Discussion Papers In Economics And Business

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The aging labor and ICT imbalance

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February 2009

この研究は「大学院経済学研究科・経済学部記念事業」
基金より援助を受けた、記して感謝する。

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Abstract

The purpose of this paper is to investigate what decreases TFP, why TFP has decreased in some countries and how large the decreases of TFP are. We focus on the quality of labor and capital inputs and use cross country data for the manufacturing industries of some OECD countries. We provide a comprehensive empirical investigation based on two hypotheses, substitutability and complementarity of labor input age and skill categories. Further, we provide an aging index, which tells how much the share of ICT capital should be increased to counterbalance decreases of TFP caused by the aging of the labor input.

Keywords: TFP; quality of labor and capital, substitutability and complementarity of age and skill groups, aging index
JEL Classification Number: O11; J00;J80;O40

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Earlier versions of this paper were presented at the seminars in Tohoku University and Osaka University. We are very grateful toYoshiro Tsutsui, Mototsugu Fukushige, Hiroshi Yoshida and participants at the seminars for their helpful comments. The research of the first author was supported by Grant-in-Aid 20530271 from the Ministry of Education, Culture, Sport, Science and Technology of Japan.

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1. Introduction

As empirically found by Lebow (1993), Sbordone (1996) and Basu and Fernand (2001), among others, the Total Factor Productivity (TFP) accounts for a large percent of growth within economies and behaves pro-cyclically in a business cycles. The TFP is often seen as the real driver of growth within an economy. Basu and Fernand (2001) provide four channels from the TFP to the business cycle which lead to pro-cyclical productivity: technology fluctuation that affect both productivity and output; increasing returns and imperfect competition that cause productivity to increase with an increase in inputs; variation of utilization rate of inputs over the business cycle; and reallocation of resources between sectors or firms with different productivities. In (at least some) of the channels the TFP changes are exogenous shocks for the business cycle.

The next logical step is to investigate what causes the TFP changes and why the TFP has decreased in some countries. Since Japan has experienced a long period of slow growth, it serves as a good example of attempts to explain the productivity slowdown. Hayashi and Prescott (2002) found that the low TFP accounts well for the Japanese lost decade of growth, and conjectured that the low TFP growth was the result of a policy that subsidized inefficient firms and declining industries. This policy resulted in lower TFP because the inefficient producers produce a greater share of the output. Though many other papers have mentioned the TFP decrease in the business slump, they have not investigated what decreased it. Exceptions are Nishimura et.al. (2005), who found that efficient firms in terms of TFP exited while inefficient ones survived, implying that the natural selection mechanism of economic Darwinism is not working properly. Further, this phenomenon is observed mainly for new entrants and contributes substantially to a fall in macro TFP after 1996. The work of Fukao, et.al (2005) is in the same strand. They focused on the aggregation aspect of the production function. Caballero et al. (2008) argue that bank credits to insolvent borrowers depressed job creation and destruction and led to lower productivity. Jorgenson and Motohashi (2005), Jorgenson and Nomura (2005), and Hayashi and Nomura (2005) mostly expand a single-sector growth model of Hayashi and Prescott to a multi-sector model, focusing on the relationships between information technology, labor input and the TFP through the price mechanism. They did not include the idiosyncratic characters like aging and skill levels directly into the physical inputs of labor and capital, and did not estimate the effect of each factor on the TFP. This alternative aspect is one of determinants for the TFP but has not been analyzed yet. The quality of labor as a determinant of productivity has been suggested in the micro context by Griliches (1967) and Hellerstein and Neumark (Hellerstein et al., 1999, Hellerstein and Neumark, 1999), among others.

The purpose of this paper is to investigate what decreases the TFP, why the TFP has decreased in some countries and how the TFP can decrease through aging. We focus on the quality of labor and capital inputs, and incorporate the aging of the physical labor input and the information technology component of the physical capital input in the framework used by Hellerstein et al. (1999) and Ilmakunnas and Maliranta (2005). We then can identify the effect of each labor characteristic on the TFP, while we have no growth theory basis used by the previous researches. We also provide a comprehensive investigation based on two hypotheses of the relationship between workers of different ages and skills, substitutability and complementarity, by using cross country data. This is different from the literature on worker characteristics and productivity, where perfect substitutability of labor categories is assumed and the analysis is conducted with single country micro data. We finally suggest a new measure, the Aging Index, to measure how much of the decrease of the TFP can be attributed to the aging of the labor input. We use cross country data for the manufacturing industries of some OECD countries.

We find that (i) Based on the perfect substitutability hypothesis among age groups, the low TFP is related to the aging of the labor input and to insufficient information technology content in the capital input. The aging of the labor input improves productivity only in the low skilled labor category, but contributes negatively to productivity in the medium to high skilled labor category. However, the total labor effect has still been positive in all of the countries examined. Due to the imbalances of the effects of aging and ICT (Information and Communication Technology), the TFP has since 1990 increased in Austria, Finland, Netherlands, and USA, while it has stagnated or decreased in Australia, Denmark, and Japan. (ii) Based on the complementarity hypothesis among the age groups, the increased share of the old workers has improved the productivity of the young and mid-aged workers in the low skilled labor category, while it has had no effect in the medium to high skilled group. The aging process has had positive effects in the low-skilled labor group in Japan and Finland, consistent with the results based on the perfect substitutability hypothesis. However, the test results for both hypotheses support the complementarity hypothesis in the low-skilled labor group and the perfect substitutability one in the medium to high skilled labor group, respectively. (iii) Both countries with a low value of the Aging Index (Finland and USA) and with a high value of the index (Austria, Netherland and UK) have successfully increased the share of the ICT to overcome the aging problem. Exceptions are Japan, Australia and Denmark.

With these findings we provide a new explanation of a low TFP, which differs from the previous viewpoints suggested in the literature. Moreover, we provide an empirical study of why the TFP has stagnated or increased in some countries, based on the idiosyncratic feature in aging labor and ICT imbalance.

This paper is organized as follows. In Section 2, we sketch the model. In Section 3, we investigate what cause the low TFP, by using OECD panel data. In Section 4, we empirically investigate why TFP has decreased in some countries. In Section 5 we provide the analysis based on the complementarity hypothesis. In Section 6, we propose the Aging Index reflecting the aging of the labor input and using the index we investigate which countries are in a serious aging problem. Finally, in Section 7, we provide concluding remarks.

2. Production Function: quality adjusted labor and capital input

We can formulate a Cobb–Douglas production function with capital and labor inputs:

$$Y = AK^{\alpha}L^{\beta} = A_0 \exp(\gamma_t t) K^{\alpha} L^{\beta} \tag{1}$$

Where the trend γ_t is allowed to vary over time and A_0 is constant over time. The TFP is defined as output unexplained by inputs, i.e., described as follows:

$$\ln(TFP) \equiv \ln(Y) - \alpha \ln(K) - \beta \ln(L) = \ln(A_0) + \gamma_t t \qquad (2)$$

The TFP change can be explained by the changing time trend γ_t. However, this formulation cannot tell what kinds of economic factors affect the TFP change. In what follows, we investigate whether this kind of factors can be found in the characteristics of the labor and capital inputs.

The productivity varies by worker characteristics like age and skills. These can be included in the production function in several alternative ways. One alternative, which dates back at least to Griliches (1967) and has more recently been popularized by Hellerstein and Neumark (Hellerstein et al., 1999, Hellerstein and Neumark, 1999) is based on the shares of different types of employees.[1] It starts from the assumption that different types of employees are perfect substitutes (we call this assumption "substitutability hypothesis"), but may have different marginal productivities. Using age groups among the low-skilled as an example, divide workers to two categories (e.g. young (y) and old (o)) with employment shares s_{ly} (=L_{ly}/L_l) and s_{lo} (=L_{lo}/L_l) where L_l is a total low-skilled labor input (hours or number of employees). The group y's and o's productivities equal to ϕ_{ly} and ϕ_{lo}, respectively. Then, the total low-skilled labor input, considering the productivity difference, is $L_l^* = \phi_{ly} s_{ly} L_l + \phi_{lo} s_{lo} L_l$. If we take group y as the base group, the relative productivity of group o is measured by a parameter $\hat{\phi}_{lo} = \phi_{lo} / \phi_{ly}$ and

$$L_l^* = L_l \phi_{ly} (s_{ly} + \hat{\phi}_{lo} s_{lo}) = L_l \phi_{ly} (1 + (\hat{\phi}_{lo} - 1) s_{lo}) . \qquad (3)$$

Here L is the quantity and $\phi_{ly}(1 + (\hat{\phi}_{lo} - 1)s_{lo})$ is the quality of low-skilled labor. The relative increase in productivity when we go from the reference group y to group o is denoted $\hat{\phi}_{lo} - 1$. The term $\ln(L_l^*)$ could be used as a variable in a logarithmic production function, but the model would have to be estimated using non-linear methods. The approach of Ilmakunnas and Maliranta (2005), among others, is to simplify estimation by using first-order Taylor expansion around $(\hat{\phi}_{lo} - 1)s_{lo} = 0$,

$$\ln\left[1 + (\hat{\phi}_{lo} - 1)s_{lo})\right] \approx (\hat{\phi}_{lo} - 1)s_{lo} \qquad (4)$$

This gives the share of workers in a group directly as a variable in a log-form production function. The approximation is reasonable unless the relative productivity (of

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[1] Related work in the macro growth literature includes Lindh and Malmberg (1999) where GDP growth is explained by the shares of population age groups. The relationship between the quality of labor and the productivity can be analyzed also in other ways, for example using averages of worker characteristics (average age, average education years, etc.), as in Ilmakunnas, et.al. (2004). Some other forms in which human capital or more specifically education can be included in a production function has been discussed also in the growth literature (Temple, 2001).

the old in this example) is very high and at the same time the labor share is high. When the approximation (4) is used in a Cobb–Douglas production function $Y = AK^{\alpha} L^{*\beta}$, the estimated model is described as follows, in the case of two work characteristics *j* (low-skilled (l) and high (h) skilled workers) and three possible age groups *n* (=young (y), mid-aged (m), old(o))

$$\ln(Y) = \theta + \alpha \ln(K) + \beta_l \ln(L_l) + \beta_h \ln(L_h) + \phi^*_{lm} s_{lm} + \phi^*_{lo} s_{lo} + \phi^*_{hm} s_{hm} + \phi^*_{ho} s_{ho} \quad (5)$$

where L_l and L_h are low-skill and high-skill labor inputs, respectively, $\theta = \ln(A) + \beta_l \ln(\phi_{ly}) + \beta_h \ln(\phi_{hy})$, $A \equiv A_0 \exp(\gamma_t t)$, and $\phi^*_{jn} = \beta_j (\hat{\phi}_{jn} - 1)$.

The productivity also varies by capital characteristics like vintage, the high-tech (e.g. information technology) content of the capital input, etc.. These characteristics can be included in the production function in several alternative ways, while it is very difficult to obtain the necessary data. The vintage capital was a main alternative for that, used by Mizon (1974), Malcomson and Prior (1979) and Mcintosh (1986), among others. However, the accounting value for capital based on the constant capital depreciation already reflects the vintage. There are also other problems. As pointed out by Caballero (1999), Cummins and Violante (2002), and Mukoyama (2008), the acceleration of investment-specific technological progress can distort the measurement of the aggregate capital stock. Accordingly, Mukoyama (2008) writes:

"Many economists reported an acceleration of investment-specific technological progress in the late 1970s. In a recent paper, Cummins and Violante (2002) argued that during this period, investment-specific technological progress accelerated from an annual rate of 3% to 5%. Our analysis shows that this acceleration can cause a large change in the rate of replacement. As a result, with the conventional measurement of capital (the perpetual inventory method with constant depreciation), the aggregate capital stock is overestimated. This bias has an important consequence in measuring total factor productivity (TFP). In the usual growth accounting exercise, the growth rate of TFP is measured as output growth minus the contribution of the growth in capital and labor. When the existing amount of capital stock is overestimated, the contribution of capital accumulation is overstated. Therefore, the growth rate of TFP is underestimated." (Mukyoma, 2008, p.514).

Following this suggestion, we use for the capital input the same kind of formulation as was used for the labor input in (3), with ICT capital and other capital as different categories. Then, we can revise a Cobb–Douglas production function as $Y = AK^{*\alpha} L^{*\beta}$, and the estimated model is in the case of 2 worker skill characteristics in 3 age groups and 1 capital characteristic in 2 groups (Information and Communication Technology (ICT), and Non-IC Technology (NICT))

$$\begin{aligned} &\ln(Y) = \theta + \alpha \ln(K) + \psi^*_{ICT} q_{ICT} \\ &+ \beta_l \ln(L_l) + \beta_h \ln(L_h) + \phi^*_{lm} s_{lm} + \phi^*_{lo} s_{lo} + \phi^*_{hm} s_{hm} + \phi^*_{ho} s_{ho} + \varepsilon_0 \end{aligned} \quad (6)$$

where $\theta = \ln(A_0 \exp(\gamma_t t)) + \alpha \ln(\psi_{NICT}) + \beta_l \ln(\phi_{ly}) + \beta_h \ln(\phi_{hy})$ and ψ_{NICT} is the productivity for NICT, $\psi^*_{ICT} = \alpha(\psi_{ICT} - 1)$ and $q_{ICT} = K_{ICT} / K$. We have also added an error term to account for stochastic shocks and left-out variables. If the production function (6) is true, the TFP defined in (2) can be expressed as:

$$\begin{aligned}\ln(TFP) &= \ln(Y) - \alpha\ln(K) + \beta_l \ln(L_l) - \beta_h \ln(L_h) \\ &= \ln(A_0) + \alpha\ln(\psi_{NICT}) + \beta_l \ln(\phi_{ly}) + \beta_h \ln(\phi_{hy}) + \gamma_t t \\ &\quad + \psi^*_{ICT} q_{ICT} + \phi^*_{lm} s_{lm} + \phi^*_{lo} s_{lo} + \phi^*_{hm} s_{hm} + \phi^*_{ho} s_{ho} + \varepsilon_0\end{aligned} \tag{7}$$

TFP can now be explained by the quality of labor (age/skill group shares) and quality of capital (ICT capital share), and the time effect $\gamma_t t$. The time effect has no economic meaning, while it is a proxy for the other economic variables except for the quality of the labor and the capital. In practice we will model the time effect with year dummy variables.

To calculate the TFP, we proceed as follows. First, by using (6), we estimate the parameters of the production function and by checking the significance of the estimated parameters we investigate what affects the TFP and why the TFP has decreased in some countries. In addition, by using (7), we investigate how much the manufacturing TFP change is correlated with manufacturing value added growth country by country. Second, we provide an alternative production function based on the complementarity hypothesis of labor age categories, thereby relaxing the perfect substitutability assumption used in (6).

3. Influential economic factors on TFP

Cross-country data

In the cross-country analysis we use data that are from the EU-KLEMS data base.[2] Since we are interested in the characteristics of the labor and capital input, we include countries for which the division of the labor input to different age/skill-combinations and information on ICT capital are available. Further, we require that the data are available for a long time period. With these restrictions we end up with data on the aggregate manufacturing of the following eight OECD countries: Australia, Austria, Denmark, Finland, Japan, Netherland, UK and USA.[3] Some of the data are available for the period

[2] EU KLEMS Growth and Productivity Accounts: March 2008 Release, available at www.euklems.net.

[3] In addition to these countries, both the labor input file (which includes the information on age/skill shares) and the capital input file (which has information on ICT capital) were at the time of writing this paper available for Czech Republic, Germany, Italy, Korea, and Slovenia. We dropped Czech Republic and Slovenia because of the short time periods (from 1995 only), Germany because of the break caused by German unification, and Italy because the skill shares deviate so much from the other countries and show very little variation over time that the classifications are most likely different. In addition, since Korea has experienced a quite drastic growth, the time series cannot be regarded as representative of the whole period. When we include Czech Republic, Germany, Italy, Korea, and Slovenia in the analysis, the main conclusions are similar but some results are not significant.

1970-2005, but because of missing information on labor characteristics or ICT the period is shorter for most of the countries.[4]

We measure output with the volume index of value added, labor input with total hours worked, and capital input with real fixed capital stock. All of these variables are measured in real terms, and since country differences in levels can be accounted for by country dummy variables, we need not convert the variables to common currency. The labor characteristics are measured by the shares in total hours worked of the following age/skill-combinations: there are three skill types, low-skilled (35% of labor hours in the pooled data), medium-skilled (56%) and high-skilled (9%), and within each skill category the employees are divided to the young (15-29 year olds), mid-aged (30-49 year olds), and old (50 years and over). Since the share of high-skilled category is minor, we unify medium-skilled and high-skilled and create a new category, called 'medhigh-skilled' (65%). There are hence two skill characteristics divided to three age groups.[5] That is, their shares are s_{lm} for the mid-aged and s_{lo} for the old-aged among the low-skilled and s_{hm} for the mid-aged and s_{ho} for the old among the medhigh-skilled in eq. (6). The reference groups are the young low-skilled and young medhigh-skilled. As to capital input, we use information on the share of ICT capital in the total capital stock as the capital input characteristic. ICT includes computing equipment, communications equipment, and software. There is therefore one capital characteristic divided to two groups (i.e., ICT and NICT) in eq. (6) where the share of ICT is q_{ICT}.

Production function estimation and analysis of what affects the TFP

Table 1 shows the estimated production function for the country panel on manufacturing by using (6). To allow for technological differences, we let the coefficient of the ICT share vary by country, using Japan as the reference country.[6]

First, we estimate the production function by including country and year dummy variables as follows:

$$\begin{aligned}\ln(Y)_{CY} &= \lambda + \alpha \ln(K)_{CY} + + \beta_l \ln(L_l)_{CY} + \beta_h \ln(L_h)_{CY} \\ &+ \psi^*_{ICT} q_{ICT} + \Sigma_C \delta_C q_{ICT} CD_C + \phi^*_{lm} s_{lm} + \phi^*_{lo} s_{lo} + \phi^*_{hm} s_{hm} + \phi^*_{ho} s_{ho} \\ &+ \Sigma_C \rho_C CD_C + \Sigma_Y \lambda_Y YD_Y + \varepsilon_{CY}\end{aligned} \qquad (8)$$

[4] The data periods by country are the following: Australia 1982-2005, Austria 1980-2005, Denmark 1980-2005, Finland 1970-2005, Japan 1973-2005, Netherlands 1979-2005, UK 1970-2005, and USA 1970-2005.

[5] In the EU-KLEMS project these data have been used for adjusting the labor input in growth accounting, assuming that labor compensation corresponds to productivity. In contrast to this, we use the information on the labor characteristics to estimate their relative productivities.

[6] We can allow for heterogeneity across countries by using different kinds of labor input categories, while we cannot do the same as easily with capital data. Therefore we interact the ICT share with country dummies to account better for capital-related heterogeneity.

where $\lambda \equiv \ln(A_0) + \alpha \ln(\psi_{NICT}) + \beta_l \ln(\phi_{ly}) + \beta_h \ln(\phi_{hy})$, CD and YD are country and year dummy variables and suffixes Y and C are from year 1971 to 2005 and from country 2 to 8, respectively. We also estimate the production function excluding the year dummy variables YD from (8). As shown in column (a) and (b) of Table 1, the estimated coefficients show that both production functions with and without year dummy variables are homogeneous with degree one, $\alpha + \beta_l + \beta_h - 1 = 0$.[7] Re-estimation with this constraint may be necessary, but in the present paper we do not impose it. Also, those countries with clearly insignificant coefficients for the ICT share may be combined to the reference group. However, we leave these variables in the equation for the TFP estimation.

We use the specification without year dummies in column (b) as our basic model. The coefficients of physical inputs are all significantly positive in column (b). In the labor groups we use young as the reference group. In the low-skilled category, in (b), the mid-aged are equally productive to the young because of the insignificant coefficient but the old are more productive by $\hat{\phi}_{lo}$ = (1+0.598/0.092) = 7.5 times[8]. In the medhigh-skilled category the mid-aged are more productive than the young by (1+0.472/0.498) = 1.95 times but the old and young are equally productive. These results can be interpreted to show that in low-skilled jobs the greater physical strength of the young workers is not enough to compensate their lack of experience, whereas in medhigh-skilled jobs the more recent education of the young and mid-aged compensates for the lack of experience. As a result, among the medhigh-skilled, the mid-aged are the most productive.

The coefficients of the age categories are illustrated in Figure 1. These figures show an U-shape for the low-skilled and an inverted U, $\cap$-shape, for the medhigh-skilled labor. The shape of the age-productivity profile in the medhigh skill category is consistent with some "stylized facts" of the development of productivity by age. The bars next to the productivity coefficients indicate the average (over countries and over time) share of the category in question. Each share multiplied by the productivity coefficient is close to zero, which supports the linear approximation shown in (4).

The coefficients of the ICT share show big variations across countries. The estimation results show that ICT has been more productive in the reference group country Japan than NICT by (1+4.953/0.508) = 10.75 times (significant at 10% level), whereas the ICT productivity is lowest in Denmark by (1+(4.953-5.924)/0.508) = -0.91 times and in Australia by (1+(4.953-4.913)/0.508) = 1.08 times.[9] For the other countries (Austria, Finland, Netherland, UK, USA), the coefficients of the country-specific ICT shares are insignificant at the 10% level. We can conclude that their coefficients are the same as that of Japan, with ICT capital more productive than NICT capital. Some of the ICT coefficients are too large to be quite plausible in the simple model above. It could be that the assumption of perfect substitutability of the capital categories is not tenable, or our approximation for the logarithmic form is not particularly good. Therefore, we should

[7] We can allow for heterogeneity across countries by using different kinds of labor input categories, while we cannot do the same as easily with capital data. Therefore we interact the ICT share with country dummies to account better for capital-related heterogeneity.

[8] $\phi^*_{lo} = \beta_l(\hat{\phi}_{lo} - 1) = 0.598$, since $\beta_1 = 0.092$.

[9] $\psi^*_{lo} + \delta_C = 4.953 - 5.924 = -0.971$ and therefore $\hat{\psi}_{lo} = 1 - 0.971/0.598 = -0.91$.

pay more attention to the relative magnitudes of the coefficients, rather than on their absolute values.

We do a robustness check of the results by including the year dummy variables (which play the role of proxy variables for the other economic variables). The results are shown in column (a) of Table 1. The sign of the old medhigh-skilled coefficient is changed from negative to positive, while it is not significant. The coefficient of the mid-aged low-skilled stays negative, but is now significant. Also, similar changes happen for capital characteristics, while the order of ICT productivity among countries is not significantly changed. Second, while we include 35 year dummy variables, the adjusted R-squared increases only by 0.01. Finally, the shapes of the age-productivity profiles for the low-skilled and the medhigh-skilled labor categories are roughly similar to our basic results. Thus, the results seem robust to including the other economic variables (proxied by the year dummies).

Insert Table 1 and Figure 1

The TFP is estimated as:

$$\begin{aligned} \ln(TFP)_{CY} &\equiv \ln(Y)_{CY} - (\alpha \ln(K)_{CY} + +\beta_l \ln(L_l)_{CY} + \beta_h \ln(L_h)_{CY}) \\ &= \lambda + \psi^*_{ICT} q_{ICT} + \Sigma_C \delta_C q_{ICT} CD_C + \phi^*_{lm} s_{lm} + \phi^*_{lo} s_{lo} + \phi^*_{hm} s_{hm} + \phi^*_{ho} s_{ho} \qquad (9) \\ &\quad + \Sigma_C \rho_C CD_C + \varepsilon_{CY} \end{aligned}$$

where the parameters are replaced by the estimates from column (b) of Table 1. The first row in (9) shows the estimated TFP. The second row and Table 1 show that the positive influential economic factors are the share of the old low-skilled worker hours and the share of mid-aged medhigh-skilled worker hours, whose coefficients are significantly positive, i.e., they are more productive than young workers in the same skill categories. Also, the share of ICT in all countries is a positive (or at least non-negative) factor on the TFP increases except for Denmark. The estimated TFP is shown in Figure 2 (change) and Figure 3 (level). In Figure 3 the values of ln(TFP) and ln(Y), are rescaled to be zero in 1990.

Insert Figure 2 and Figure 3

Business cycles and TFP

The same way as some papers including Lebow (1993), Sbordone (1996) and Basu (2000), we investigate the cyclicality the TFP by visual inspection of the estimated TFP change and by calculating the correlation of ln(TFP) and value added ln(Y) changes. We define TFP to be pro-cyclical if the correlation is above 0.5. The graphs in Figure 2 for all countries show pro-cyclicality and the correlation with ln(Y) change is at least 0.5 for all the countries with maximum 0.91 for Japan and minimum 0.50 for Australia, as shown in Table 2. On the other hand, we report in Table 2 also the average of the ratio (absolute value of TFP growth)/(absolute value of input growth) for each country. The input growth is calculated as $\alpha \ln(K)_{CY} + \beta_l \ln(L_l)_{CY} + \beta_h \ln(L_h)_{CY}$. The figures in Table 2 show that a large portion of the manufacturing value added growth can be explained by the TFP growth, i.e., the TFP is a main driver of growth.

Insert Table 2

4. Why has some countries' TFP decreased?

The main results in Table 1 in the context of the aging trend and ICT imbalance are as follows. The aging trend in a labor skill category means a decrease in the shares of young and mid-aged workers (and their hours of work). Among the low-skilled labor this negative aging trend increases the share of the more productive old workers, implying a positive productivity effect. On the other hand, the aging trend in the midhigh-skilled labor group decreases the share of the more productivity mid-aged workers with a negative productivity effect. The aging trends can be counteracted by investments in ICT. The ICT capital is more productive than the NICT except for Denmark, while the productivity is different depending on the country.

The TFP for each country is explained by the estimated coefficients for equation (9) (Table 1, column (b)) and the share variables of each country. Based on the estimation result, we check the age shares country by country (Figures 4a to 4c) and consider why the TFP of Japan, and Australia, Denmark and UK has recently slowed down or that of Austria, and Finland, Netherlands and USA has increased, as shown in Figure 3. As seen in Figure 4a and 4c, the USA has no aging trend in either labor skill group in the sense that there is no increase in the share of the old workers' hours. The recent aging since 1990 among the medhigh-skilled labor (seen in Figure4c; Japan, Australia, Denmark, Finland, Netherlands, UK) has caused a reduction of the most productive mid-aged workers in some countries (Japan, Australia, Finland, as seen in Figure4b), while its effect has not been strong enough to decrease the share of mid-aged workers in Denmark, Netherland and UK. On the other hand, the aging of the low-skilled labor has increased the most productive old workers in some countries (Japan, Finland, Netherlands, and UK as can be seen in Figure 4a).

The total labor effect, obtained by summing all effects $\phi^*_{lm}s_{lm} + \phi^*_{lo}s_{lo} + \phi^*_{hm}s_{hm} + \phi^*_{ho}s_{ho}$ in (9), is still positive (see Table 3) and increasing over time for all countries (see Figure 4e). In addition to these effects of aging, ICT has had an effect, $\psi^*_{ICT}q_{ICT} + \Sigma_C \delta_C q_{ICT} CD_C$ on TFP in (9). In most cases the total labor effect dominates the ICT effect (column 4 of Table 3). The ICT effect is increasing over time in some countries, but relatively flat in others (Figure 4e).[10] The slow growth of ICT in Japan (as shown in Figure 4d) has contributed to the stagnating TFP (the share of the ICT effect is relatively low), whereas for example in Finland the fast ICT growth has contributed to the larger share of the ICT effect.

Insert Figures 4a,b,c,d,e and Table 3

[10] Note that in Figure 4e we have scaled the graphs so that they are zero in 1990. Therefore the levels of the lines should not be compared.

Thus, in a wake of the aging trend, some countries lose the productive workers (i.e., the mid-aged workers in the medhigh-skilled category), while immigrant countries like USA are able to appropriately adjust the shares of the young and mid-aged workers in each skilled category over time. Also, in a wake of information technology trend with higher productivity, the countries like Finland using the technology efficiently have obtained a high TFP.

5. Complementarity among labor groups

We already found the contributions of the composition of labor and ICT effects on TFP in Table 3. A large portion of the TFP can be explained by the labor effect. Next we examine in detail the complementarity between different age groups. To simplify the analysis, we reduce the number of groups by using a new age group "y-worker" which means the young and the mid-aged workers combined. We hence have two age groups, y-workers and old workers, divided to low-skilled and medhigh-skilled ones. The increase in the share of the old within the skill groups then shows the aging trend. Related to equation (3), we assume that the y-workers' productivity is complemented by the old workers. Previously we have assumed perfect substitutability of the age groups. In that case the relative productivity of the young is independent of the share of the old. Departing from that assumption we now assume that the y-workers' relative productivity $\hat{\phi}_{jy}(s_{jo})$ depends on the share s_{jo} of the old workers in each skill category j. This relationship is represented by a decreasing or an increasing function around $s_{jo} = 1$, as shown in Figure 5. An increasing function shows complementarity between the age groups, whereas a decreasing function would imply (imperfect) substitutability of the age groups. This relationship can be interpreted as a particular character of team work (discussed e.g. by Benders and Hootegem, 2000, in the context of Japanese working place). On the other hand, many papers are dealing with the capital - skilled labor complementarity (e.g. Yasar and Morrison Paul, 2008), while there are few papers studying the complementarity of the old workers and young workers. We add a further assumption about the shape of the complementarity function: $\hat{\phi}_{jy}(s_{jo}) = 1$ at $s_{jo} = 1$ even though the function may be increasing or decreasing. The y-worker's productivity increases or decreases depending on the share of the old workers and finally the productivities are equal.

Insert Figures 5

Consider the case of low-skilled workers ($j=l$). We express the function $\hat{\phi}_{ly}(s_{lo})$ as a first-order Taylor expansion around $s_{lo} = 1$:[11]

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[11] We can relax the assumption as follows: $\hat{\phi}_{ly}(1) \geq 1$ when $A_{ly} > 0$ and $\hat{\phi}_{ly}(1) \leq 1$ when $A_{ly} < 0$. The former means that the old improve the young's productivity, and the latter is the

$$\hat{\phi}_{ly}(s_{lo}) = \hat{\phi}_{ly}(1) + A_{ly}(s_{lo} - 1) \quad where \quad \hat{\phi}_{ly}(1) = 1 \qquad (10)$$

Equation (4), productivity, for young low-skill workers can be expressed, by using (10):

$$\mathrm{X}(\mathrm{s}_{lo}) \equiv \mathrm{s}_{ly}(\hat{\phi}_{ly}(\mathrm{s}_{lo}) - 1) \approx \mathrm{s}_{ly}(\hat{\phi}_{ly}(1) + A_{ly}(\mathrm{s}_{lo} - 1) - 1) = -A_{ly}(1 - \mathrm{s}_{lo})^2 \qquad (11)$$

This formulation satisfies also the approximation in (4). This introduces an interaction term of the shares of the y-workers and old workers, but since we have only two age groups, this implies a quadratic form in the share of old workers. We estimate the TFP by inserting this approximation (11) into equation (9).

The coefficients are related to the shape of the productivity of low-skilled labor in (11), due to the first order and the second order conditions:

$$\mathrm{dX}(\mathrm{s}_{lo})/\mathrm{ds}_{lo} = 2A_{ly}(1 - \mathrm{s}_{lo}), \quad \mathrm{d}^2\mathrm{X}(\mathrm{s}_{lo})/\mathrm{ds}^2{}_{lo} = -2A_{ly} \qquad (12)$$

This productivity X is a convex function decreasing from a positive value to zero with the increase of s_{lo} when A_{ly} <0, which means that the productivity of y-workers is decreasing in the share of old workers as seen in Figure 5. On the other hand, it is a concave function increasing from a negative value to zero when A_{ly} > 0, which means the productivity of y-workers is increasing. In particular, A_{ly} = 0 means X = 0, which means that the productivity of y-workers is equal to that of the old workers. Note that we are not trying to find a point where the share of old workers maximizes total productivity. For example, if the function $\hat{\phi}_{\mathrm{ly}}(s_{lo})$ is quadratic, we would end up with X being a third-order polynomial. This could have a (local or global) maximum at some value of s_{lo} between zero and one. Instead, we analyze the shape of the function (and X), and thereby the complementarity or substitutability at large values of the share of old workers.

The results are shown in Table 3[12]. The productivity X is significantly concave in the low-skilled labor category (the coefficient of $(1\text{-s}_{lo})^2$ implies A_{ly} =0.354) and zero (insignificant) in the medhigh-skilled labor group (the coefficient of $(1\text{-s}_{ho})^2$ implies A_{hy} =0.178). Considering these characteristics and the first order condition in (12), we can find the location of each country by using the average shares of s_{lo} and s_{ho}. We show in Figure 6 the cases of Japan and USA, which have the highest and lowest share of old

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opposite case. Note that we assume that $\hat{\phi}_{ly}(1) - 1$ is appropriately small in order not to affect the $A_{ly}(\mathrm{s}_{lo} - 1)$ in (11). Then, we can know whether X is increasing or decreasing, depending on the sign of A_{ly}: $X = -A_{ly}(1 - \mathrm{s}_{lo})^2 + (1 - s_{lo})(\hat{\phi}_{ly}(1) - 1)$.

[12] Note that in (8) the coefficients of labor characteristics should not be very negative, since $\phi^*_{jn} = \beta_j(\hat{\phi}_{jn} - 1)$ and the relative productivity $\hat{\phi}_{jn}$ is not negative. In contrast, in the complementarity formulation the parameters are slopes of a function and can be large in absolute value.

low-skilled labor, respectively, among the countries in our data. Moreover, considering the increase of the share of old workers in both skill groups in Japan (see Figures 4a and 4c), the aging trend implies moving towards the right hand side in Figure 6, which increases the productivity of low-skilled labor and stagnates it in the medhigh-skilled labor group. On the other hand, the USA has no aging trend and therefore no change in the labor productivity over time. Similar facts hold in the other countries.[13]

These results are not inconsistent with the results based on the hypothesis of perfect substitution. We can reconcile the findings as follows. As shown in Figure 5, the result that $A_{ly} > 0$ in the low-skilled labor group means that an increase in the old worker's share improves the productivity of y-workers. Further, the result $A_{ly} = 0$ in the medhigh-skilled labor group means no improvement of their productivity, but they have the same productivity as the old workers. These results can be interpreted to show that in low skilled jobs a large number of the old workers can easily transmit their experience to the young workers (i.e., the age groups are complements), whereas in medhigh-skilled jobs the more recent education of the young brings the same productivity as that of the old and the old cannot improve the young with their experience (i.e., the age groups are perfect substitutes). Thus, this is the same interpretation as what we drew form our earlier results.[14]

The column (a) in Table 4 shows the robustness check with including the year dummies. Our main implications remain the same. The main difference to column (b) in Table 4 is that some of the coefficients of the ICT shares change, but even then their relative orders of magnitude do not change much.

Insert Table 4 and Figures 6

6. The Aging Index

The ICT effect and the total labor effect on the TFP have positive trends over time as shown in Figure 4e. However, as the aging proceeds more, the labor effect may slow down, as evidenced by Japan. The labor effect is but moderated by the ICT progress. In fact, a country with high progress of the ICT needs not pay attentions on aging. How do we recognize the seriousness for the aging labor problem on the TFP for each country? Focusing on the moderating effect of ICT progress and using (9), the following change of the ICT share is needed to make the TFP equal to random shocks $\Delta \ln(TFP)_{CY} \equiv \ln(TFP)_{CY} - \ln(TFP)_{CY-1} = \Delta\varepsilon_Y$:

[13] Again, we should not give too much emphasis on the absolute values of the ICT coefficients. The ICT coefficient for Denmark in column (b) of Table 4 is 1+(5.070-6.759)/0.591 = 1-(1.689)/0.591 = -1.86, which is significant. This negative coefficient (negative relative productivity) is somewhat a problem. The ICT coefficients for Australia and UK are significantly negative, while the second one plus ICT coefficient is positive and moreover, the first one plus ICT coefficient is insignificant by t-test.

[14] However, the results are not exactly comparable, since in the complementarity analysis we have aggregated the young and the mid-aged workers (with more productivity than the young) to the y-workers.

$$\Delta q_{ICT,Y} = \frac{-1}{\psi^*_{ICT}} (\phi^*_{lm} \Delta s_{lm,Y} + \phi^*_{lo} \Delta s_{lo,Y} + \phi^*_{hm} \Delta s_{hm,Y} + \phi^*_{ho} \Delta s_{ho,Y}) \qquad (13)$$

where the subscript Y refers to years. Here, the numerator in (13) is change in the term that we have already defined as 'total labor effect on the TFP' in Section 4. $\Delta q_{ICT,Y}$ is the change of the ICT share which is necessary to stop the TFP decrease (or increase) caused by the change in the total labor effect. Since the ICT productivity parameter ψ^*_{ICT} and the changes of the labor input shares ($\Delta s_{lm,Y}, \Delta s_{lo,Y}, \Delta s_{hm,Y}, \Delta s_{ho,Y}$) vary across countries, the term $\Delta q_{ICT,Y}$ in (13) reflects the idiosyncratic index for the necessary increase of ICT share in each country. Considering the coefficients in Table 1, for example, the index for Finland for 2005 is $\Delta q_{ICT,Y} = -(-0.0165)/(4.953+1.658)$ = 0.0025 percentage points, where -0.0165 percentage points decrease is the total labor effect on the TFP and 4.953+1.658 is the productivity parameter of the ICT. This value of the index means that 0.0025 percentage points increase of $\Delta q_{ICT,Y}$ is needed to stop the TFP decrease caused by the aging effect of labor. Also, for Japan the index for 2005 is $\Delta q_{ICT,Y} = -(0.0347)/4.953$ = -0.0007 percentage points, which means that a larger increase of the ICT share is needed in Finland. This is because the total labor effect is negative in Finland. In this sense, we call this index is an Aging Index of the country. A country with ICT share change at least equal to the index is meeting the aging problem.

By using the Aging Index, we investigate which countries are in a serious aging problem and when. As shown in Figure 7, the aging index of countries with high productivity of ICT, like Austria, Finland, Japan, Netherlands and USA, is generally smaller than for the other countries. Also, the index of each country is larger in the recent years due to aging-caused changes in the total labor effect. In order to overcome this aging problem, most of the countries have been able to increase the actual share of the ICT as shown in Figure 7 and as a result, most of the countries have been able to increase the TFP as shown in Figure 3. Exceptions are Australia and Denmark, which have low ICT productivity (negative productivity coefficients). In those countries an increase of ICT share means a decrease of the TFP. Another exception is Japan with the stagnated TFP, where the actual increase of ICT share has been higher than the required increase of ICT share (Aging Index), but still relatively low.[15]

7. Concluding Remarks

The purpose of this paper was to investigate what decreases the TFP and why it has decreased in some countries, focusing on the quality of labor and capital inputs. We did this by using cross country data for the manufacturing industries of some OECD countries.

[15] Note that the scales of the panels in Figure 7 vary by country.

We found that (i) the low TFP is related to the aging of the labor input and to insufficient information technology content in the capital input. The aging of the labor input improves the productivity only in the low skilled labor category, but leads to a fall in productivity in the medium to high skilled labor group. The productivity impact of ICT capital varies from country to country. Due to these positive and negative effects of aging and ICT imbalance, the TFP has since 1990 increased in Austria, Finland, Netherland, and USA, while it has stagnated or decreased in Australia, Denmark, and Japan. In particular, the decrease or stagnation of the TFP initiated by aging is not a problem in an immigrant country like USA, which is able to adjust to the problem by immigration. (ii) Based on the complementarity hypothesis, increased share of the old workers in the low skilled labor group improves the young and mid-aged low-skilled workers' productivity. On the other hand, increased share of old medium to high-skilled workers has no effect on the young and mid-aged workers in this skill group. An interpretation of the results is that the aging of the low-skilled labor improves the productivity of the younger workers through the old workers' experience, but in the higher skilled groups the better education of the young dominates, so no complementarity is found between the age groups. These results add to the recent results dealing with the complementarity of capital and skilled labor. (iii) We have calculated the change in ICT which is necessary to compensate for the aging of the labor input and called this the Aging Index. Both countries with a low value of the aging index (Finland and USA) and with a high value of the index (Austria, Netherland and UK) have successfully increased the share of the ICT to overcome the aging problem. Japan, Australia and Denmark are exceptions.[16]

With these findings we provide a new explanation of a low TFP, which differs from the previous viewpoints suggested by Hayashi and Prescott (2002), Jorgenson and Motohashi (2005) and Hayashi and Nomura (2005).

[16] The change of the total labor effect for Australia fluctuates between positive and negative values, while the size of ICT coefficient is very small compared with the other countries, 0.040 (= 4.953 - 4.913) as shown in Table 1. As a result, even small changes in the age effect require large changes in ICT (see Figure 7). The ICT is therefore not effective for stopping the problem of aging labor.

References

Basu, S. and Fernald, J.G (2001), "Why is productivity procyclical? Why do we care?" in New Developments in Productivity Analysis, edited by C. R. Hulten, E.R. Dean, and M.J. Harper, Chicago: University of Chicago Press**,** 225-296**.**

Benders, J. and Hootegem,V. (2000), "How the Japanese got teams", in S. Procter and F. Mueller (eds.) *Teamworking*, Macmillan Business.

Caballero, R.J. (1999), "Aggregate investment", In: Taylor, J.B., Woodford, M. (Eds.), Handbook of Macroeconomics, vol. 1B. Amsterdam: North-Holland.

Caballero, R.J., Hoshi, T. and Kashyap, A.K. (2008), "Zombie lending and depressed restructuring in Japan", American Economic Review 98, 1943-1977.

Cummins, J.G. and Violante, G.L. (2002), "Investment-specific technical change in the US (1947–2000): Measurement and macroeconomic consequences", Review of Economic Dynamics 5, 243–284.

Fukao, K., Ito, K. and Kwon, H.U. (2005), "Do out-in M&As bring higher TFP to Japan? An empirical analysis based on micro-data on Japanese manufacturing firms", Journal of the Japanese International Economies 19, 272–301.

Griliches, Z. (1967), "Production functions in manufacturing: some preliminary results', in M. Brown M., ed., The Theory and Empirical Analysis of Production, Columbia University Press, New York, NY, 275–340.

Hayashi, F. and Prescott, E. (2002), "The 1990s in Japan: a lost decade", Review of Economic Dynamics 5: 206–235.

Hayashi, F. and Nomura, K. (2005), "Can IT be Japan's savior?", Journal of the Japanese and International Economies 19, 543–567.

Hellerstein, J. K., Neumark, D. and Troske, K. R. (1999), "Wages, productivity, and worker characteristics: evidence from plant-level production functions and wage equations", Journal of Labor Economics 17, 409–446.

Hellerstein, J.K. and Neumark, D. (1999), "Sex, wages, and productivity: an empirical analysis of Israeli firm-level data", International Economic Review 40, 95–123.

Ilmakunnas, P., Maliranta, M. and Vainiomäki, J. (2004), "The roles of employer and employee characteristics for plant productivity", Journal of Productivity Analysis 21, 249-276.

Ilmakunnas, P. and Maliranta, M. (2005), "Technology, labour characteristics, and wage-productivity gaps", Oxford Bulletin of Economics and Statistics 67, 623-645.

Jorgenson, D.W. and Motohashi, K. (2005), "Information technology and the Japanese economy", Journal of the Japanese and International Economies 19, 460-481.

Jorgenson, D.W. and Nomura, K. (2005), "The industry origins of Japanese economic growth", Journal of the Japanese and International Economies 19, 482-542.

Lebow, D. (1993), "The covariability of productivity shocks across industries", Journal of Macroeconomics 15, 483-510.

Malcomson, J. and Prior, M. (1979), "The estimation of a vintage model of production for U.K. manufacturing", Review of Economic Studies 46, 719-736.

Mcintosh, J. (1986), "Economic Growth and Technical Change in Britain 1950-1978", European Economic Review 30, 117-128.

Mizon, G. (1974), “The estimation of non-linear econometric equations: An application to the specification and estimation of an aggregate putty-clay relation for the U.K.”, Review of Economic Studies 41, 353-369.
Mukoyama, T. (2008), “Endogenous depreciation, mismeasurement of aggregate capital, and the productivity slowdown”, Journal of Macroeconomics 30, 513–522.
Nishimura, K.G., Nakajima, T. and Kiyota, K. (2005), “Does the natural selection mechanism still work in severe recessions? Examination of the Japanese economy in the 1990s”, Journal of Economic Behavior & Organization 58, 53–78.
Sbordone, A.M. (1996), “Cyclical productivity in a model of labor hoarding”, Journal of Monetary Economics 38, 331-361.
Temple, J. R. W. (2001), “Generalizations that aren’t? Evidence on education and Growth”, European Economic Review 45, 905–918.
Yasar,M. and Morrison Paul, C.J. (2008), “Capital-skill complementarity, productivity and wages: Evidence from plant-level data for a developing country”, Labour Economics 15, 1–17.

Table 1. Estimated coefficients of production with country panel data: Substitutability hypothesis

	Dependent variable ln(value added)	
	Including year dummies (a)	Excluding year dummies (b)
$\ln(L_l)$: β_l	0.276* (5.27)	0.092* (3.11)
$\ln(L_h)$: β_h	0.467* (4.79)	0.498* (6.58)
ln(K) : α	0.325* (3.19)	0.508* (5.53)
Young low-skilled	Ref.	Ref.
Mid-aged low-skilled ϕ^*_{lm}	-0.477* (-2.60)	-0.252 (-1.22)
Old low-skilled ϕ^*_{lo}	0.647* (3.21)	0.598* (2.64)
Young medhigh-skilled	Ref.	Ref.
Mid-aged medhigh-skilled ϕ^*_{hm}	0.650* (3.51)	0.472* (2.26)
Old medhigh-skilled ϕ^*_{ho}	0.636 (1.61)	-0.602 (-1.48)
Non-ICT	Ref.	Ref,
ICT	-1.623 (-0.46)	4.953# (1.69)
ICT Australia	0.296 (0.09)	-4.913# (-1.77)
ICT_Austria	5.627# (1.83)	0.357 (0.13)
ICT Denmark	-0.712 (-0.23)	-5.924* (-2.11)
ICT_Finland	5.076* (1.97)	1.658 (0.69)
ICT Netherlands	3.267 (1.14)	-1.254 (-0.47)
ICT UK	1.366 (0.45)	-4.187 (-1.54)
ICT_USA	4.702 (1.47)	-0.910 (-0.33)
Number of significant country dummies (of 7)	6*	6*
Number of significant year dummies (of 35)	20*	
H0: $\alpha+\beta_l+\beta_h-1 = 0$.;t-value	0.69	1.29
Adjusted-R^2	0.96	0.95
Observations	244	244

Notes: t-values in parentheses. * denotes 5% significance, # 10% significance. 'Ref.' indicates the base group. The non-reported constant terms are significant in both columns.

Table 2: Correlations and ratios between value added, input and TFP growth rates

Country	Correlations		Ratios	
	(a) year dummies	(b) no year dummies	(a) year dummies	(b) no year dummies
AUS	0.39	0.50	1.60	2.77
AUT	0.87	0.90	3.60	16.01
DNK	0.80	0.85	5.80	6.19
FIN	0.70	0.74	9.60	10.78
JPN	0.89	0.91	5.04	3.01
NDL	0.41	0.69	5.12	2.68
UK	0.59	0.64	44.70	1.63
USA	0.77	0.84	7.45	10.38

Notes: Correlations denote the correlations between TFP growth and GDP growth, and ratios denote the average of the ratios (absolute value of TFP growth)/(absolute value of input growth) over time.

Table 3: Composition of labor effect and ICT effect in the TFP

	(a) year dummies		(b) no year dummies	
	labor	ICT	labor	ICT
AUS	1.36	-0.36	0.98	0.02
AUT	0.81	0.19	0.64	0.36
DNK	1.32	-0.32	0.50	0.50
FIN	0.80	0.20	0.59	0.41
JPN	1.08	-0.08	0.74	0.26
NDL	0.81	0.19	0.49	0.51
UK	0.21	0.79	-0.04	1.04
USA	0.71	0.29	0.56	0.44

Notes: The composition of labor effect is defined as:

$$\phi_{lm}^{*}s_{lm}+\phi_{lo}^{*}s_{lo}+\phi_{hm}^{*}s_{hm}+\phi_{ho}^{*}s_{ho}\,/(\phi_{lm}^{*}s_{lm}+\phi_{lo}^{*}s_{lo}+\phi_{hm}^{*}s_{hm}+\phi_{ho}^{*}s_{ho}+\psi^{*}_{ICT}q_{ICT}+\Sigma_{C}\delta_{C}q_{ICT}CD_{C})$$

The ICT effect is 1- the composition of labor effect.

Table 4. Estimated coefficients of production with country panel data: Complementarity hypothesis

	Dependent variable ln(value added)	
	Including year dummies (a)	Excluding year dummies (b)
$\ln(L_l)$	0.052* (4.45)	0.088* (3.03)
$\ln(L_h)$	0.478* (4.95)	0.437* (5.78)
ln(K)	0.444* (4.36)	0.591* (6.47)
Y-worker low-skilled $(1\text{-}S_{lo})^2$:-A_{ly}	-0.631* (-5.55)	-0.354* (-2.87)
Y-worker medhigh-skilled $(1\text{-}S_{ho})^2$: -A_{hy}	-0.210 (-1.25)	-0.178 (-0.94)
Non-ICT	Ref.	Ref
ICT	1.081 (0.32)	5.070* (2.41)
ICT Australia	-2.879 (0.98)	-5.459* (-2.81)
ICT_Austria	2.170 (0.77)	-0.004 (-0.00)
ICT Denmark	-4.033 (-1.41)	-6.759* (-3.46)
ICT_Finland	2.847 (1.18)	1.189 (0.66)
ICT Netherlands	0.270 (0.10)	-1.477 (-0.78)
ICT UK	-1.707 (-0.61)	-4.568* (-2.37)
ICT_USA	2.147 (0.71)	-1.147 (-0.56)
Number of significant country dummies (of 7)	6*	6*
Number of significant year dummies (of 35)	12*	
H0: $\alpha+\beta_l+\beta_h-1=0$; t-value	1.54	1.47
Adjusted-R^2	0.97	0.95
Observations	244	244

Notes: see note of Table 1. The non-reported constant term is significant in both columns.

Figure 1: Relative productivities of age groups by skill

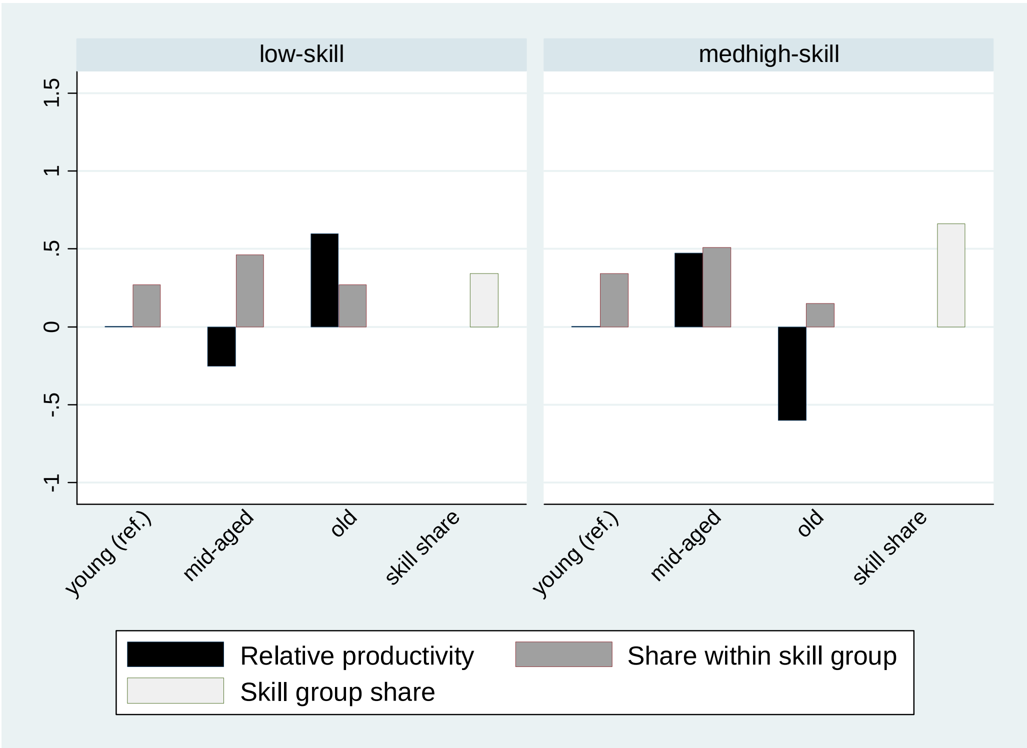


Figure 2: Growth rates of manufacturing value added and TFP by country

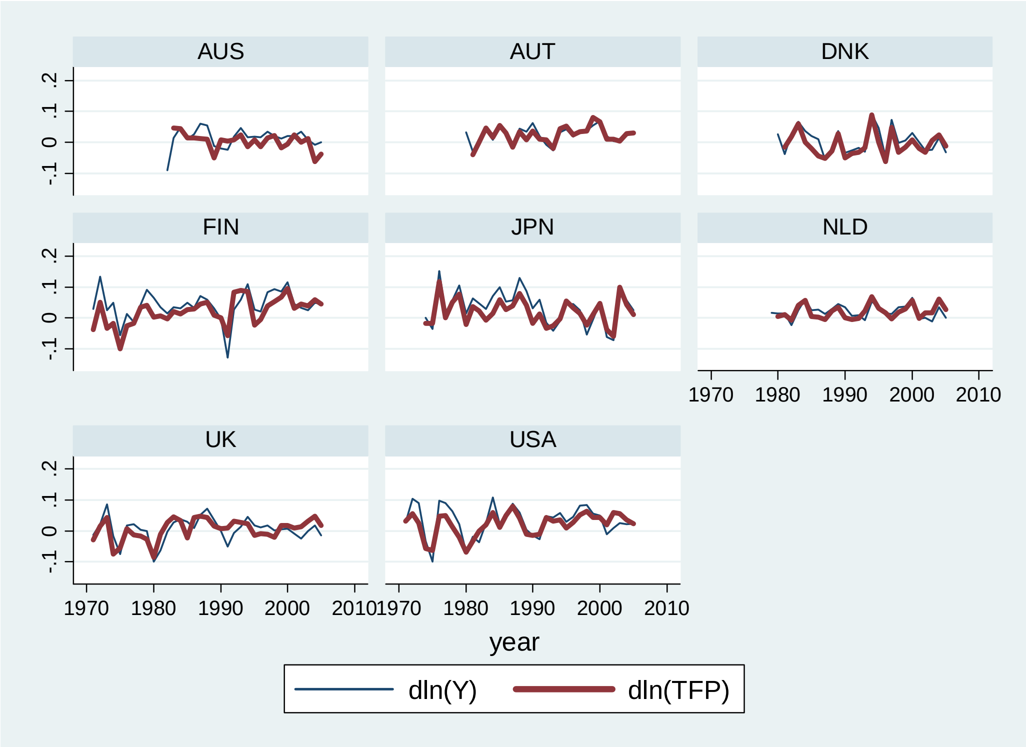


Figure 3: Levels of manufacturing value added and TFP by country (1990=0).

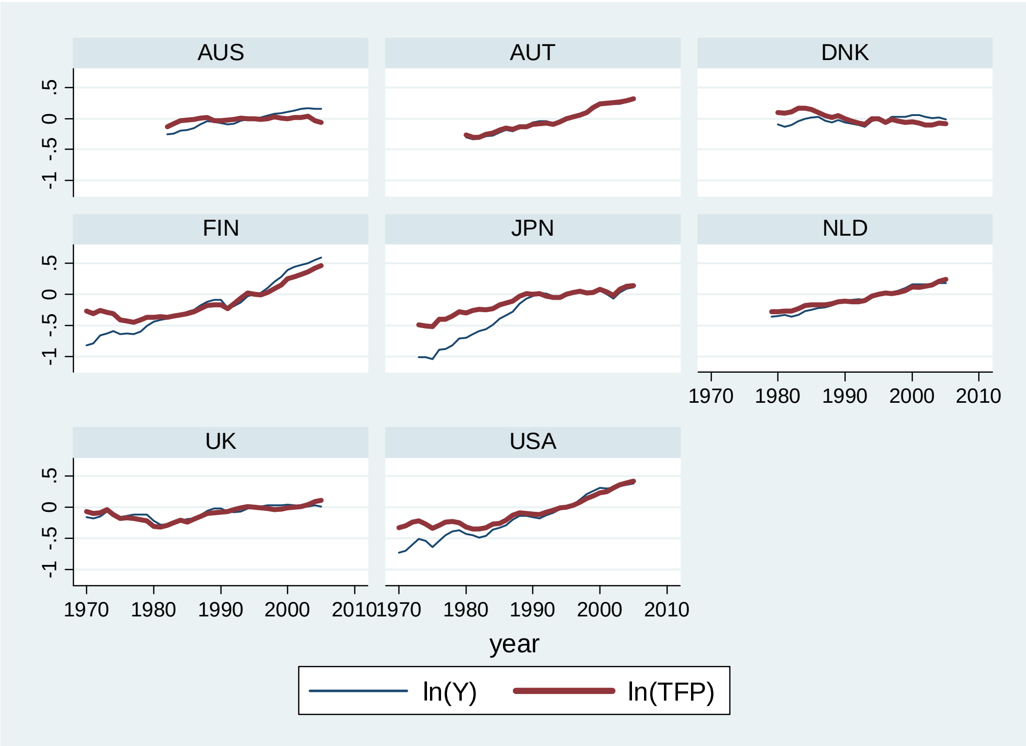


Figure 4a: Share of old low-skilled labor input by country

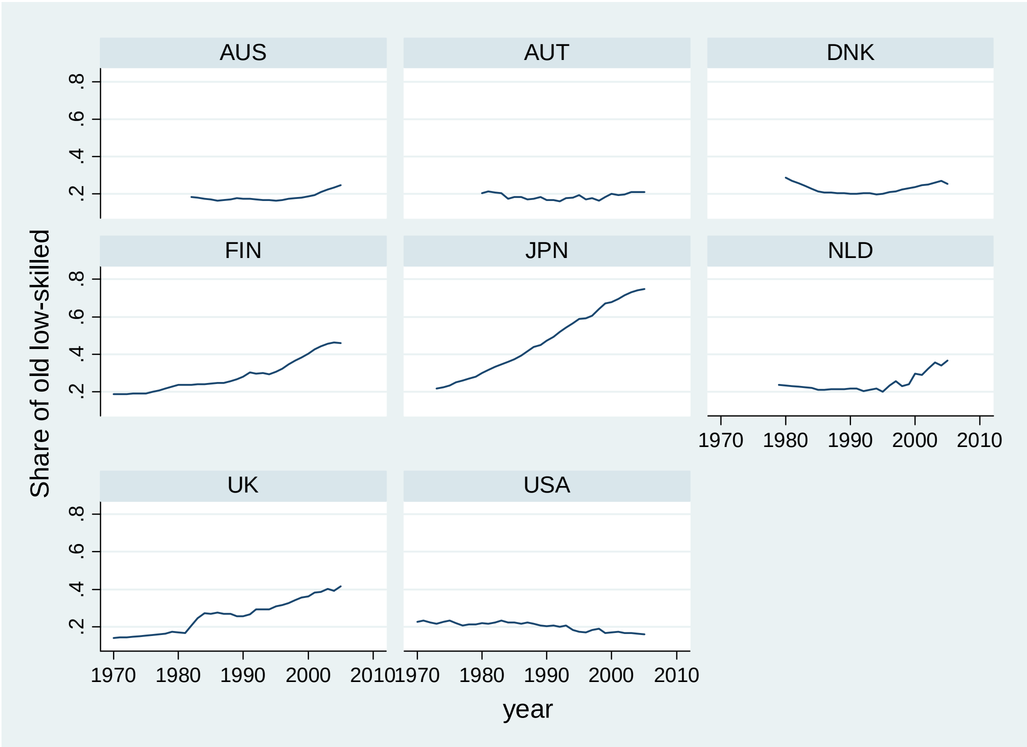


Figure 4b: Share of mid-aged medhigh-skilled labor input by country

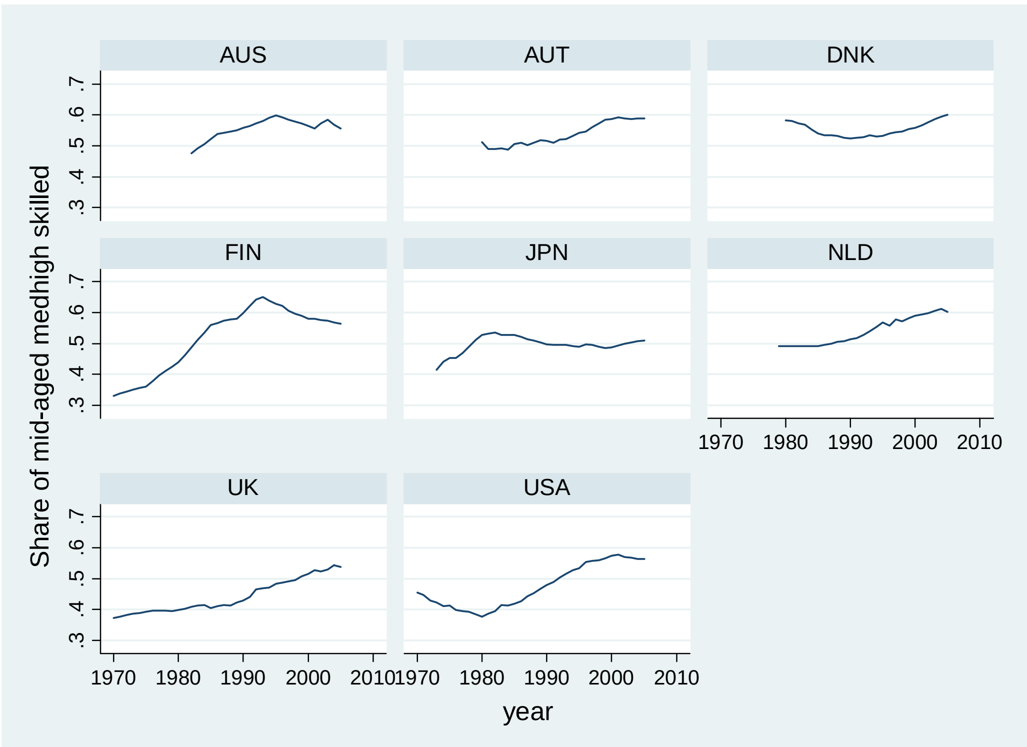


Figure 4c: Share of old medhigh-skilled labor input by country

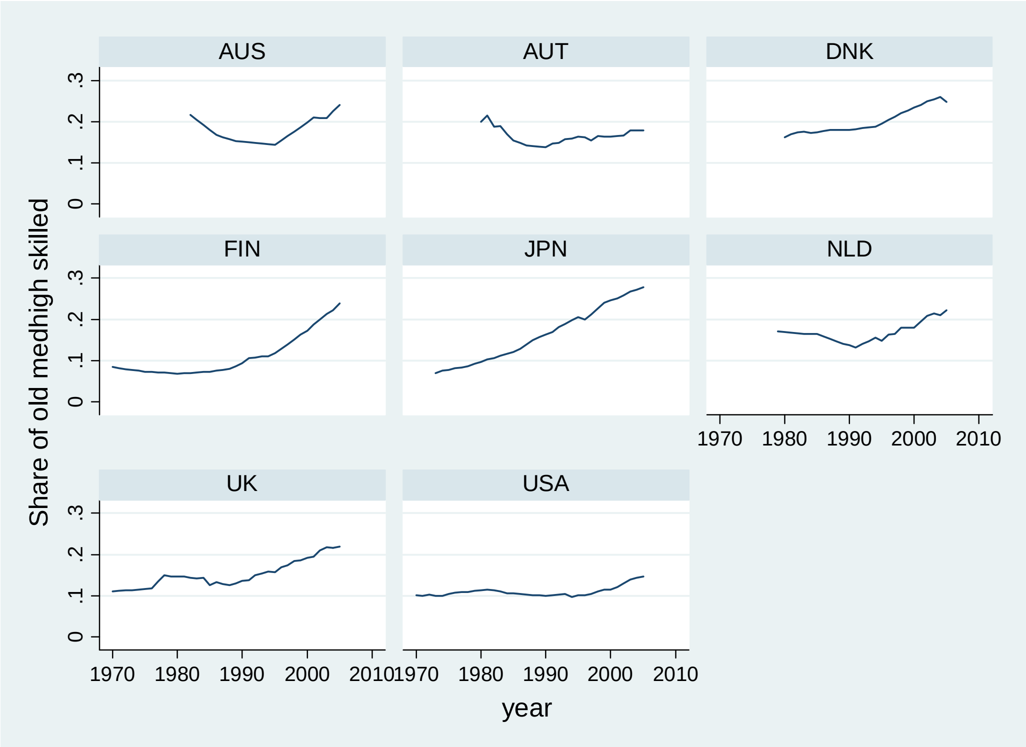


Figure 4d: Share of ICT capital by country

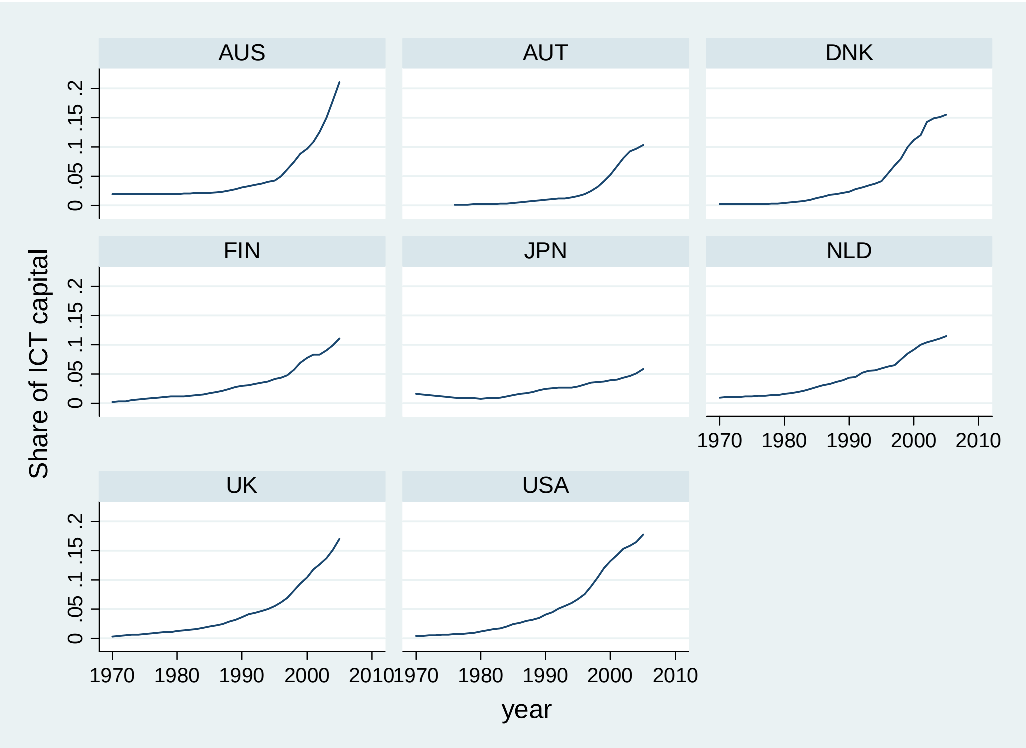


Figure 4e: Total labor effect and ICT effect by country (1990=0).

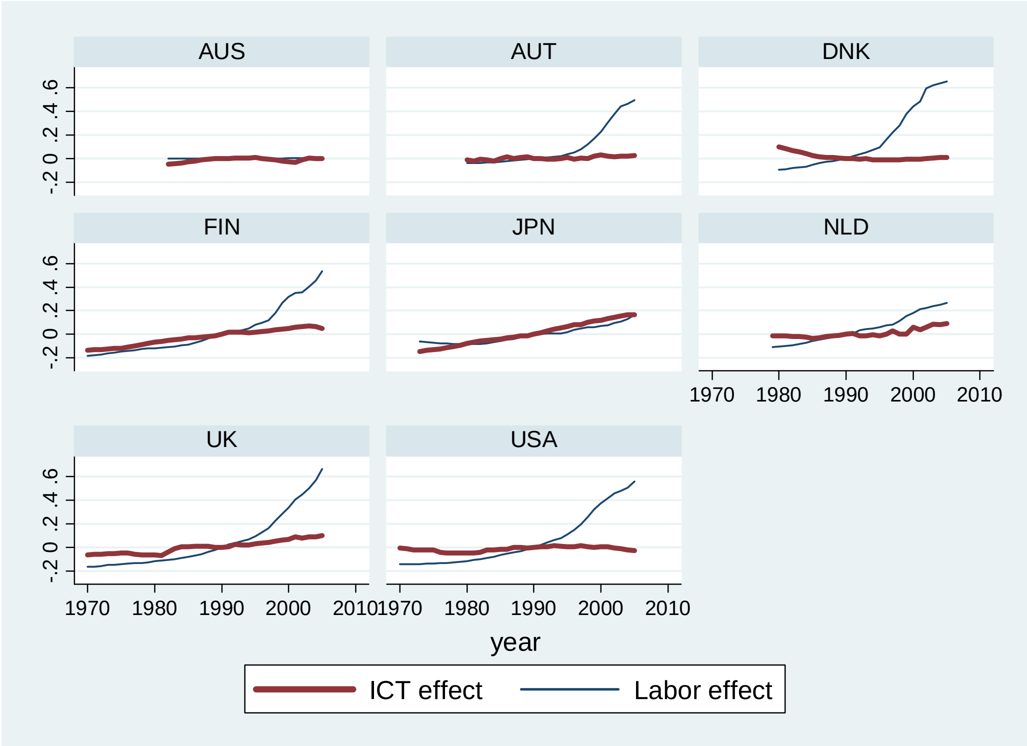


Figure 5: Complementary between y-workers (young and mid-aged) and old workers

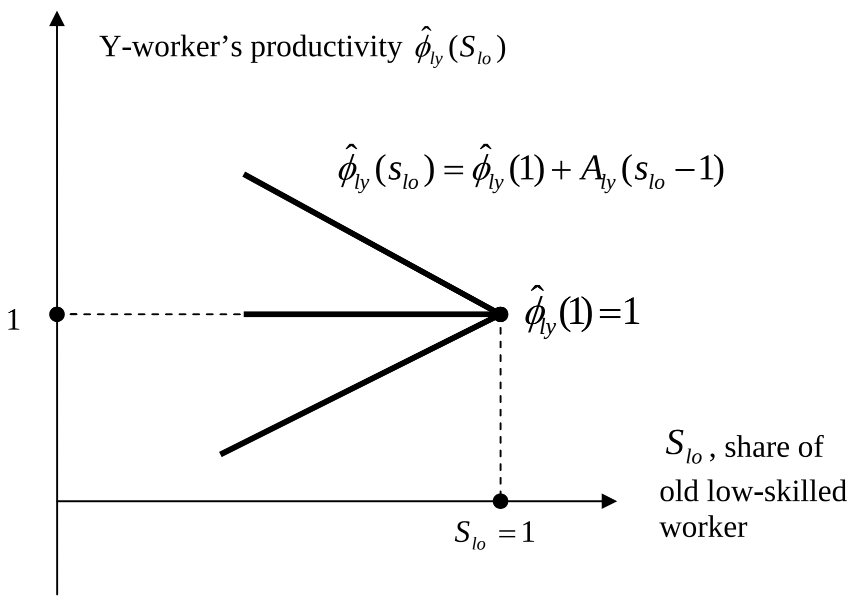
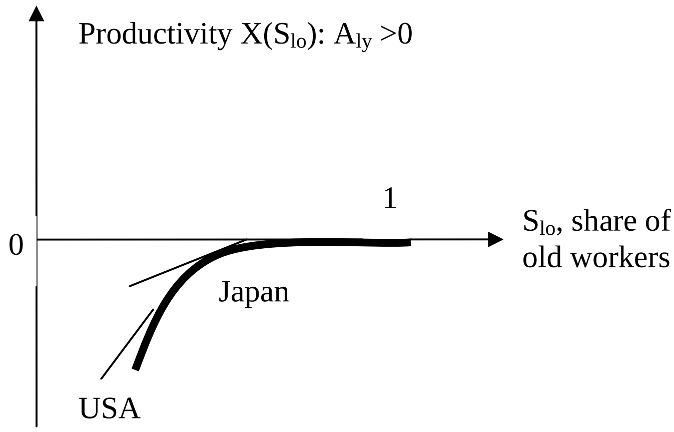
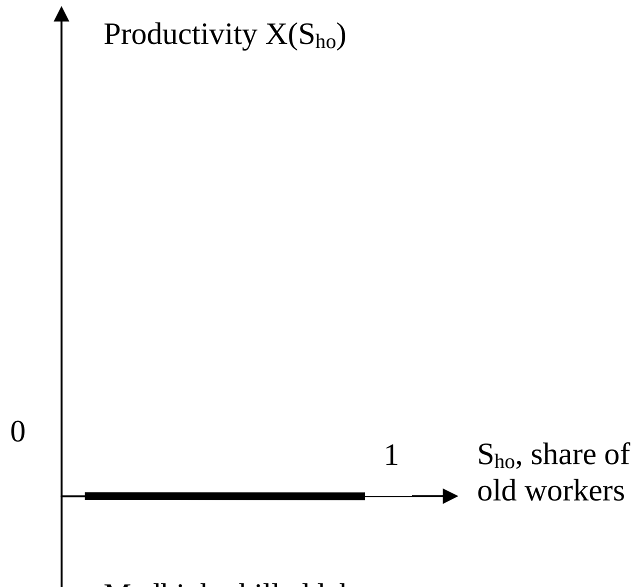


Figure 6: Complementarity of labor in each skill category



Low-skilled labor



Medhigh-skilled labor

Figure 7: Aging Index