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ABSTRACT

Technical Progress and Early Retirement*

This Paper claims that technical progress induces early retirement of older workers. It supports this claim both theoretically and empirically. We present a model where part of human capital is technology-specific, so that technical progress erodes some existing human capital. This affects mostly older workers, who do not learn the new technology, since their career horizon is short. As a result their participation in the labour force declines. We find strong support to this erosion effect in US data, which shows that labour supply of older workers is negatively related to technical progress across sectors. Unlike the cross-section effect, the model is ambiguous about the aggregate effect of technical progress on labour participation of older workers. While in sectors with many innovations it falls due to erosion of human capital, in other sectors it increases due to higher wages. To examine which effect dominates, we run a time-series test and find that the effect of average technical progress on aggregate labour-force participation by the old is negative. Namely, the erosion effect dominates.

JEL Classification: J24, J26, O15, O33
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NON-TECHNICAL SUMMARY

Technical progress continuously changes the way we produce goods and services. It introduces new goods, new machines and new production methods. It also creates new professions and destroys old ones, namely, it makes some existing human capital obsolete and creates demand for new types of human capital. We claim that as a result, technical progress reduces labour-force participation of older workers and is therefore one of the major explanations for early retirement. The reason why such technical progress has an effect on older rather than on younger workers is because their career horizon is much shorter and hence it is less beneficial for them to invest in learning a new technology. We present this idea using a simple theoretical model and then test some of its implications using US data in recent decades and find strong support for it.

The main idea of the Paper is presented by use of a simple growth model, where production is organized in sectors. Each sector uses a specific technology, which requires specific human capital. Individuals learn and acquire technology-specific professions in the first period of life and work using these technologies in the second and third periods of life. Meanwhile new innovations arrive and replace existing technologies. The new technologies are more productive, but they require learning. Hence, reactions to new innovations differ by age. While younger workers learn the new, more productive profession, older workers do not learn, since their career horizon is much shorter. Instead they stick to a less productive technology and their income falls due to competition from the young. As a result they reduce their labour supply and tend to retire earlier. We call this effect of technical progress on labour participation of older workers, whose human capital has been eroded, the 'erosion effect'. One implication of this effect is cross-sectional, namely that labour supply of older workers should be negatively correlated with the rate of technical progress across sectors.

The model then analyses the effect of the average rate of technical progress on labour supply of older workers. This time-series effect is more ambiguous. On the one hand, during periods of rapid technical progress, workers in sectors with many innovations supply less labour, due to the erosion effect. But on the other hand, workers in sectors with fewer innovations supply more labour, as technical progress raises aggregate wages. We call this the 'wage effect'. The model weighs these two opposite effects and predicts that under plausible conditions on the labour-supply function the erosion effect dominates.

The Paper next turns to empirically testing these predictions with US data on labour-force decisions of older men. We first test the cross-section prediction by looking at labour decisions of men over 50 and how these decisions are affected by technical progress in their respective sectors. We find that the

coefficient of sector total factor productivity (TFP) growth on employment of men over 50, while controlling for the usual other variables, is negative. We find the result to be fairly robust.

We next turn to examine the relationship between aggregate technical progress and aggregate labour supply of older workers over time. This test is important, since it enables us to empirically compare the erosion effect and the wage effect. We cannot simply regress labour participation rate on TFP growth, since the latter includes strong temporary shocks in addition to technical progress. In order to separate the two shocks we use the Blanchard and Quah (1989) Structural VAR method. Our analysis shows that the effect of technical progress on labour-force participation of men above 55 is indeed negative. Hence, the erosion effect dominates the wage effect in the data as well.

The Paper links together two areas: technical progress and labour economics of older workers. It presents contributions to both areas. Technical progress has long been viewed as the most important driving force of global economic growth in the previous two centuries. While there is much research on how technological innovations are created and disseminated around the world, there has been relatively little discussion of the costs involved in adoption of technological innovations. This Paper describes one such specific cost, namely erosion of technology-specific human capital and its negative effect on labour-force participation. The literature on labour-force participation of older workers is vast and extensive. But this literature focuses mainly on issues like health, social security, pension funds, health insurance and similar institutions. This Paper adds an important variable, which affects early retirement of workers: technical progress. It describes this effect in a theoretical model and tests it empirically both across sectors and over time.

As we stress in the Paper, the erosion of technology specific human capital affects mostly older workers, since their career horizon is shorter than that of younger workers. But if we could reduce the cost of retraining, namely of learning the new technology, it could also reduce the negative effect of technical progress on labour of older workers. Hence, the effect we describe in the Paper depends crucially on the ability of the educational system to supply retraining for new technologies. This opens interesting topics for future research. Can differences in educational and training systems explain international differences in the reaction of labour to new technologies? Do institutional arrangements of retraining, on the job or out of the job, have an effect on labour-force fluctuations? Are there policy implications?

Technical Progress and Early Retirement

1. Introduction

Technical progress changes continuously the way we produce goods and services. It introduces new goods, new machines and new production methods. It also creates new professions and destroys old ones. More generally, new technologies always make some existing human capital obsolete and create demand for new types of human capital. This paper claims that as a result, technical progress reduces labor force participation of older workers, and is therefore one of the major explanations for early retirement. The reason why such technical progress has an effect on older rather than on younger workers is because their career horizon is much shorter, and hence it is less beneficial for them to invest in learning a new technology or another profession. We present this idea using a simple theoretical model and then test some of its implications using US data in recent decades and find strong support for it.

The main idea of the paper is presented by use of a simple growth model, where production is organized in sectors. Each sector uses a specific technology, which requires specific human capital. Individuals learn and acquire technology specific professions in first period of life and work using these technologies in second and third periods of life. Meanwhile new innovations arrive and replace existing technologies. The new technologies are more productive, but they require learning. Hence, reaction to new innovations differs by age. While younger workers learn the new more productive profession, older workers do not learn, since their career horizon is much shorter. Hence, they stick to a less productive technology and their income falls due to competition from the young. As a result they reduce their labor supply and tend to retire earlier.

The major point of the paper is therefore that older workers adjust less to new technologies, since investment in the new human capital would benefit them for a short period only. As a result they face competition from younger workers, who use a new better technology, and hence they retire earlier. Note, that the decision to retire early may be the worker's own decision as in our model, or the decision of the employer, who prefers not to retrain an older worker. The prediction of the model is the same. We call this effect of technical progress on labor participation of older workers, whose human capital has been eroded, the '*erosion effect*'.

The model has two main empirical implications. The first implication is cross-sectional, namely that labor supply of older workers should be negatively correlated with the rate of technical progress across sectors. This is a direct result of the erosion effect. The second implication is on the effect of the average rate of technical progress on labor supply of older workers. This time-series effect is more ambiguous. On the one hand, during periods of rapid technical progress, workers in sectors with many innovations supply less labor, due to the erosion effect. But on the other hand, workers in sectors with fewer innovations supply more labor, as technical progress raises aggregate wages. We call this the '*wage effect*.' The model weighs these two opposite effects and predicts that under very plausible conditions on the labor supply function the erosion effect dominates.

The paper next turns to empirically test the predictions of the model by use of US data on labor force decisions of older men. We first test the cross-section prediction of the model by looking at labor decisions of men over 50 and how these decisions are affected by technical progress in their respective sectors. The data on individual labor decisions is from the Health and Retirement Survey (HRS), which also includes information on job histories. We merge this information with data on productivity growth in sectors, as measured by Jorgensen (2000), which have been found to be a good measure for technical progress by Bartel and

Sicherman (1999). We find that the coefficient of sector TFP growth on employment of men over 50, while controlling for the usual other variables, is negative. We find the result to be fairly robust and it thus supports the first result of the model.

We next turn to examine the relationship between aggregate technical progress and aggregate labor supply of older workers over time. This test is important, since it enables us to empirically compare the two opposite effects described above: the erosion effect and the wage effect. We cannot simply regress labor participation rate on TFP growth, since the latter includes strong temporary shocks in addition to technical progress. In order to separate the two shocks we use the Blanchard and Quah (1989) Structural VAR method. Our analysis shows that the effect of technical progress on labor force participation of men above 55 is indeed negative. Hence, the erosion effect dominates the wage effect in the data as well.

There is vast literature, which tries to explain why so many older workers retire early recently.[1] The literature also tries to understand why their number has steadily increased over recent decades. Most of the literature that tries to explain the decline in labor participation rates of older workers focuses on the effect of health and of social institutions such as Social Security, pension funds and health insurance. Prominent recent papers in this line of research are Diamond and Gruber (1999), Costa (1998), and Gruber and Wise (1997).[2] While we agree that these factors account for much of the secular trend of decline in labor participation rates of older workers, we focus instead on the fluctuations in these rates around the trend. We show that these fluctuations, both across sectors and across time, are strongly negatively related to technical progress.

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[1]In 1996 the average labor participation rate in all OECD countries of men of ages 55-64 was 63.6% while in ages 25-54 it was 93.1%. Labor participation rates in the US of these two groups have been 67.0% and 91.8%, respectively.

[2]A theoretical analysis of how social security affects retirement appears already in Feldstein (1974).

The literature that relates technical progress to employment of older workers is not large. Some empirical studies have shown that technological innovations tend to be followed by short-run reduction in employment. A recent example of such studies is Gali (1996), who also lists other papers with similar results. Closer to our paper is Peracchi and Welch (1994), who analyze the recent declines in labor participation rates of older men and raise the possibility that older unskilled workers were pushed out of the labor force as a result of the recent technological advances. Much closer to our work is a paper by Bartel and Sicherman (1993), who examine the relationship between technical progress and labor supply of older workers across sectors. Our paper extends their work in two important directions: first, by embedding the empirical analysis in a theoretical model and second, by testing the aggregate effect of technical progress over time, in order to examine the relative weights of the erosion effect and the wage effect.

Our paper is also related to another line of research, which emphasizes the costs associated with growth and technical progress, as in Helpman and Trajtenberg (1998), Aghion and Howitt (1994), and Hornstein and Krusell (1996). Our paper provides a description of a specific cost of technical progress. It is the erosion of some human capital accumulated by workers, and the resulting early retirement of those workers who are too old to adjust to the new technologies.

The paper is organized as follows. Section 2 presents the basic model of technical progress and investment in human capital. Section 3 analyzes individual choice in equilibrium. Section 4 describes the equilibrium and discusses the cross-section and aggregate effect of technical progress. Section 5 presents the cross-section analysis of labor participation and technical progress, while Section 6 reports the time-series aggregate results. Section 7 concludes.

2. The Model

Consider a small open economy in a world with one final good. The final good is produced by a continuum of intermediate goods $i \in [0, 1]$. The production of the final good is described by the following Cobb-Douglas production function:

$$\log y_t = \log z_t + \int_0^1 \log x_{i,t} \, di, \tag{1}$$

where y_t is output of the final good, $x_{i,t}$ are inputs of the intermediate goods, and z_t is a random i.i.d. variable with expectation z. Note that z_t is the transitory element in productivity, which is not driven by technical progress. Time is assumed to be discrete.

The intermediate goods are produced by labor with fixed marginal productivity. The available technology in period t for production of the intermediate good i, enables each worker to produce an amount $a_{i,t}$ in one unit of time. This technology is not freely available to workers and is acquired by training, namely by investing in human capital. Using a technology is therefore a specific profession, for which the individual needs to train before production begins.

We next turn to describe technical progress. In each period new technologies for production of intermediate goods, which replace the old technologies, arrive exogenously.[3] The new technologies are more productive, namely they increase productivity in the following way:

$$a_{i,t} = a_{i,t-1} b_{i,t}, \tag{2}$$

where $b_{i,t}$? 1. Note that the new technologies become operative in period t, but must be known already in period t-1 for workers to learn them. The sector's rate of technical progress is $\log b_{i,t}$.

[3] The creation of innovations is not modeled in the paper, which focuses on adoption only.

We next assume that the rates of technical progress across sectors are correlated. Namely, there are periods of rapid average technical progress, where $\log b_{i,t}$ is high in many sectors, and periods of low average technical progress, where many sectors grow slowly. This assumption is necessary in order to analyze the effect of aggregate technical progress, and it is also supported by our US data. We formalize this assumption by decomposing the sector's rate of technical progress to two components, one that is common to all sectors and the other differs across sectors in the following way:

(3) $$\log b_{i,t} = g_t f_{i,t}.$$

The common component g_t is assumed to be i.i.d. with expectation $g > 0$, and the sector specific component $f_{i,t}$ is assumed to be independent over time and across sectors with expectation 1. Note that it is possible that $f_{i,t}$ is zero across a set of sectors, in case that new innovations arrive only at some sectors. The two shocks are independent of each other.

We next turn to describe workers in this economy. Assume an overlapping generations economy, where individuals live three periods each. They go from young to grownup and then to old. Population is fixed and each generation consists of a mass of individuals of size 1. People study in first period of life and work in second and third periods in life. In the second period of life an individual works 1 unit of time in the profession acquired in first period. In third period of life the old supplies only l units of labor, where: 0 ? l ? 1, namely the old can retire early, as they have disutility from labor in this period of life. In order to keep the analysis within the discrete time framework, we assume that whenever the individual works part time, this time is spread uniformly throughout the period. For the sake of simplicity we also assume that individuals consume in third period of life only. The utility function of each individual is therefore from consumption and leisure when old:

(4) $$u = \log c_3 + v(1 - l),$$

where c_3 is consumption in period 3 and the utility from leisure v is increasing, concave and Inada. The main decisions facing the individual are, therefore, for which profession to train when young, whether to retrain when grownup or work, and how much labor to supply when old.

As mentioned above, the economy is small and open. We assume that the final good is fully traded, while the various types of labor and the intermediate goods are non-traded. Capital is fully mobile and the world interest rate is equal to r.[4] Markets are assumed to be perfectly competitive and expectations are rational. In order to simplify the analysis we further assume that there is no insurance to employment risk.

3. Equilibrium Conditions

The young in the economy choose professions based on their expectations for the future. They already know which new technologies will be used in next period and hence they know the output levels in next period as well. The demand for intermediate good i in period t is given by:

(5) $$p_{i,t} = \frac{\partial y_t}{\partial x_{i,t}} = \frac{y_t}{x_{i,t}}$$

due to Cobb-Douglas production function (1). Prices of all goods are given in terms of the final good, which serves as a numeraire. When the young in period t-1 choose sectors, they equate expected income across all sectors in period t, namely they equate $p_{i,t}a_{i,t}$ across all sectors.[5] This equalization is achieved by changes in $x_{i,t}$ as sectors are chosen. Denote the common income across sectors by w_t and call it the wage rate.

[4] Note that individuals only lend in this economy. Since borrowers are abroad we do not model them, but borrowers could be easily added to the model, either as governments or as firms.

[5] Clearly, workers care about future wages in period t+1 as well, but these are equalized across sectors by the next generation. The effect of new technologies is independent of sector.

We next turn to optimal behavior of the old. Consider an old worker, who has earned income I last period when grown up and who faces a wage w per unit of time when old. Below we specify precisely the values of I and w. An old worker maximizes

(6) $$\log[I(1+r)+wl]+v(1-l)$$

in order to determine the optimal labor supply in third period of life. The first order condition is

(7) $$\frac{1}{v'(1-l)}-l=\frac{1+r}{\frac{w}{I}}=\frac{1+r}{W},$$

where W denotes the ratio between current wage and past income: $W = w/I$. This first order condition determines labor supply as long as $W \geq (1+r)v'(1)$. A corner solution holds if $W < (1+r)v'(1)$ and then the old do not work at all. Namely $(1+r)v'(1)$ is the reservation wage. Individual labor supply of the old therefore depends on the ratio between the current wage rate and past income W:

(8) $$l=l^S\left(\frac{w}{I}\right)=l^S(W).$$

[Insert Figure 1 about here]

Figure 1 describes the individual labor supply in third period of life. Note that it is bounded by l^*, which is defined by: $v'(1-l^*)l^*=1$. As W rises to infinity the slope of the supply curve $l^{S'}(W)$ becomes smaller and approaches zero. Furthermore, as figure 1 shows, it approaches zero more rapidly than $1/W$, namely $l^{S'}(W)W$ falls to zero as W goes to infinity. This leads us to add the following assumption to the model.

Assumption 1: $l^{S'}(W)W$ is decreasing in W.

As shown above this assumption is fairly plausible. It is easy to show that this assumption holds if the elasticity of marginal utility from leisure is 1, namely if: $v(1-l) = \log(1-l)$.

We next turn to determine the equilibrium value of the variable W. As for past income we assume that all workers have worked in period t-1 and have earned w_{t-1}. This assumption is justified below in Lemma 1. In period t all workers producing the same good charge the same price for it. Hence, old workers are faced by competition from younger workers, who use a new more productive technology and charge a lower price for it. As a result, the income or wage of such workers, who use the former technology, is:

(9) $$a_{i,t-1}p_{i,t} = \frac{a_{i,t-1}w_t}{a_{i,t}} = \frac{w_t}{b_{i,t}}$$

and it is lower the higher technical progress is. This is the reason why workers in sectors with a higher rate of technical progress tend to retire earlier. We therefore conclude that W is equal to $w_t/(w_{t-1}b_{i,t})$.

We next calculate the rate of growth of real wage: w_t/w_{t-1}. First, note that:

(10) $$x_{i,t} = \frac{y_t}{p_{i,t}} = a_{i,t}\frac{y_t}{w_t}.$$

Substitute in (1) and get:

(11) $$\log w_t = \log z_t + \int_0^1 \log a_{i,t}\,di.$$

Hence, the change in aggregate wages over time is equal to

(12) $$\log w_t - \log w_{t-1} = \log z_t - \log z_{t-1} + \int_0^1 \log b_{i,t}\,di = \log z_t - \log z_{t-1} + g_t,$$

or

(13) $$\frac{w_t}{w_{t-1}} = \frac{z_t}{z_{t-1}}e^{g_t}.$$

Hence, the rate of growth of wages fluctuates over time with the rate of technical progress g_t and with transitory productivity z_t. The average rate of growth of real wages is g.

We now have all the building blocks of equilibrium and we can calculate the labor supply of older workers. As shown above this depends on W, namely on the ratio of current wage of the old workers to their past income. This ratio is equal to the rate of growth of wages, which is given by (13), deflated by the rate of technical progress in the sector, namely by b_{it}. We can therefore calculate the labor supply of the old in each sector and in the economy as a whole. This is done in the next section. The remainder of this section is devoted to discuss the issue of retraining. In the above analysis we have assumed that grownup workers choose to work in their profession. We assume they do so even if they realize that this profession will become obsolete by a new technology when they become old, and they choose not to learn the new technology. We next turn to analyze this choice and rationalize it.

When a grownup worker realizes that the new technology, which has been invented for his sector, will significantly reduce his income in the next period, he can go to school again, in order to earn more when old. But such a policy is of course costly, as the worker loses income in second period of life. Note that this cost does not deter young individuals, who invest in the new technology in order to use it for a longer period of time. The grownup worker can use it only during a much shorter period and hence is less likely to make the investment. The key element of the model used here is therefore the finite life horizon or career horizon of workers.[6] The returns from investment in human capital are accrued over a finite period of time, and when this period of time is short enough this investment is not profitable. We next introduce a fairly plausible condition under which grownup workers choose not to retrain and learn the new technology.

Assumption 2: Technical progress satisfies the condition: $1+r > e^{\bar{g}}(1-e^{-\bar{g}\bar{f}})\bar{z}/\underline{z}$, where $\bar{g}$ is the upper bound for g_t, $\bar{f}$ is the upper bound of $f_{i,t}$, $\bar{z}$ is the upper bound for z_t and $\underline{z}$ is the lower bound of z_t.

Note that since growth rates are usually lower than interest rates, this assumption is very plausible. We next add assumption 2 to the model and show that under this assumption grownups do not return to school to learn the new technology and prefer to work instead, even if they lose income in third period of life.

Lemma 1: If assumption 2 holds, grownups do not return to school to retrain.

Proof: We show that this condition is sufficient for a stronger result, that utility of going back to school is lower than utility of not going to school at any labor input:

$$\log\left[w_{t-1}(1+r)+\frac{w_t}{b_{i,t}}l\right]+v(1-l)\geq \log(w_t l)+v(1-l)$$

for all l. This is equivalent to:

$$1+r\geq l\frac{w_t}{w_{t-1}}\left(1-\frac{1}{b_{i,t}}\right)=l\frac{z_t}{z_{t-1}}e^{g_t}(1-e^{-g_t f_{i,t}}).$$

This inequality holds under assumption 2.

Q.E.D.

Lemma 1 therefore completes the characterization of the equilibrium in the economy. Young workers choose a profession, work in this profession when grown up and continue when old, even when the income from this profession is smaller. They work less when they are old and

[6]Hence, the OLG model is used for introducing finite career horizons rather than trade frictions.

their labor supply depends on the rate of technical progress, both in their sector and in the economy as a whole. In the next section we examine precisely how.

4. The Effect of Technical Progress on Labor Participation

We next turn to analyze labor supply by the old. From Section 3 we deduce that an old worker in sector *i* in period *t* has the following labor supply:

$$(14) \qquad l^S\left(\frac{w_t}{w_{t-1}b_{i,t}}\right)=l^S\left(\frac{z_t}{z_{t-1}}e^{g_t}e^{-g_t f_{i,t}}\right)=l^S\left(\frac{z_t}{z_{t-1}}e^{g_t(1-f_{i,t})}\right).$$

Note that labor supply is negatively related to $f_{i,t}$, namely that in sectors with high rates of technical progress the supply of labor by the old is low. This is the first main result of the paper and is formally stated in Proposition 1.

<u>Proposition 1</u>: The labor supply of old is negatively correlated across sectors with the rates of technical progress.

We next turn to analyze the correlation between the aggregate rate of technical progress, i.e. g_t, and the aggregate labor supply of the old $L_{t,O}$. Equation (14) shows that technical progress has two different effects on the labor supply of old workers. The first effect is negative due to the erosion of human capital, which reduces wages of old workers and induces them to retire early. When average technical progress is higher, it is also higher in many individual sectors and thus labor supply of the old in these sectors is reduced. This effect is described in equation (14) by the term $e^{-g_t f_{i,t}}$, and we call it the 'erosion effect.' The second effect is positive and is due to the positive effect of average technical progress on the wage rate. This effect is described in equation (14) by the term e^{g_t} and we call it the 'wage effect.' Note that the erosion effect is dominant for sectors with high *f*, namely sectors with high technical progress, while the wage effect is dominant for sectors with low f, namely sectors with low technical progress.

The rate of technical progress therefore has two opposite effects on the rate of labor participation by older workers. A high rate of technical progress brings new innovations with high productivity to some sectors on the one hand, but on the other hand it raises the aggregate real wage. The first effect erodes human capital and reduces labor supply by old in the progressive sectors. The second effect tends to increase labor supply of the old in the other sectors. These are the erosion effect and the wage effect, respectively. A-priori we cannot weigh the two effects and cannot say which is dominant. We next examine under what conditions we can say, which effect dominates.

The aggregate amount of labor supplied by the old is:

$$L_{t,O} = \int_0^{\bar{f}} l^S \left[\frac{z_t}{z_{t-1}} e^{g_t(1-f)} \right] h(f)df \, , \tag{15}$$

where h is the density function of $f_{i,t}$. In this equation we clearly see the two effects of technical progress g_t on labor participation by the old, as it is multiplied by positive and negative values for different values of f. We can now weigh the two effects together.

<u>Proposition 2</u>: The effect of aggregate technical progress on labor participation is zero when g_t is zero. As g_t increases this effect becomes negative if Assumption 1 holds.

<u>Proof</u>: The derivative of labor supply of the old with respect to g_t is equal to:

$$\frac{dL_{t,O}}{dg_t} = \int_0^{\bar{f}} (1-f) l^{S'} \left[\frac{z_t}{z_{t-1}} e^{g_t(1-f)} \right] \frac{z_t}{z_{t-1}} e^{g_t(1-f)} h(f)df \, .$$

In times of no technical change, when g_t=0, we get:

$$\frac{dL_{t,O}}{dg_t} = \int_0^{\bar{f}} (1-f) l^{S'}\left[\frac{z_t}{z_{t-1}}\right]\frac{z_t}{z_{t-1}} h(f)df = 0\,,$$

since the expectation of f is 1. Hence, at low rates of technical progress the effect on labor supply by the old is close to zero.

We next apply assumption 1 that $l^{S'}(W)W$ is decreasing in W and get:

If $f < 1$ then: $(1-f)l^{S'}\left[\frac{z_t}{z_{t-1}} e^{g_t(1-f)}\right]\frac{z_t}{z_{t-1}} e^{g_t(1-\zeta)} < (1-f) l^{S'}\left[\frac{z_t}{z_{t-1}}\right]\frac{z_t}{z_{t-1}}$.

If $f > 1$ then: $(1-f)l^{S'}\left[\frac{z_t}{z_{t-1}} e^{g_t(1-f)}\right]\frac{z_t}{z_{t-1}} e^{g_t(1-\zeta)} < (1-f) l^{S'}\left[\frac{z_t}{z_{t-1}}\right]\frac{z_t}{z_{t-1}}$.

Hence:

$$\frac{dL_{t,O}}{dg_t} < \int_0^{\bar{f}} (1-f) l^{S'}\left[\frac{z_t}{z_{t-1}}\right]\frac{z_t}{z_{t-1}} h(f)df = 0\,.$$

Hence, the effect of technical progress on the aggregate labor supply is negative if the aggregate rate of technical progress is positive.

Q.E.D.

Proposition 2 has two claims. First, it claims that at low rates of technical progress the erosion effect and the wage effect cancel each other and the rate of technical progress has no effect on the aggregate labor supply of the old. Second, it claims that at high rates of technical progress the erosion effect dominates if Assumption 1 holds. As mentioned above, this is a fairly plausible assumption. But it is clear that the issue of which effect dominates, whether the erosion effect or the wage effect, is an empirical issue and should be taken to the data. This is indeed what we do in Section 6.

5. Technical Progress and Early Retirement across Sectors in the US

This section explores the empirical interrelation between technical progress, employment and income of elderly workers across sectors in the US economy. Proposition 1 claims that labor supply of workers, who are close to retirement age, should be negatively correlated with the rate of technical progress in the sector they work in. In other words, we expect to find that individuals in their 50s or early 60s, that are employed in sectors, which have experienced fast technical changes, are less likely to work in the following periods. These non-working individuals are unemployed, temporary out of the labor force, or officially retired.

In the empirical analysis, we also examine effects of other variables, such as age, background, education and profession status, on labor participation of older workers. It is interesting to analyze the interaction of these variables with technical progress, namely to examine which group of workers has a harder time adjusting to technical changes, and which workers are more able to shift to other jobs. Although our formal model does not distinguish between workers within a sector, we expect that managers usually find it easier to adjust to technical changes than production workers, since their job is less technology specific. Hence, we expect labor supply of managers to be less negatively affected by technical progress.

The data source we use for labor participation is the Health and Retirement Survey (HRS). This data set contains detailed information on individuals of age 50 and above, including retrospective responses to questions on their job and career histories in the 10 years prior to the survey. The HRS has a total of 12,652 individual records. We restrict ourselves to men who were between the age of 50 to 64 in 1992, due to data limitations, and hence end up with 5,196 observations. About 69 percent of the men worked in 1992, and 15 percent defined themselves as retired. In 1994, 64 percent worked and 19 percent were retired. As expected, labor force participation is sensitive to age, whereas in the early 50s the rate is above 80 percent, and it drops down to below 50 percent over the age of 62. Using the retrospective questionnaire, we mark the economic sector and profession in the present and in past jobs of each individual. Our final sample that includes all respondents, who report on their job histories, includes 5,085 individuals.

Our data source for technical progress across sectors is Jorgenson's measure of productivity growth for 35 economic sectors, which is taken from Jorgenson (2000).[7] We are fully aware that this TFP growth measure consists of many fluctuations in productivity in addition to technical progress. We take care of this problem in two main ways. First, we calculate for each sector a five-year average of TFP growth, which smoothes much of the temporary fluctuations.[8] Second, we compare sectors in a similar period of time, where they differ only in their respective rates of technical progress. We implicitly assume here that transitory productivity shocks are common to all sectors, namely are cyclical in nature. Our data set indeed reveals considerable fluctuations in TFP growth, both over time and across sectors. Thus, for example, durable manufacturing and transportation exhibited the fastest growth between 1970 and 1991, while repair services and entertainment had negative TFP growth.

In the empirical analysis we merge the information on individual labor market experience from HRS with Jorgensen's data on TFP growth across sectors. Similar to Bartel and Sicherman (1993 and 1999), we match the reported employment sector of each respondent in the HRS sample to five-year averages of TFP growth in that sector. Using this joint data set, we run regressions of individual's outcomes (both employment status and log wage) in which the average TFP growth rate of the corresponding sector is one of the explanatory variables.

[7]Bartel and Sicherman (1999) compare six indicators that have been used by researchers as proxies for technical progress. We use Jorgenson's measure because his data set is the only one that contains all economic sectors, so that we can match sectors to all respondents, who have ever worked.

[8]We also use 3 and 10 years averages of TFP growth in our regressions and the results are similar.

The results of our estimations are presented in Table 1. We present only results based on cross-section estimations.[9] The main result reported in Table 1 is quite striking. The coefficients on TFP growth are positive in the wage regressions (columns 1 and 2), while the coefficients on TFP growth in the employment and retirement regressions are negative (columns 2-4). From this we infer that productivity growth increases wage rates of older workers who were able to keep their positions. At the same time, however, many older workers in these industries are *pushed* into early retirement, or other statuses of non-employment. The magnitudes of these effects are surprisingly strong, one- percent increase in TFP increases the average wage rate by 3.6 percent and decreases employment by 3.5 percent.

[Insert Table about 1 here]

To check robustness of the results, we run several additional specifications of each model.[10] Thus for example, one specification deals with an alternative interpretation of our results. In times of declining demand firms tend to lay off workers, mainly the least productive ones. This tends to increase TFP, as firms become more efficient. This mechanism also leads to positive correlation between TFP and labor force participation, especially of older workers. To examine this possible interpretation, we add to regressions 2 and 4 the variable 'output growth' to control for this type of demand shift. The result is that output growth has no effect on older workers' employment and wages, while the effect of TFP growth is almost the same as in regressions 1 and 3.

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[9]The estimates of panel data regressions for the years 92, 94 and 96, that control for unobserved heterogeneity and self-selection have basically very similar results.

[10]The specifications include: (1) Heckman-Two-Stage (controlling for self-selection); (2) regressions with income and employment status in 1994; and (3) using a sample of respondents that are over the age of 55. In all these experiments the main results are similar, namely the coefficient of TFP growth is positive in the wage regressions and negative in the employment regressions.

Other interesting results from our cross-section regressions are with respect to schooling. We find that return to schooling is about 4.5 percent, with no additional return to college degree. Years of schooling have no effect on employment, but educated men retire earlier, implying that this group has a higher reservation wage, maybe because they have saved more in the past. The above results do not allow us to conclude whether older educated workers adjust to technological progress better or worse than the less educated. This is in contrast to young workers, who differ by education clusters as reported by Bartel and Sicherman (1999).

Another result, which is in line with the relevant literature, is that bad health has a strong negative effect on labor participation, whereas it reduces earning by about 20 percent. Marital status has a positive effect on income due to combined effects. Married men earn by 20 percent more than unmarried men, and they work more as well. The Black and Hispanic minorities manage badly in the labor markets. Blacks have harder time finding jobs, and both groups have relatively low earnings, whereas Blacks earn about 10 percent less than whites and Hispanics 13 percent less.

6. The Effect of Aggregate Technical Progress in the US

This section examines the relationship between the average rate of technical progress and the aggregate rate of labor participation of older workers. While Section 5 provides cross sectional evidence on the erosion effect, this section examines how strong this erosion effect is in the economy as a whole, by weighing it against the wage effect. For that we need to test the relationship over time between the labor participation rate of older workers and the rate of technical progress. We know from Proposition 2, that under plausible conditions on the supply function of labor (Assumption 1) this relationship is should be negative, namely the erosion effect should dominate. The problem in empirically testing this hypothesis is that, while we have data on aggregate Labor Force Participation (LFP) of older workers, we cannot observe technical progress. All we have are observations on Total Factor Productivity (TFP). The latter consists of two components: technical progress, which is g_t in the model, and transitory changes in productivity, which are z_t in the model. In order to break up the rate of total productivity growth between these two components, we apply the Blanchard and Quah (1989) method of Structural VAR.

Before applying the Structural VAR model, we present the available data and the main relationships between the variables. We examine two main variables, the rate of Growth of Total Factor Productivity (GTFP) and the rate of Growth of Labor Force Participation of Older workers (GLFPO). We calculate the series of GTFP by using Jorgenson (2000) and Jorgenson and Stiroh (1999) US annual data from 1948-1996, and construct the series of GLFPO for the same years by using data from the Bureau of Labor Statistics (2000). The series of GLFPO is calculated by taking logarithm changes of LFP rates of men between the ages 55-64. During the sample period, the index of TFP has increased from 0.89 to 1.34, at an average annual rate of 0.7 percent. Labor force participation of all working-age men (age 16-64) has decreased from 78.5 to 70.5 percent, where most of this decline is due to reduction in participation of older men, which has dropped from 86.7 percent to 62.6 percent.

[Insert Figures 2-A and 2-B here]

A simple analysis of the data reveals interesting relationships between labor force participation rates and productivity changes. The correlation between GLFP for all working-age men (ages 16-64) and GTFP in the US from 1948 to 1996 is 0.3, while the same correlation for older men, namely between GLFPO and GTFP is only 0.04. These relationships are also manifested in Figures 2-A and 2-B, which display series of annual changes of LFP of men of age 16-64, of men age 55-64, and of GTFP. The figures show, similar to the simple unconditional correlation, that GLFP of all men and GTFP are positively correlated, while GLFPO and GTFP are not correlated. This probably reflects the wage effect, which is especially strong for young workers. In particular, Figure 2-B shows that in years with high GTFP (above 1.5%), the rate of GLFPO tends to be below 1%. In addition, combining facts from both figures show that changes in labor force participation rates of all men and of older men did not coincide, which suggests substitution between young and old.

We next turn to describe the Structural VAR model we use to separate technical changes from transitory changes in productivity growth. Assume, as in the theoretical model, that the two observed variables, namely the rate of Growth of Total Factor Productivity (GTFP) and the rate of Growth of Labor Force Participation of Older workers (GLFPO) are both functions of two disturbances: ε_{1t} and ε_{2t}. The first disturbance is the rate of transitory changes in productivity and is similar to z_t / z_{t-1} in the theoretical model. The second disturbance is the rate of technical progress, and is similar to the g_t shock from the model. Hence, the joint process followed by GTFP and GLFPO follows the following stationary process:

(16) $$\begin{bmatrix} GTFP_t \\ GLFPO_t \end{bmatrix} = \begin{bmatrix} C_{11}(L) \; C_{12}(L) \\ C_{21}(L) \; C_{22}(L) \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$$

where ε_{1t} and ε_{2t} are assumed to be independent white-noise disturbances with constant variances, and the C(L)'s are polynomials in the lag operator L.

Since the model is stationary we can estimate a reduced form VAR representation of the form:

(17) $$\begin{bmatrix} GTFP_t \\ GLFPO_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) \; A_{12}(L) \\ A_{21}(L) \; A_{22}(L) \end{bmatrix} \begin{bmatrix} GTFP_{t-1} \\ GLFPO_{t-1} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \end{bmatrix}$$

where A(L) is the matrix of the coefficients estimated, and e_{1t} and e_{2t} are the VAR residuals. We next use the Blanchard and Quah (1989) method to recover the ε's and the C(L)'s from this VAR estimation, by use of the identifying restriction that only technical progress shocks have a permanent effect on total factor productivity, while transitory productivity shocks have a temporary effect.

In order to use this method we first test the crucial assumption, that both variables originate from stationary processes, by using the Dickey-Fuller test. We reject the null hypothesis of a unit root for each of the two variables (at 1-percent significance level), empirically motivating the VAR specification of equation (16) and (17). Second, we estimate several specifications of lags, and find that AR(2) fits the data better than other specifications. The properties of the VAR and the moving average representation, which is calculated by direct inversion of A(L), do not have important economic meaning for our model, so they are not discussed here.[11]

[Insert Figures 3-A and 3-B here]

Figures 3-A and 3-B display two representations of the dynamic responses of labor force participation of older workers to technical progress. Figure 3-A displays the Impulse Response Function of GLFPO to a unit change at period zero in ε_{2t}. In response to a positive technology shock of one percent, GLFPO experiences an immediate decrease of 0.6 percent. After two periods, the growth rate stabilizes slowly and converges to zero after 6-7 periods. We therefore see that according to this empirical test the erosion effect is strong enough and it dominates the wage effect. Hence, the US data that we employ supports the result of Proposition 2 - positive technological shocks reduce aggregate labor participation rates of older workers.[12]

The empirical results support the theoretical model on the time horizon as well. The model predicts that technical progress reduces labor force participation of the old temporarily,

[11] They can be provided upon request.

[12] It is interesting to note that some recent studies on business cycles have found that technological shocks have a negative effect on employment in general. Recent examples are Baumol and Wolff (1996) and Gali (1999), who also cites similar results by Blanchard (1989), Blanchard and Quah (1989), and Cooley and Dwyer (1995).

where the relevant unit of time is half the length of a career. Indeed, the empirical analysis suggests that technical progress reduces labor force participation for a long period of time. Figure 3-B illustrates this result, by displaying the effect of a one-period one-percent shock of ε_2 in 1949 on the labor force participation rates of men ages 55-64 during the next 15 years. The upper line in the figure displays the actual rates, while the lower line displays the calculated series. The calculation includes an adjustment for entry of new men to the 55-64 age group every year. As in Figure 3-A, the shock has an immediate negative effect. However, in the following years the rates of LFPO continue to remain lower by almost the same size and the two lines meet only after more than twenty years. For example, a unit technology shock in 1949 would have reduced the 1955's LFP of men age 55-64 by 0.7 percentage points (from 84.2 to 83.5), by 0.5 in 1960, and by 0.3 percentage points in 1965 (from 81.9 to 81.6). Thus, the negative effect of aggregate technology shocks on LFPO withstood for a long period.

This result might add an explanation to the observed decline in LFP of older workers in recent decades, in addition to the explanation of increased social security coverage, as in Diamond and Gruber (1999). During the sample period, TFP increased by 45 percentage points, from 0.89 to 1.34, and LFP of older men decreased by 24 percentage points, from 86.7 to 62.6. Our results suggest that a sequence of positive technology shocks may have contributed to this decline in LFP of men ages 55-64.

7. Conclusions

This paper combines together two distinct lines of research from two different areas in economics. One area is the study of technical progress, which is usually related to the study of economic growth and productivity, and the other area is labor participation of older workers, which is an important issue in labor economics. We combine these two areas together by showing that technical progress has a substantial negative effect on labor participation rates of older workers, as it has an erosion effect on technology specific human capital of such workers. We describe this effect by a simple growth model with finite career horizons and then test for this effect across sectors in the US, where we find that indeed a substantial negative effect.

Our model also enables us to analyze the aggregate effect of technical progress on labor participation of older workers. We find two opposite effects: a negative effect due to the erosion of technology specific human capital and a positive effect due to higher wages in times of technical progress. Using US data, we find that in the years 1950-1996 the erosion effect has dominated the wage effect, namely that years of high technical progress were characterized by low labor force participation of older workers.

The paper presents a contribution both to studies of technical progress and to studies of labor market performance of older workers. Technical progress has long been viewed as the most important driving force of global economic growth in the recent two centuries. While there is much research on how technological innovations are created and disseminated around the world, there has been relatively little discussion of the costs involved in adoption of technological innovations. This paper describes one such specific cost, namely erosion of technology specific human capital, and its negative effect on labor force participation. The literature on labor force participation of older workers is vast and extensive. But this literature focuses mainly on issues like health, social security, pension funds, health insurance and similar institutions. This paper adds an additional important variable, which affects early retirement of workers: technical progress. It describes this effect in a theoretical model and tests it empirically both across sectors and over time.

As we stress in the paper, the erosion of technology specific human capital affects mostly older workers, since their career horizon is shorter than that of younger workers. But if we could reduce the cost of retraining, namely of learning the new technology, it could also reduce the negative effect of technical progress on labor of older workers. Hence, the effect we describe in the paper depends crucially on the ability of the educational or training system to supply retraining in new technologies. This opens interesting topics for future research. Can differences in educational and training systems explain international differences in the reaction of labor to new technologies? Do institutional arrangements of retraining, on the job or out of job, have an effect on labor force fluctuations? Are there policy implications?

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Table 1: Estimates from Wage and Employment Equations

Variables	(1) Log Annual Earning	(2) Log Annual Earning	(3) Employment Status	(4) Employment Status	(5) Retirement Status
TFP growth	2.321	2.216	-8.200	-8.168	11.479
	(0.401)**	(0.411)**	(1.412)**	(1.412)**	(1.740)**
Age	0.022	0.018	1.516	1.517	-1.260
	(0.121)	(0.121)	(0.319)**	(0.319)**	(0.380)**
Age-square	-0.001	-0.001	-0.015	-0.015	0.013
	(0.001)	(0.001)	(0.003)**	(0.003)**	(0.003)**
Black	-0.100	-0.104	-0.285	-0.288	0.190
	(0.043)*	(0.043)*	(0.110)**	(0.110)**	(0.135)
Hispanic	-0.131	-0.136	-0.076	-0.076	-0.280
	(0.061)*	(0.062)*	(0.168)	(0.168)	(0.223)
Foreign born	-0.073	-0.071	0.207	0.207	-0.397
	(0.054)	(0.054)	(0.162)	(0.162)	(0.206)*
Currently married	0.194	0.196	0.459	0.459	0.292
	(0.038)**	(0.038)**	(0.102)**	(0.102)**	(0.138)*
Years of schooling	0.045	0.044	0.017	0.017	0.112
	(0.007)**	(0.007)**	(0.016)	(0.016)	(0.022)**
College degree	-0.020	-0.027	0.191	0.188	-0.191
	(0.045)	(0.046)	(0.133)	(0.133)	(0.147)
Regions:					
central	-0.132	-0.130	0.117	0.119	0.187
	(0.043)**	(0.043)**	(0.124)	(0.124)	(0.142)
south-east	-0.224	-0.223	0.135	0.137	0.219
	(0.040)**	(0.040)**	(0.113)	(0.113)	(0.133)*
pacific	-0.090	-0.088	-0.131	-0.131	0.389
	(0.048)	(0.049)	(0.138)	(0.138)	(0.158)**
Bad health	-0.204	-0.202	-1.725	-1.725	0.319
	(0.042)**	(0.042)**	(0.089)**	(0.089)**	(0.112)**
High-status profession	0.477	0.471	-0.077	-0.083	-0.088
	(0.035)**	(0.035)**	(0.105)	(0.106)	(0.115)
Output growth		0.728		1.031	1.596
		(0.649)		(1.826)	(2.062)
Constant	9.324	9.412	-37.58	-37.635	25.489
	(3.398)**	(3.399)**	(9.089)**	(9.091)**	(10.933)**
No. of Observations	3,268	3,268	4,629	4,629	4,629
R^2	0.201	0.201			

Notes: Standard errors in parentheses; * significant at 5% level; ** significant at 1% level

Figures

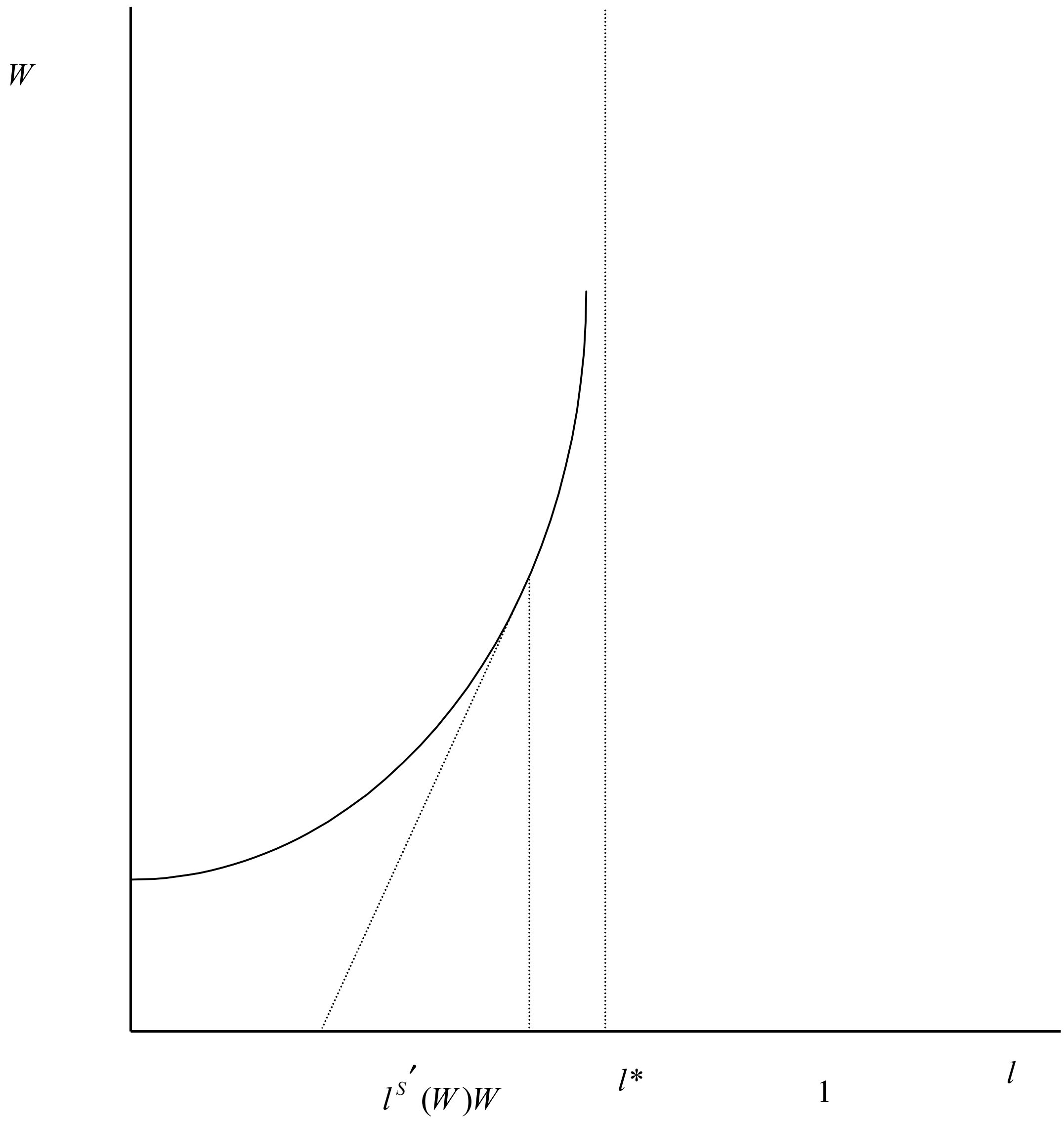

Figure 1

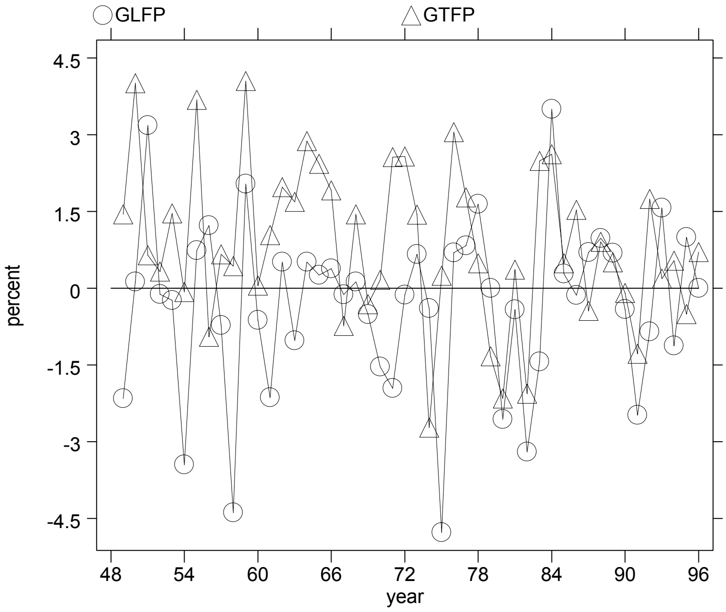

Figure 2-A

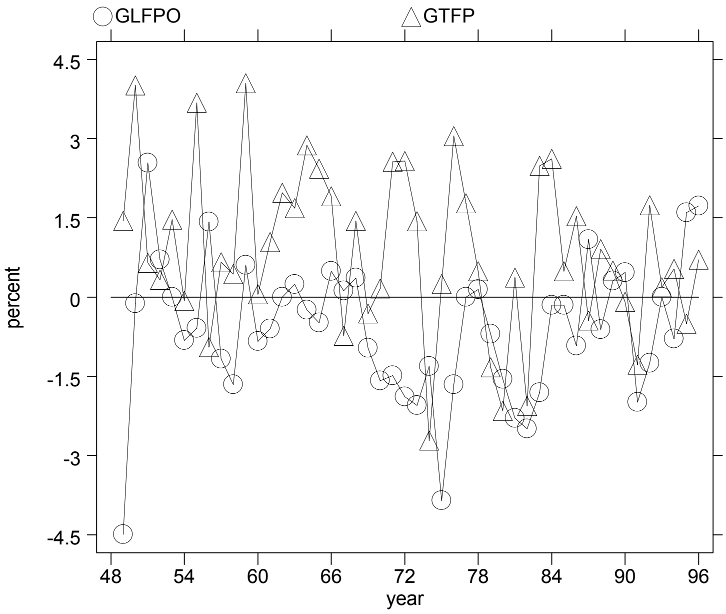

Figure 2-B

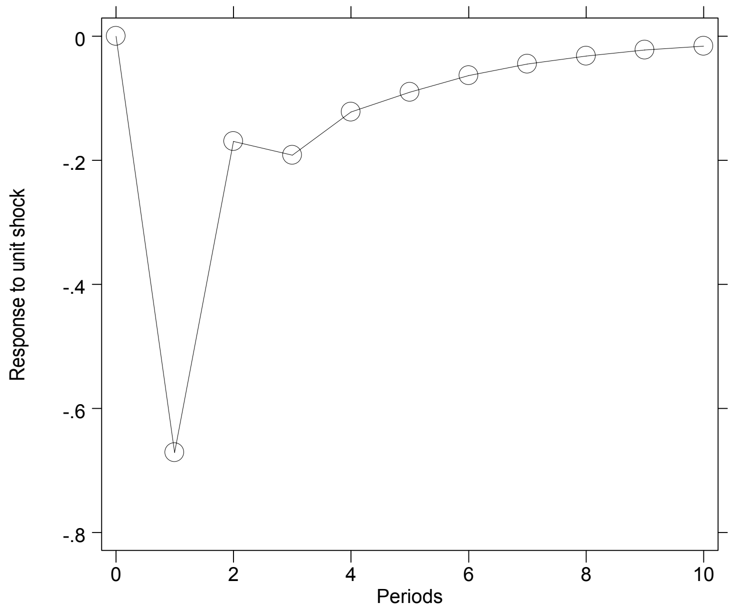

Figure 3-A

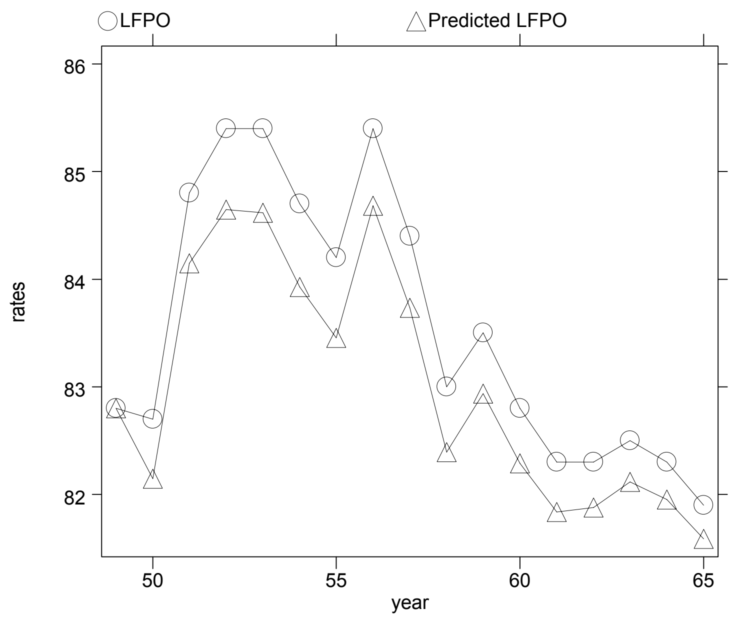

Figure 3-B