the same in the two groups, while under the alternative; the error variance would differ systematically. However, an important limitation of the Chow test is that the break date must be known a priori. A researcher has only two choices: to pick an arbitrary candidate break-date or to pick a break-date based on some known feature of the data. In the first case the chow test can be uninformative, as the true break-date can be missed. In the second case, the Chow test can be misleading, as the candidate break-date is endogenous—it is correlated with the data—and the test is likely to indicate a break falsely when none in fact exists. In addition, since the results can be highly sensitive to these arbitrary choices, different researchers can easily reach quite distinct conclusions—hardly an example of sound scientific practice.

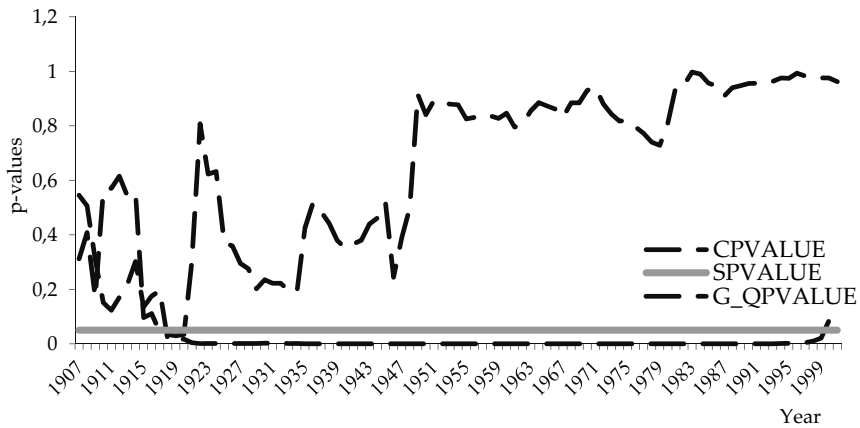
Since the multifactor productivity data unified from two different sources one can say the split point 1947-1948 could be structural break point for the data and it would be better to check for structural break at this point using a Chow test and Goldfeld-Quandt test. While a Chow test value of 0.876 with (47,59)—p value of 0.500—is indicating there is no evidence for structural break, a Goldfeld-Quandt test value of 3.880 (42,54)—p value of 0.000—suggests that there is evidence for structural break at this split point. These different results supports the problems of

36 Gregory Chow, "Tests of Equality between Subsets of Coefficients in Two Linear Regressions", *Econometrica*, Vol. 27, 1960, pp. 591-605.

37 Stephen M. Goldfeld and Richard E. Quandt, "Some tests for homoscedasticity", *Journal of the American Statistical Association*, Vol. 60, 1965, pp. 539-547.

Chow test discussed above. In addition, following figures for the p-values of Chow test values and Goldfeld-Quandt test values bring the question of how difficult is to determine the structural break point.

Figure 1. Comparison of p-values for Chow and Goldfeld-Quandt Tests



CPVALUE is p-values for Chow test G-QPVALUE is p-values for Goldfeld-Quandt test
 SPVALUE is the p-value for 5 percent significance level

The difference between the Chow test and Goldfeld-Quandt test to determine structural break points is inevitable from the figure. Moreover, it is difficult to determine break points from the neither test values, because the points below the statistical significance line (SPVALUE) much more than just one point. Especially, Goldfeld-Quandt test shows almost every splice point would bring the problem of error variances would be different systematically for the sub-periods.

Later work relied on recursive residuals to provide a test of parameter stability using the CUSUM and CUSUMSQ plots³⁸ and formalized in a test statistics³⁹. Recursive residuals technique is appropriate for time-series data and might be used if one is uncertain about when a structural change might have taken place. The null hypothesis is that the coefficient

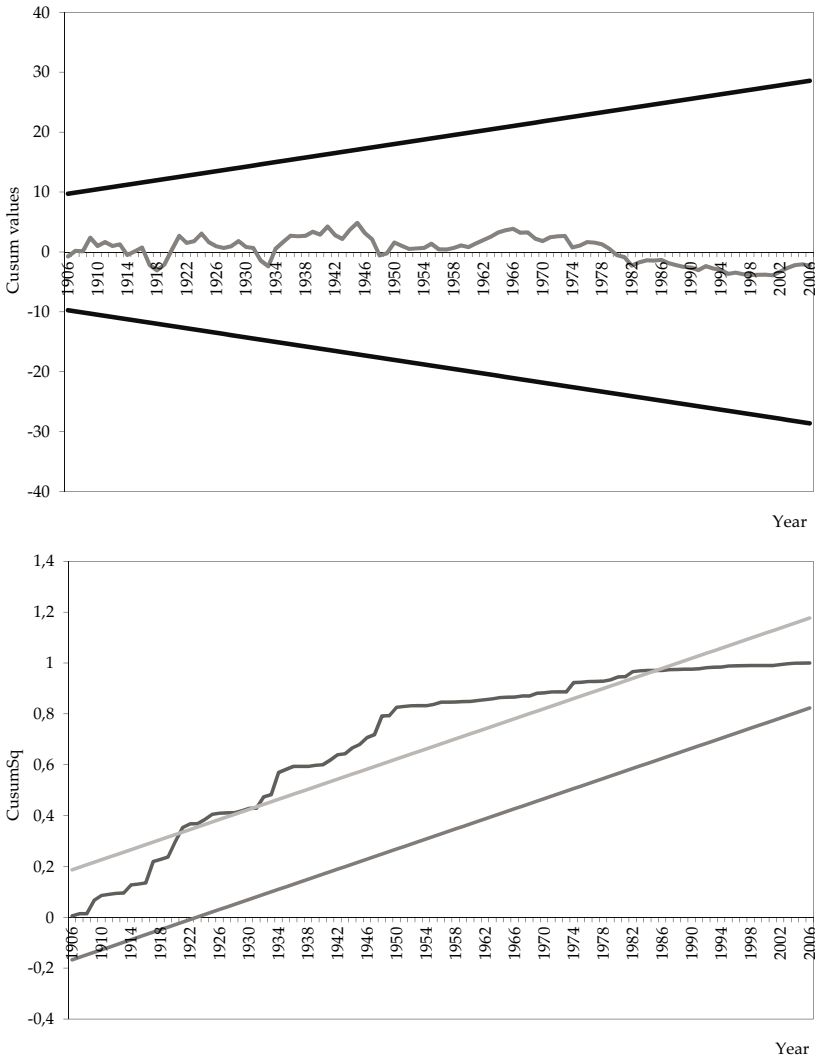
38 R. L. Brown, James Durbin and J. M. Evans, "Techniques for Testing the Constancy of Regression Relationships over Time", *Journal of the Royal Statistical Society. Series B (Methodological)*, Vol. 37, No. 2, 1975, pp. 149-192.

39 Andrew Harvey and Patrick Collier, "Testing for Functional Misspecifications in Regression Analysis", *Journal of Econometrics*, Vol. 6, No. 1, July 1977, pp. 103-119.

vector BETA (β) is the same in every period. The test is quite general in that it does not require a prior specification of when the structural change takes place. The cost, however, is that the power of the test is rather limited compared with that of the Chow test. Greene criticizes this test as having low statistical power⁴⁰. These tests also reveal nothing about which particular coefficients vary, how much they vary, or whether variation is systematic. Rather, they are tests of *global* coefficient stability that apply to entire regression specifications. Figure 2 plots these two test statistics. The CUSUM test, shown in the upper panel, does not reveal instability in the mean since the CUSUM values are inside the boundaries, while the CUSUM of squares test, shown in the lower panel, detects instability in the variance between 1930s and beginning of 1980s because during this period CUSUM of square values are outside the upper bound. Similar to Chow test results, it is difficult to decide which year is really a splice point to test for structural break.

40 William H. Green, *Econometric Analysis*, (New Jersey: Prentice Hall, 2008).

Figure 2: Another Test for Structural Change; Cusum and Cusum of Squares



In contrast to these techniques, flexible least square (FLS) can be applied where the expected coefficient instability is sudden or evolving slowly through time. It provides a global test for coefficient stability, evidence concerning which coefficients varies, how much they vary, and whether those variations follow systematic pattern. FLS also requires no *ad hoc* prior assumptions about the structure driving the coefficient variation or about

the distribution of disturbances from the estimated model. And unlike methods relying on recursive estimates, FLS uses true time-varying estimation and the full data set in computing the time paths of the coefficients. Before we apply data to flexible least square estimates more information about FLS and the comparison with OLS is discussed in the next section⁴¹.

4.2. Definition of Flexible Least Square

FLS is a multi-criterion estimator that seeks to discover the *particular coefficient vector that obtained at each time t, considering all time T*. In contrast, OLS seeks to find an *average coefficient vector for all time t, without taking into account possible coefficient variation*. Like OLS, FLS minimizes an objective function, but unlike OLS, the FLS objective function considers two different types of specification error—residual measurement error due to specifying an incomplete set of independent variables, and residual-dynamic error due to possible coefficient variation for the included variables. In minimizing the multi-criterion objective function, FLS is more flexible in that it allows temporal variation in the coefficients. OLS is just a special case of FLS in that a restriction is imposed that fixes the potentially time-varying coefficients to constant values. Absent true coefficient variation, the two methods yield identical results, but if the restriction is invalid then the two methods can yield different results.

4.3. The Rationale of Flexible Least Square

The general approach taken by FLS in exploring coefficient-time variation is to investigate the relative costs for fixed versus time-varying coefficient assumption. These costs are measured in terms of residual measurement and dynamic error. Mainly, we could fail to minimize prediction error due to improper model specification, or we could fail to minimize prediction error because there is parameter variation. In this sense FLS tells the user what are the feasible efficient trade-offs between dynamic and measurement-specification errors, efficient in the sense that there is no way to obtain smaller dynamic errors without an increase in measurement-specification error, and vice versa. However, the optimal choice can only be made on the basis of a researcher's utility for different amounts of parameter variation. FLS makes explicit the costs of fixed versus time-varying

41 Detailed analyses can be seen in B. Dan Wood, "Weak Theories and Parameter Instability: Using Flexible Least Squares to Take Time Varying Relationships Seriously", *American Journal of Political Science*, Vol. 44, No. 3, 2000, pp. 603-618.

assumptions in terms of residual-measurement error. As such, it provides the tools required for analyst to make reasonable choices between the two options.

4.4. The Tools of Flexible Least Square

How a researcher uses FLS to evaluate global coefficient stability, determine which coefficients vary and by how much, and explore the patterns of coefficient variation.

4.4.1. Evaluating global coefficient stability

In evaluating global coefficient stability, the researcher traces out a residual efficiency frontier (REF) by changing the value of delta in the cost function across the range from 1 to 0. If delta is near 1, the cost function places most of the weight on the dynamic-specification errors, forcing them to be near zero. On the other hand, if delta is set near zero, the cost function places most of the weight on the measurement specification errors, forcing measurement specification errors to be zero. Thus, this end point reveals the minimum amount of time variation in the coefficients that must be allowed in order to have no residual-measurement error (i.e., a perfect fit for the regression).

Suppose the model has truly has time-invariant coefficients, then starting from the OLS extreme point, the REF will indicate (as we move delta toward zero) only small decreases in measurement error are possible for large increases in dynamic error. Therefore, the REF should decline slowly with changing delta. In contrast if the true model has time varying coefficients, then starting from the OLS extreme point large decrease in measurement error will be possible for allowing small increases in parameter variation. The REF should slope downward more steeply from the OLS extreme point.

4.4.2. Evaluating which coefficients vary by how much

A second level analysis is to observe the standard deviations and averages of the estimated sequence of time varying coefficients at different values of delta. The reason for doing so is to gather evidence concerning which particular coefficients exhibit the most time variation. Because delta is a smoothing coefficient, the standard deviation of time-varying coefficients

may change substantially when moving delta away from the OLS extreme points.

The average of a time-varying coefficient sequence can be compared directly with the OLS coefficient to check for large differences over the range of the REF. The average of a time-varying coefficient sequence can change substantially the further one moves delta away from 1. The average for a fixed-coefficient sequence should remain the same for all values of delta.

4.4.3. Evaluating the pattern of coefficient variation:

A third level of analysis is to plot the actual coefficient-vector sequences to observe the nature of the time variation. FLS generates an estimated time path for each regression coefficient, conditional on delta. The value of delta should be chosen so as not to arbitrarily restrict the coefficients of constancy. Typically, there is a threshold delta less than 1, below which the means, standard deviations, and residual-measurement errors change very little. Below this threshold, the choice of delta is arbitrary, since the qualitative patterns exhibited by the FLS time paths occur at all points along the REF, and the scale of the variations remains similar below the threshold.

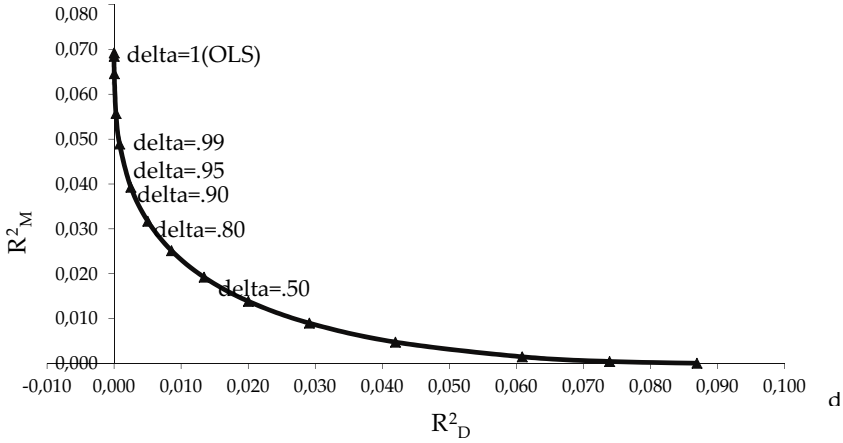
Plots of the time-varying coefficients can be used to evaluate whether coefficient-time variation is consistent with substantive theory positing some breakpoint or a gradually changing process.

5. EMPIRICAL RESULTS OF TIME-VARYING PARAMATER MODEL

After giving the theatrical explanation for the use of FLS, we should apply our data to re-estimate our results. Thus, one can compare the results from OLS and those from FLS. The main problem we had with the OLS estimations was the unexpected sign of the number of published articles. According to FLS, this variable can be time varying thus estimated coefficients from the OLS could be misleading.

First, following the discussion in the previous section we can plot residual efficiency frontier (REF) for the FLS. Figure 3 plots the REF for the equation (11).

Figure 3. Residual Efficiency Frontier: Multifactor Productivity



R^2_M is the cost of violating the measurement specification

R^2_D is the cost of violating the dynamic specification

Plotted REF does give strong support for the assumption that coefficients are time varying because REF is declining fast with changing delta.

As a second step, we should check which particular coefficient are changing and by how much. Table 4 reports the coefficient averages and standard deviations at each value of delta along the residual efficiency frontier. One can see that when delta is very close to one, estimated coefficients are almost precisely same as those reported in table 3.

Table 4. Summary Statistics for FLS Estimates over the Residual Efficiency Frontier

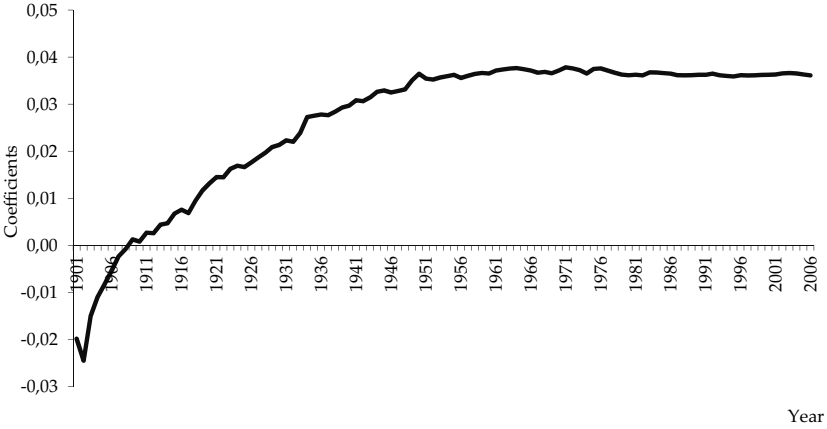
0,999	-0,239	0,286	0,076	-0,039
	(0,0000)	(0,0000)	(0,0000)	(0,0003)
0,99	-0,191	0,241	0,072	-0,041
	(0,0005)	(0,0001)	(0,0001)	(0,0021)
0,95	-0,108	0,174	0,064	-0,044
	(0,0020)	(0,0006)	(0,0007)	(0,0058)
0,90	-0,065	0,149	0,062	-0,045
	(0,0035)	(0,0012)	(0,0014)	(0,0084)
0,80	-0,026	0,146	0,062	-0,046
	(0,0064)	(0,0022)	(0,0028)	(0,0117)
0,70	-0,006	0,160	0,065	-0,047
	(0,0092)	(0,0031)	(0,0041)	(0,0142)
0,60	0,011	0,177	0,068	-0,047
	(0,0121)	(0,0041)	(0,0053)	(0,0164)
0,50	0,026	0,195	0,071	-0,048
	(0,0151)	(0,0051)	(0,0062)	(0,0184)
0,40	0,044	0,213	0,073	-0,048
	(0,0183)	(0,0062)	(0,0070)	(0,0204)
0,30	0,065	0,229	0,075	-0,049
	(0,0218)	(0,0075)	(0,0078)	(0,0223)
0,20	0,090	0,244	0,076	-0,050
	(0,0256)	(0,0089)	(0,0088)	(0,0244)
0,10	0,124	0,256	0,074	-0,051
	(0,0300)	(0,0107)	(0,0109)	(0,0267)
0,05	0,145	0,260	0,073	-0,051
	(0,0325)	(0,0117)	(0,0128)	(0,0279)
0,01	0,164	0,264	0,071	-0,052
	(0,0347)	(0,0126)	(0,0148)	(0,0289)

Note: the numbers in the table are time-varying coefficient averages at each specified delta. The numbers in parentheses are time-varying coefficient's standard deviations at each specified delta.

As we change delta by a small amount to 0.99 the coefficient averages changes, as do the standard deviations. It is very important to see that coefficient averages of total number of published articles have the positive sign as we change the delta away from one. One can see from the table that estimated average coefficients of total number of published articles have the expected signs when delta's assigned value is 0.6. Moreover, as the value of delta is reduced significance of the estimated coefficient increases. This shows that total number of published articles via increasing scientific knowledge is an important determinant of multifactor productivity.

Figure 4 plots the coefficient sequences for the total number of published articles with delta set arbitrarily to 0.5.

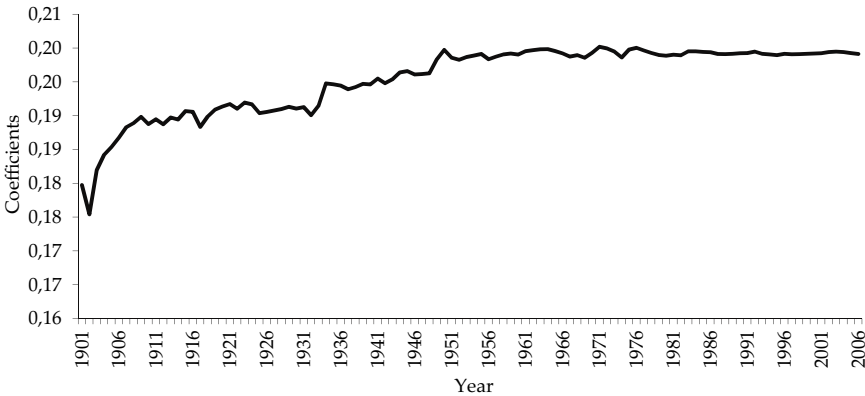
Figure 4. FLS Coefficients, Total Number of Published Articles



The effects of published papers are smaller and exhibit steady increase until 1950s, then after estimated coefficients seems stabilized. The estimate average coefficient centered on about 0.026 for the last century. This parameter estimate is also statistically significant at the 10% significance level with standard error of 0.015. If the total number of paper grows by 1%, multifactor productivity grows by 0.026 percent.

Similarly other explanatory variables can be plotted at the same delta to evaluate whether coefficient time variation is consistent with substantive theory positing some break point or a gradually changing process. Figure 5 through Figure 9 plots the other explanatory variables of the multifactor productivity model to evaluate the effects of other variables over the different time periods at $\delta=0.50$.

Figure 5. FLS Coefficients, Total Number of Doctorates Earned



The estimated average coefficients of total number of doctorates earned shows consistent movement throughout the twentieth century except the initial 10 years. The estimate average coefficient centered on about 0.20 for the last century. Estimated standard deviation for this coefficient is 0.005 and it is highly significant. Thus, 1% growth in the total number of doctorates would increase the multifactor productivity growth by 0.20%.

Figure 6. FLS Coefficients, Life Expectancy

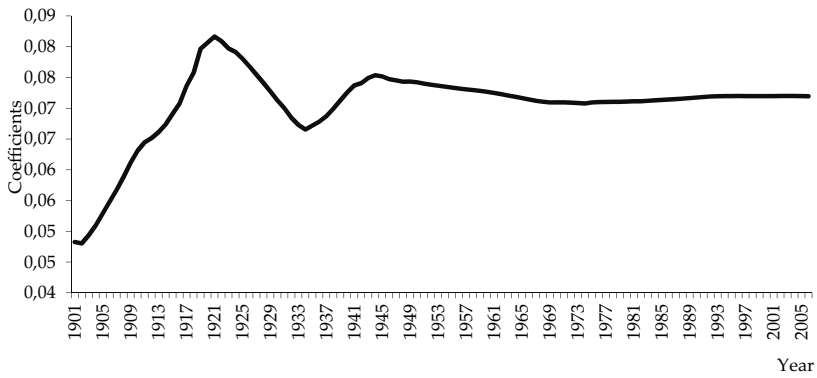
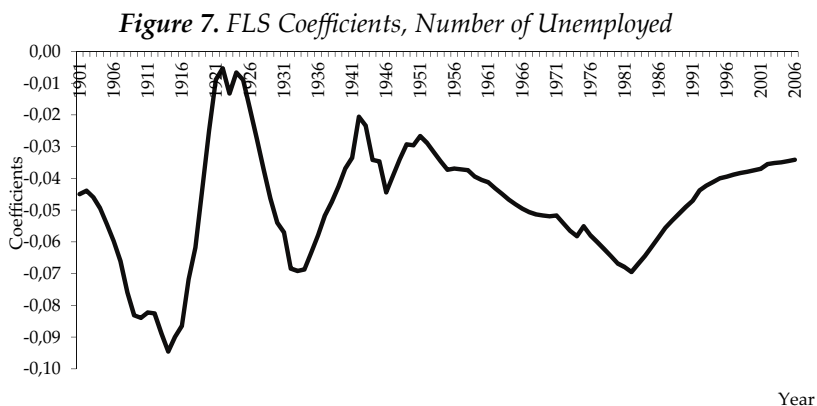


Figure 6 shows the estimated average coefficients for life expectancy variable. First half of the century, estimated coefficients of life expectancy at birth seems to be inconsistent, but for the second half they are changing steadily. Estimated coefficient is small and has been centered on 0.07 with a standard deviation of 0.006. Thus, it is statistically significant at 1% significance level. Increase in the life expectancy that measures non-educational human capital influences the desirable performance of a society. Consequently, better society with better work habits would improve the multifactor productivity of private business sector.



Total unemployed plotted in figure 7 fluctuates significantly over time representing macroeconomic fluctuations. 1% increase in unemployment rate produces 0.05% decline in growth of multifactor productivity with 0.018 standard deviation, estimated coefficient is highly statistically significant. Generally, staying out of job market for quite some time may cause unemployed to lose job skills. In addition, unemployed cannot utilize the externalities coming from learning by doing. Furthermore, unemployed by not learning the new technology coming to market every day may lose the productive abilities, thus causing a decline in the multifactor productivity.

6. CONCLUSION

Using a time-varying technique FLS, we estimated all the explanatory variables with the expected signs and all are statistically significant. Positive and significant sign on total number of doctorates earned reflects there are externalities coming from having advanced education since the multifactor productivity data already corrected for labor compensations. Another significant conclusion is that when the dynamic analysis evolves, time varying parameters could generate structural break over the time period. Number of published articles is an example. After correcting for such issue, we found that sum of paper stock positively influence the private sector multifactor productivity of the United States economy. Other control variables per capita life expectancy at birth and total unemployed are also captured their expected signs.

In addition, using graphs for the estimated coefficients gave us a chance to see how the explanatory variables evolved over time. This knowledge

can be used to see effects of different time periods on multifactor productivity of the private business sector. Moreover, after checking for the different time periods, one can focus on these time periods more intensively to figure out the main problems and use this knowledge for future policy analysis.

For future analysis, role of gender on determining multifactor productivity can be analyzed. One of the contributions of “caring economics” is bringing the gender differences to table and search for the role of women and men separately. Thus, effects of women’s life expectancy compared to that of men, and separating number of doctorates earned by gender upon multifactor productivity would be next research topics to be considered.

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