Workforce Aging and Labor Productivity. The role of supply and demand for labor in the G7.

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Abstract

The aim of this paper is to study the sensitivity of projected labor productivity (measured by output per worker) in the G7 with respect to projected labor force participation rates, the age-productivity profiles of workers and the degree of substitutability of workers at different ages. Simulations suggest that in a pure labor economy, the assumption of imperfect substitution of workers at different ages implies a dividend from workforce aging during the next decades. Workforce aging implies that the actual age distribution of the workforce can be expected to shift closer to the optimal age distribution generating a dividend in terms of labor productivity. The dividend is likely to be non-trivial in magnitude, although the size of the effect depends very much on the values of elasticities of substitution about which little is known. Simulations further suggest that variations in age-productivity profiles have only a small impact on projected labor productivity while increases in labor force participation rats may significantly help to alleviate the projected demographic pressure on labor productivity.

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1 Introduction

Population aging currently receives high attention in economics, in particular with respect to its implications for the sustainability of social security systems such as the pension, health and elderly care system. In addition, population aging will also affect other markets like the labor market, the markets for goods and services and capital markets (see e.g., Börsch-Supan, 2002). In this paper we focus on the labor market and consider the fact that population aging will affect the *quantity* and the *composition* of the current workforce. It is now well accepted that in most industrialized countries, the economic output must be achieved by a smaller and an older labor force in the future. The question is then how this development might have an impact on the labor productivity as measured by output per worker.[1]

According to the view of many economists, an aging population leads to negative consequences in terms of growth of output per capita for two reasons. First, there is a change in the support ratio because a decreasing ratio of the working-age population to the total population increases the ratio of consumers to producers. This contributes negatively to growth of output per capita. Second, there might also exist behavioral effects on growth of output per worker, i.e., negative effects of an aging population on labor productivity as measured by output per worker. It is the latter effect that we want to investigate in the current paper. In particular we shall study the sensitivity of projected labor productivity with respect to three key assumptions in the labor market. These include the projected labor force participation rates, the assumption of the age-productivity profile of workers and the degree of substitutability between labor of different ages. Assuming that workers of different age are not perfectly substitutable and exhibit different levels of productivity implies that there is an optimal age mix of the workforce and that demographic change can move the actual age mix either closer or further from the optimal mix and therefore affect labor productivity. The magnitude of this *age distributional* effect depends on how substitutable workers are by age. As indicated in Guest (2005) for Australia and Prskawetz and Fent (2004) for Austria the age distribution effect could be easily as important for growth as policies that aim to increase the labor force participation rates of older workers and women.

Our aim is to present qualitative results and rough orders of magnitude rather than proposing detailed projections of the future development of la-

[1] The recent development accounting literature (Hall and Jones (1999)) has stressed that only workers can contribute to production and therefore an understanding of differences in output per worker is more important than an understanding of differences in output per capita.

bor productivity. We therefore follow the work of Blanchet (1992) and Lam (1989) and choose a pure labor economy as our theoretical framework to study the impact of labor force aging on economic output. For our numerical simulations we use age-specific demographic data provided by World Population Prospects: The 2004 Revision, medium variant and age-specific labor market data provided by OECD Labor Market Statistics.

A restrictive assumption in Blanchet (1992) is the production technology that allows for perfect substitutability between workers of different ages. Though the assumption on the production technology was relaxed in Blanchet (2002) and a CES (Constant Elasticity of Substitution) production function was applied instead, the study is restrictive since it only considers the effect of workforce aging in a stable population. However, as is well known from recent studies in the economic growth literature relating differences of economic growth rates to changes in demographic structures (e.g., Higgins and Williamson, 1997), an analysis that restricts itself to steady states of the population distribution may be at best insufficient and at worst misleading in times of severe demographic changes. Since in many industrialized countries we will experience pronounced fluctuations of the working age population in the coming decades (caused by the baby boom generation which is expected to start retiring around 2020) a focus on transitional dynamics is essential.

We are aware of the fact that by focusing on a pure labor economy and ignoring physical capital we disregard one of the most important channels through which the negative impact of the labor force shrinkage on economic growth may be attenuated. As is well known in neoclassical growth theory, population decline increases the steady state capital labor ratio since less people have to be equipped with capital.[2] Moreover, as recently argued in Mason and Lee (2004), the accumulation of capital and wealth constitutes the source of the second demographic dividend. These effects are captured in general equilibrium models which commonly constitute the theoretical framework to study the economic consequences of population aging. However, most of those models are restrictive with respect to the production technology which in most cases aggregates labor of all ages into one production factor. Since our aim is to introduce imperfect substitutability across age groups in the labor market and consider its implication on labor productivity during times of rapid labor force shrinkage and aging, we regard (similarly to Lam, 1989, p.192) our assumption to concentrate on a pure labor economy as an

[2] As shown in Cutler et al. (1990, p.18), this "Solow effect" offsets the long-run dependency effect on US per capita consumption in the short run. On the other hand, it can be argued that significant proportions of excess savings may be invested abroad and not in the domestic capital stock so that the positive effects of higher capital intensity are of a smaller order of magnitude.

‘important departure for more complete models’.

The setup of the paper is as follows. In the next section we briefly review the methodology applied in projecting future impacts of demographic change on labor productivity. Our theoretical framework is reviewed in Section 3. In section 4 we present the demographic and labor supply forecasts in the G7 countries from 2005 to 2050 and outline two scenarios for the size and structure of the labor supply development. We apply alternative assumptions about the substitutability, productivity, and supply of workers of different ages to arrive at scenarios of future labor productivity in section 5. The last section concludes with a discussion of the main results and an outlook for further research.

2 Projecting the future impact of demographic change on labor productivity

To project the future impact of an aging labor force on macroeconomic variables, computational general equilibrium models (CGE models) are applied. In a recent study on labor market effects of population aging, Börsch-Supan (2002) shows that about half of the decline (of 15 per cent) in per capita output that results from the decrease in the labor force until 2035 can be compensated by the induced higher capital intensity. However, as he mentions, on p. 42, *‘... any possible age-structure related reduction in aggregate productivity ... would reduce the effect of higher capital intensity’*. He then concludes that an increase of productivity growth from 1.39 to 1.65 per cent would be necessary to maintain the per capita level of GDP as of 2000. Hence, strong productivity growth which in turn depends on increased capital intensity and human capital is necessary to keep up the consumption level if the labor force participation starts to decline.

A different approach – more related to demographic accounting than applying sophisticated economic modeling – to forecasting the effect of labor force aging on labor productivity is taken in Blanchet (1992) and Blanchet (2002). Interacting fixed and exogenously chosen age-productivity profiles with alternative projected demographic structures and age-specific labor force participation, Blanchet (1992) shows that the effect of labor force aging on labor productivity is moderate. To explain these results, the author refers to stable population theory which provides simple rules of thumb to assess the condition under which the average value of an age-dependent variable may be sensitive to changes in the population growth rate. In particular, he shows that a change in the population growth rate by 1 percentage point cannot have an aggregate impact of more than 20-25 per cent on any age-dependent phenomenon (see appendix A where we review the argument by Blanchet (1992)).

Aggregate economic productivity is not only determined by the change in individual-based productivity that works through a change in the age composition of the workforce, but as we know from the theory of factor demand, the impact of labor force aging and labor force shrinkage on labor productivity will depend on the substitutability of different factors of production. These include the substitution of capital for labor and the substitutability among workers of different age and education. Empirical studies have indicated that human capital of young and old workers are imperfect substitutes in production arguing that young and old workers have comparative advantages in complementary task (cf. Kremer and Thomson (1998)). As documented in Hamermesh (1993), chapter 3, the result of a relative decline in the supply of labor in a world consisting of homogeneous capital and labor would be declining interest rates and an increase in wage rates. However, the results are much less clear if one introduces more restrictive substitution patterns between workers disaggregated by age (Hamermesh (1993), Table 3.9).

Though Blanchet (2002) has taken up the role of imperfect substitutability of workers of different ages and its impact on labor productivity when population growth changes, his analysis is restrictive since he focused only on a stable population. However, to study the effect of imperfect substitutability between workers of different ages in times of population aging it is necessary to focus on transitional dynamics. We therefore extend the analysis of Blanchet (1992) and investigate the time path of labor productivity in a pure labor economy where workers of different ages are not perfect substitutes. Hence, we concentrate on dynamic features of population aging. In addition to studying the sensitivity of projected labor productivity with respect to the labor demand function we also investigate how future labor productivity will change depending on labor supply factors such as the individual age productivity profile and labor force participation rates.

3 Theoretical Framework

In the simulations presented in the following sections we want to analyze the sensitivity of the projected labor productivity with respect to alternative assumptions about future labor supply and the substitutability and productivity of the labor force at different ages. We assume that the output of a particular economy only depends on the input of labor and individuals aged 15 to 74 participate in the labor force according to the age-specific labor force participation rates given by the OECD labor market statistics.

We apply four different production functions. The first one is the *additive production function* which assumes perfect substitutability between labor at different ages. In this modeling framework the output at time t is given by

$$Y(t) = \sum_{x=15}^{70} \alpha_x \, {}_5L_x(t), \text{ with } \sum_{x=15}^{70} \alpha_x = 1, \tag{1}$$

where α_x indicates the productivity of the labor force in the five year age interval $[x, x+5)$ and ${}_5L_x$ indicates the labor force in this age interval, i.e., the population within that age interval, ${}_5N_x(t)$, multiplied by the age-specific labor force participation rate $\text{lfpr}_x(t)$ where we distinguish between female and male labor force participation rates. The functional form (1) implies that once workers of different ages are adjusted for their productivity differences they become identical inputs in economic terms. This is clearly unrealistic because it does not account for any degree of complementarity between workers of different ages. Examples of complementary age-dependent skills include the physical strength of young male workers that complements the skills that older workers have in managing people, including mentoring younger workers, and making decisions. Such complementarities are assumed away in the additive production function (1). Yet this is the typical functional form that has been commonly adopted to define the labor index in macroeconomic models applied to modeling demographic change.

The second production function we consider is the *Cobb-Douglas production function*,

$$Y(t) = \prod_{x=15}^{70} {}_5L_x(t)^{\alpha_x}, \text{ with } \sum_{x=15}^{70} \alpha_x = 1 \tag{2}$$

where the elasticity of substitution between any two input factors is constant and equals one. Alternatively, we assume a *constant elasticity of substitution production function* (CES) of the form

$$Y(t) = \left(\sum_{x=15}^{70} \alpha_x \, {}_5L_x(t)^{\rho} \right)^{\left(\frac{1}{\rho}\right)} \tag{3}$$

with $\sigma = \frac{1}{1-\rho}$ denoting the elasticity of substitution between labor force of different ages and $\rho \in (-\infty, 1]$. The additive and Cobb-Douglas production function are included in this general formulation and result if $\rho = 1$ and $\rho \to 0$, respectively. As already indicated in Blanchet (2002) the assumption of the CES production technology is restrictive as well. When workers from one age group are substituted by members of any other age group, the actual age difference does not matter. In reality one might assume that a person aged 25 can easily be substituted by another person aged 26 but not that easily by another person aged for instance 64. To take this into account we propose as the third alternative another kind of CES production function

$$
\begin{aligned}
Y(t) &= \Bigg[\alpha_{15}\left(\frac{3\,{}_5L_{15}(t)+\,{}_5L_{20}(t)}{4}\right)^{\rho} \\
&+ \sum_{x=20}^{65}\alpha_x\left(\frac{{}_5L_{x-5}(t)+2\,{}_5L_x(t)+\,{}_5L_{x+5}(t)}{4}\right)^{\rho} \\
&+ \alpha_{70}\left(\frac{{}_5L_{65}(t)+3\,{}_5L_{70}(t)}{4}\right)^{\rho}\Bigg]^{\left(\frac{1}{\rho}\right)} \qquad (4)
\end{aligned}
$$

which we will call *fuzzy CES* in the following. The above function takes into consideration that members of the two neighboring age groups are better substitutes than those in the age groups which are further away. Instead of just having one age group within each addend of the production function – like in formula (3) – we use a weighted average of three neighboring age groups. I.e., it is assumed that the direct elasticity of substitution of workers of different age is higher when they belong to consecutive age groups.[3] Therefore, each member of the labor force does not only contribute to the age group she actually belongs to but also – with a lower weight – to the neighboring age groups. While the previous production functions implicitly assume that an individual moves from age group x to $x+5$ at a certain moment, this production function takes into account that aging is a continuous process. This idea can be extended by combining for instance five age groups instead of three which would lead to an expression like

$$
\alpha_x\left(\frac{{}_5L_{x-10}(t)+2\,{}_5L_{x-5}(t)+4\,{}_5L_x(t)+2\,{}_5L_{x+5}(t)+_5L_{x+10}(t)}{10}\right)^{\rho}.
$$

The fuzzy CES implies that the elasticity of substitution between workers of different age groups depends (negatively) on the distance between age groups. This is an appealing notion. However, there is another appealing notion that is not readily captured by the fuzzy CES function, which is that workers of some ages are inherently more flexible than workers of other ages. Such workers are more substitutable with workers of any given age than are other workers. For example, it is reasonable to suppose that middle age workers are more flexible than either young workers or older workers,

[3]In a separate note that can be requested from the authors we show that the direct elasticity of substitution of the CES production function constitutes a lower bound for the direct elasticity of substitution between any two inputs of the fuzzy CES production function.

because middle age workers have some characteristics of both young workers and older workers. For example, they have moderate physical abilities, albeit not as much as young workers; and they have some of the attributes that come with age and maturity, such as skills in managing people. One way of capturing this idea is to assign to each age group a parameter which captures their degree of flexibility. This can be achieved through a *CRESH function* (Hanoch (1971)) of labor inputs distinguished by age that constitutes our fourth alternative of the production function:

$$\sum_{i=1}^{k} \alpha_i \left[\frac{L_i}{f(Y)} \right]^{\rho_i} = 1 \tag{5}$$

where α_i is the productivity weight of labor of age i, k is the number of age groups, L_i is the number of workers of age i, Y is the index of composite labor inputs and ρ_i is a parameter that determines the flexibility, or versatility, of L_i, meaning the degree to which L_i can substitute for any other input, L_j. We assume here that all labor inputs are substitutes to some degree, which restricts ρ_i such that $\rho_i \in (-\infty, 1]$. Note, that as $\rho = 1$ ($\rho_i = \rho$) the additive (CES) production function results. As ρ approaches zero or $-\infty$, the Cobb Douglas and alternative the Leontief production function results.

The elasticity of substitution, σ_{ij}, between L_i and L_j, is given by Hanoch (1971, p.699).

$$\sigma_{ij} = \frac{a_i a_j}{\sum_{m=1}^{k} s_m a_m} \tag{6}$$

where $a_i = \frac{1}{1-\rho_i}$ and s_m is the factor share of L_i. The larger the value of a_i, the more easily L_i is substitutable for any other labor input. This implies that two labor inputs with high values of a_i will be good substitutes and two inputs with low values of a_i will be poor substitutes. Restrictions exist on the range of values of the σ_{ij} that yield a unique solution for the CRESH function (Hanoch (1971)). The binding restriction in the present application is that for all i, either $0 < \rho_i < 1$ ($a_i > 1$) or $\rho_i < 0$ ($0 < a_i < 1$).

In applying the CRESH function we assume that middle age workers are more flexible than either young workers or older workers. The degree of flexibility is a hump shape function of age, rising to middle age then falling to old age. Appendix C gives the matrix of values of σ_{ij} that are used in the simulations. These values were chosen arbitrarily subject to the restrictions on the parameters mentioned above, and such that the resulting values for the elasticity of substitution are in the range of values for the elasticity of substitution that are commonly used in applications of CES functions.

4 Demographic and Labor supply forecasts for G7

In figure 1a) we plot the development of the total population in the G7 countries from 2005 to 2050.[4] The populations of Canada and USA are continuously increasing during the whole time period of observation but the populations of all other G7 countries have already started to gradually decrease or will start to decrease in the first half of the 21st century. As outlined in McDonald and Kippen (2001, p.2) population can be maintained in the US/Canada due to high/moderate fertility and moderate/high net immigration. UK and France are characterized by a moderate level of fertility and low levels of net immigration while the situation is even worse for Germany, Japan and Italy where fertility as well as net migration are rather low.

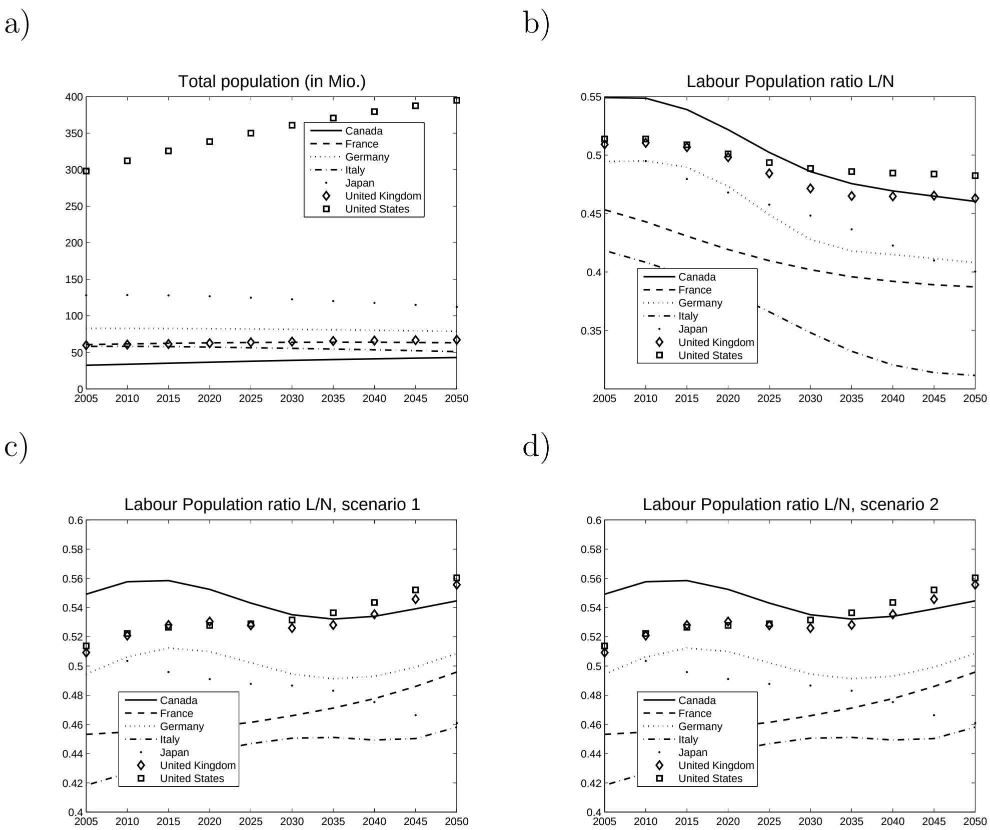


Figure 1: Total population and Labor/Population ratio

The projected demographic change will have an impact on the size and

[4]Source: World Population Prospects: The 2004 Revision, medium variant.

structure of the labor force through (a) a compositional effect that works through the age structure and (b) through a direct or behavioral effect that operates via a change of age specific labor force participation rates. As Johnson (2002), p.113 notes "... demography is not the only, or even the most important, factor influencing the relative size and structure of the labor force." p.114: "Furthermore, behavioral factors which determine age- and sex-specific participation rates are more important than the population age structure in determining economy-wide employment shares." Changes in age-specific rates may be caused by individual factors as well as institutional and macroeconomic variations, which include shifts in the demand as well as supply of labor (e.g., economic swings, delayed labor market entry due to prolonged education, early retirement exits). These micro and macro-level determinants may in turn be related to demographic changes as put forward by Easterlin (1978) and more recently by Shimer (2001).

Figures 2a) and b) show the age–specific labor force participation rates of the G7 countries in 2004.[5] For males the variance of labor force participation rates among the G7 countries is especially pronounced at older ages. The highest labor force participation rates for older males can be observed in Japan followed by the US, Canada and the UK. For France, Germany and Italy the labor force participation rates at older ages are much smaller. (Among male workers aged 60 to 64 only 19, respectively 35 and 30 percent are in the labor force. The corresponding numbers for Japan, the US, Canada and the UK are 70, 57, 53 and 56 per cent.) For females the variance of the labor force participation rates across the G7 countries is most pronounced in the middle ages with Italy and Japan having the lowest rates with female labor force participation rates in the ages 25 to 59 being between 60 and 70 per cent and reaching values as low as 30 per cent for e.g. females in Italy aged 55 to 59. At older ages we observe a similar pattern as for males. The highest lfpr can be observed for females in Japan, US, Canada and the UK where 40, 45, 35 and 30 per cent of females are still in the labor force.

If we combine the age–specific population data with the labor force participation rates and assume that the labor force participation rate is kept constant from 2005 to 2050 we obtain the support ratios depicted in figure 1b). These computations clearly neglect the changes in labor force participation rates that will take place from 2005 onwards. Therefore, these graphs are illustrations of the age–compositional effect rather than a projection of the actual support ratios. The simulations highlight the strong demographic

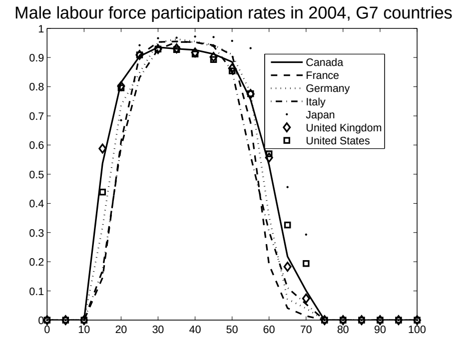
[5]Source: OECD Labor Market Statistics – INDICATORS LFS by sex and age – standard labor market indicators. The lfpr for the age groups 0–14 and 75+ are assumed to be equal to zero. The values at the x–axis always indicate five year age–groups. For instance 20 stands for the age–group 20–24.

pressures that interact with disincentives for labor force participation rates in the countries considered. Only for the United States, the United Kingdom and Canada the support ratio is currently above 50 per cent. While for UK and US a fall of the support ratio by approximately 5 per cent is projected, Canada will experience one of the most pronounced declines in its support ratio (approximately by 10 percent). For all other countries the support ratio has already fallen below 50 per cent in 2005 and is projected to further decline during the next five decades. For Italy the support ratio will fall as low as 30 percent until 2050 while the support ratio will stabilize around 40 percent for Japan, Germany and France.

A decrease in the working age population is expected in many of the developed countries. Since immigration and fertility cannot compensate this trend the need to integrate female and elderly into the workforce arises (cf. McDonald and Kippen (2001) for an extensive discussion on labor supply prospects in developed countries). Comparing the labor force of the G7 countries with those in the Nordic countries illustrated in figures 2c) and d) indicates that the potential labor force in the G7 countries is not yet exploited completely. A gradual increase of the labor force participation rates to those levels already achieved in the Nordic countries in 2004 would at least mitigate the negative impact of shrinking populations and age–compositions moving to higher ages. Since the labor force participation rates in Iceland are extremely high we will discuss two labor force scenarios in the following. In scenario 1 we take the maximum of the age– and sex–specific labor force participation rates in the G7 plus the Nordic countries not including Iceland as an upper bound and in scenario 2 we include Iceland as well. Starting from the country specific labor force participation rate as observed in 2004 we assume that this upper bound is reached gradually in 2050.

Thus, in the first scenario there is no possibility to increase the labor force participation rates of males in Japan in the future while in the second scenario this possibility exists. The impact of these two labor force scenarios on the support ratio from 2005 to 2050 is depicted in figures 1c) and d). For all countries, except Japan, an increase in labor force participation rates to levels currently observed for Nordic countries, will stabilize or even increase the support ratio. Obviously, the largest potential to raise overall employment lies within those countries with lower employment rates and/or larger working age population.

a)



b)

c)

d)

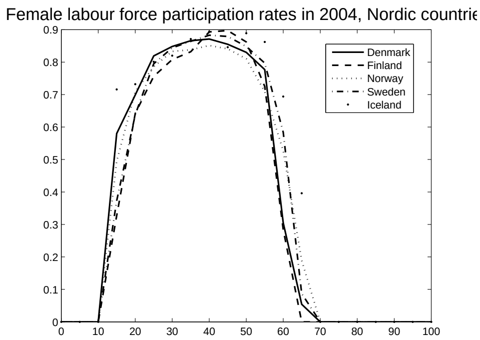


Figure 2: Labor force participation rates

5 Simulation Results

To project labor productivity we multiply the age-dependent productivity schedule α_x with the distribution of the work force by age and divide by the total size of the labor force. In a first step we investigate the sensitivity of those projections if we assume equal productivity schedules across ages, but vary the elasticity of substitution across age groups. We base this first set of simulations on the constant labor force participation scenario as of 2004. Next, we allow for alternative shapes of the age-productivity schedules and labor force participation rates to study the sensitivity with respect to labor supply as opposed to the labor demand function.

5.1 Equal productivity across age, constant labor force participation

The graphs in figure 3 illustrate output per worker Y/L in the G7 countries assuming that the age–specific labor force participation rates remain at the level from 2004 and the productivity is the same for all age groups from 15–19 to 70-74. We compare only relative levels of output per worker because alternative production functions applied for these trajectories lead to different levels of output per capita which do not allow for meaningful comparisons. Relative output means that we scale the whole trajectory such that the output in 2005 is 100.

Figure 3a) depicts the results obtained from an additive production function where the index of labor is independent of the age distribution of the labor force as reflected in the horizontal line in Figure 3a). Figure 3b) is the same with a Cobb–Douglas production function. Figure 3c) and d) illustrate the outcome applying the fuzzy CES production function with parameters $\rho = 0.5$ and -1 while figure 3e) and f) depict the outcome applying the CRESH production function with high and respectively low elasticity of substitution.

If we relax the assumption of perfect substitutability between workers of different ages, the change in the size and composition of the workforce will no longer be neutral for forecasts of output per worker. The lower the elasticity of substitution between workers of different ages (i.e., the lower the value of ρ), the more pronounced fluctuations of output per worker are to be expected. Note, that the results are qualitatively similar for the fuzzy CES and CRESH production function.

The results are intuitive since output maximization for a CES type production function with equal productivity for all ages is achieved if the age distribution is uniform (see appendix B where we review the argument brought

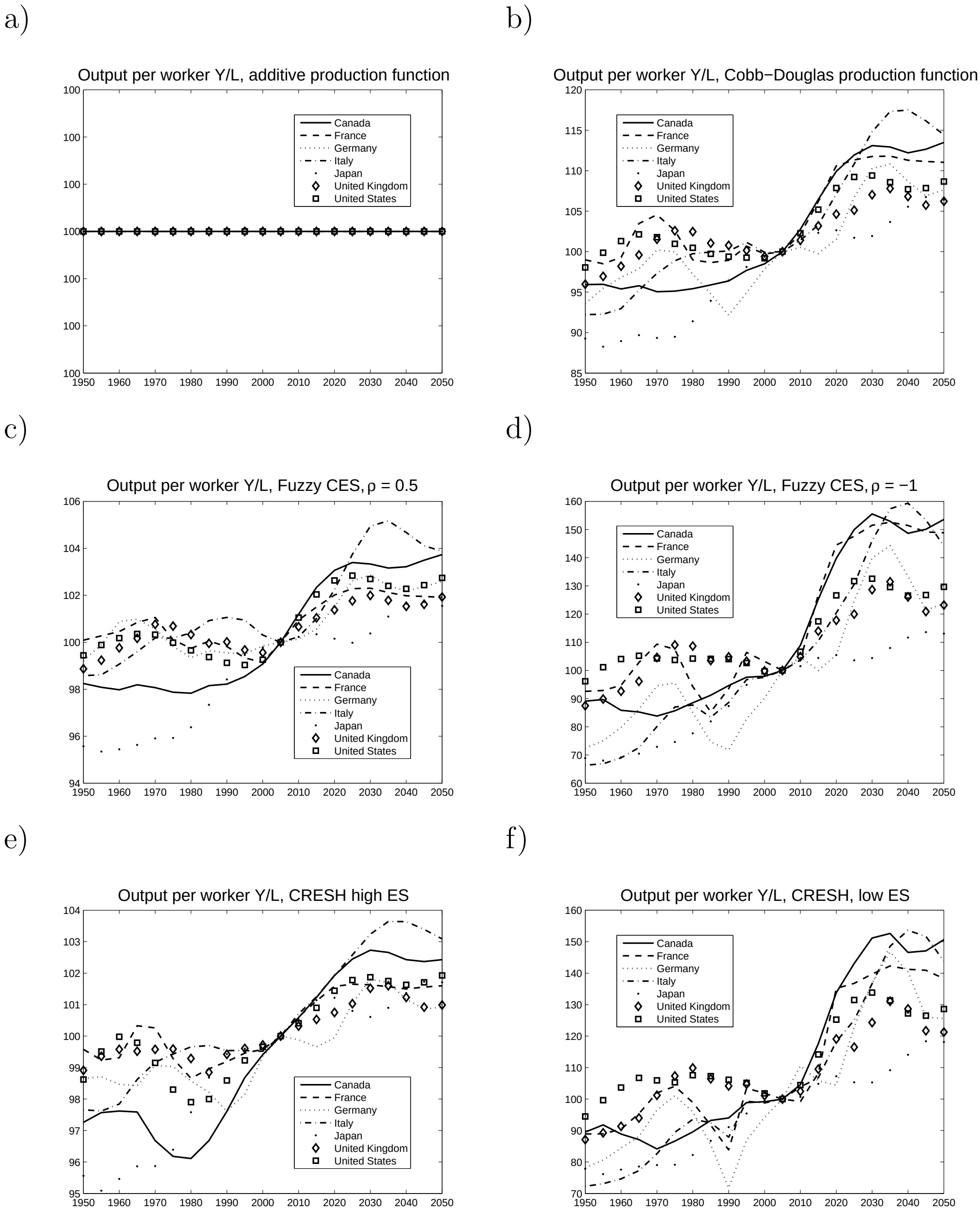


Figure 3: Output per worker Y/L

forward by Lam (1989), Section 3.) The magnitude of the age distribution effect across the G7 countries depends on the differences between the optimal age distribution and the projected actual distribution where the optimal age distribution depends on the elasticity of substitution.

It is interesting to note that for all G7 countries during the next decades the actual age distribution of the workforce can be expected to shift closer to the optimal age distribution, generating a dividend in terms of aggregate labor productivity. Our simulations indicate that the the size of the effect depends on the elasticity of substitution and differs across the countries. While Japan will experience the lowest dividend, Canada together with Italy and France are expected to experience the greatest dividend.

5.2 Age specific productivity, constant labor force participation

Now we modify our model such that we assume that workers of different age have different productivity levels. Figure 4 illustrates two age–productivity profiles. The first profile — "equal" — is the one which we applied to compute the results shown in figures 3. The second profile — "hump–shaped" — assumes that workers are most productive in the middle of their working life. We applied estimates of Skirbekk (2005) assuming that the individual productivity within a ten year age group is the same for both five year age groups within that range and individual productivity does not decrease between 65 and 75. If we apply this profile to the same lfpr profiles and production

Figure 4: Age–productivity profiles

functions like before we obtain the results depicted in figure 5.

By allowing productivity to vary by age, the projected changes in the size and composition of the labor force will have an effect on output per worker

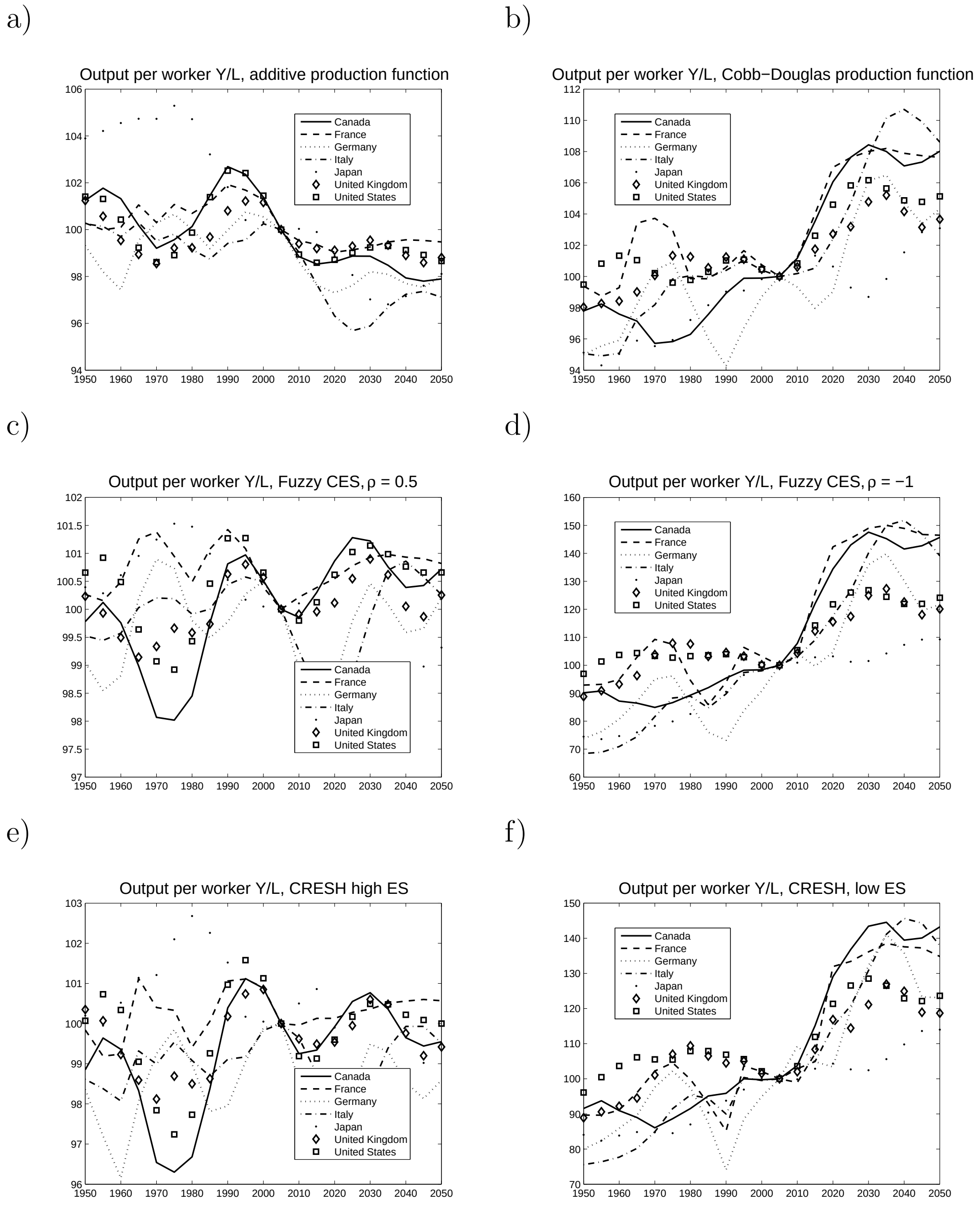


Figure 5: Output per worker Y/L

also in case of an additive production function that assumes perfect substitutability of workers of different ages. Combined with an aging labor force, the assumption of decreasing productivity by age will lead to slightly lower output per worker compared to a scenario with age-independent productivity. However, the effect of age specific productivity is rather modest as compared to the effect that is related to the choice of the production function. Similar as in the previous section our simulations indicate that Japan will experience the lowest dividend from workforce aging while Canada together with Italy and France will experience the greatest dividend. [6]

5.3 Age specific productivity, increasing labor force participation

In the next step we do not keep the labor force participation rates constant at the value of 2005 anymore but apply the scenarios 1 and 2 discussed in section 4. To facilitate comparison of the different labor force scenarios we group the results by country. Each of the figures 6 to 12 illustrates the output per worker Y/L for one particular G7 country. The graphs in the first column assume that workers of different age have the same productivity while the graphs in the second column are based on the hump–shaped age-productivity profile. The graphs in the first row are generated by keeping the labor force participation rates constant at the level of 2004 — these are the results already shown in the previous graphs but now they are sorted by country. The graphs in the second row illustrate the labor force scenario 1 (excluding Iceland for computing the upper bound) and the graphs in the third row describe scenario 2 (including Iceland).

We can draw the following conclusions from the set of simulations: (a) The effect of age specific productivity — at least given the age-specific schedule we assume — is rather modest compared to the effects that are related to the choice of the production function and the labor force projections. Compared to simulation results that assume equal productivity schedule by age (figures in first column) we find that labor productivity is slightly lower if we apply the hump shaped pattern of productivity by age (figures in second column). A hump shaped pattern of age-productivity will depress labor productivity more likely in countries where our labor force scenarios imply a pronounced increase in the number of older workers (compared to the base

[6] For the additive production function and assuming age-varying productivity, the optimal age structure, i.e., the age distribution that optimizes output, is achieved if all workers are in the age group with the highest productivity. However, the concentration of the population distribution towards these ages declines over the next few decades.

level as observed in 2005). For instance this is the case for France (cf. comparing Figure 7c) and Figure 7d) and respectively Figure 7e) and Figure 7f)). (b) The dividend of work force aging increases the lower the substitutability of workers at different ages, i.e. the projected age distribution of the labor force is close to the optimal age distribution that results if workers of different ages are substitutable at a low level. Note, that the difference between the fuzzy CES and CRESH function increases the lower the substitutability of workers of different ages. (c) A comparison across rows indicates that the dividend of workforce aging is more pronounced if we also add the assumption of increasing labor force participation rates. However the extent of this further increase in the dividend differs across countries. It is most pronounced in France (Figure 7) and the least pronounced in Japan (Figure 10) and the United States (Figure 12). For Japan, the increase in labor force participation rates even leads to a decline in projected relative productivity per worker during the next three decades as opposed to the scenario where we kept labor force participation rates constant. For Italy, the projected increase in labor force participation rates does not yield a similar increase in labor productivity as indicated for France. As argued also in McDonald and Kippen (2001, p.19) for Italy: "In the longer term, however, labor supply can only be maintained through increases in fertility."

6 Discussion

The shrinkage and aging of the work force is expected to depress labor productivity in the future. Policies aimed at increasing labor force participation rates (mainly among females and elderly) and policies that promote human capital at all ages are high on the agenda. So far, only the labor supply side has been discussed. However, as we argue in this paper, projected labor productivity will depend on the labor demand side as well. The fact that workers of different ages are not perfect substitutes in production has been studied by economists as well as demographers. In particular, the entry of the baby boom cohort into the labor market has initiated a vast literature that studied the complementarity of workers at different age and by gender. Though it is difficult, if not impossible, to project the labor demand structure over a time horizon of five decades, our paper is aimed to highlight the important role of the assumption on the demand structure of labor. In particular, our simulations indicate that in a pure labor economy, the assumption of imperfect substitution of workers at different ages implies a dividend from workforce aging during the next decades. Workforce aging implies that the actual age distribution of the workforce can be expected to shift closer to the optimal

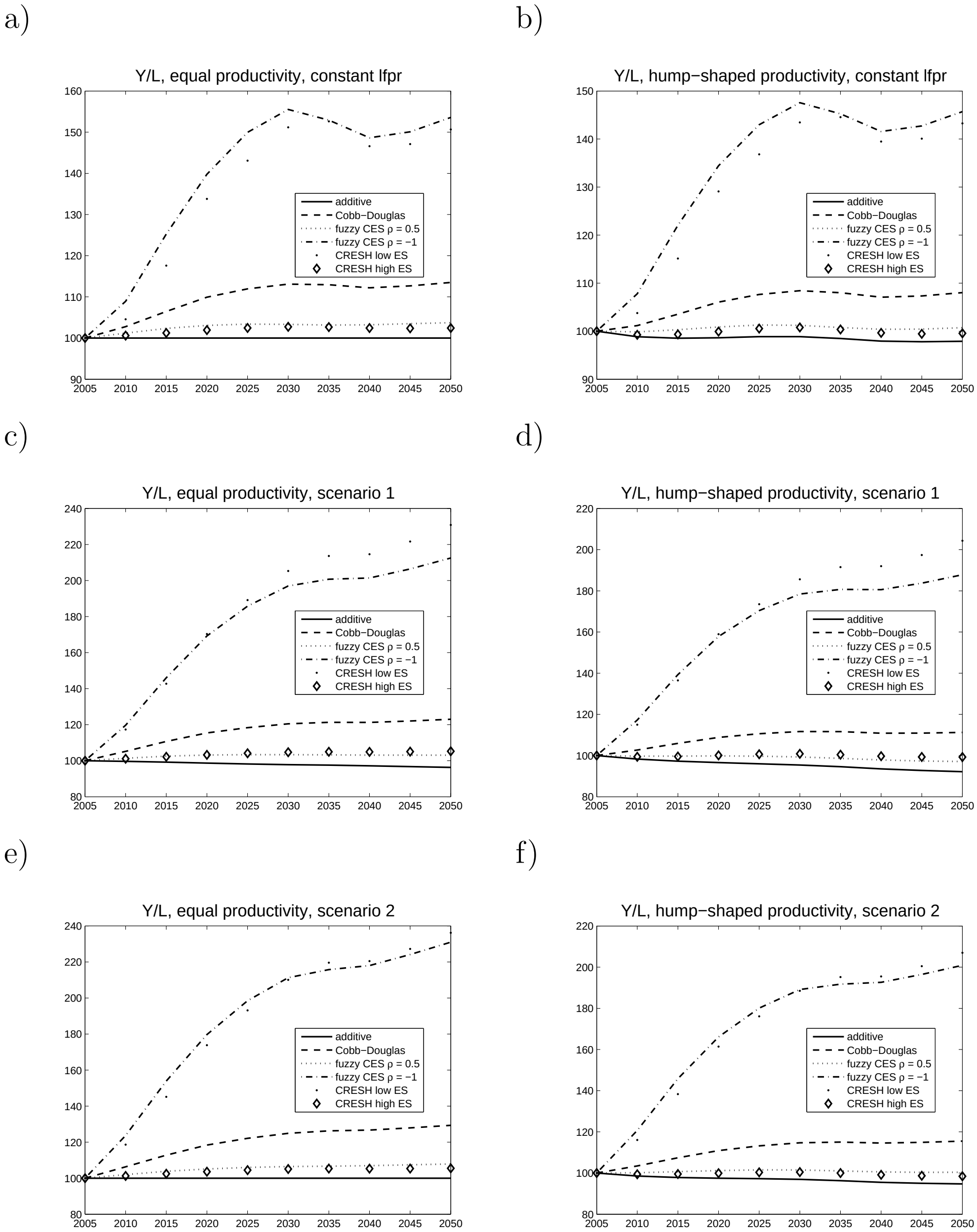


Figure 6: Canada, output per worker

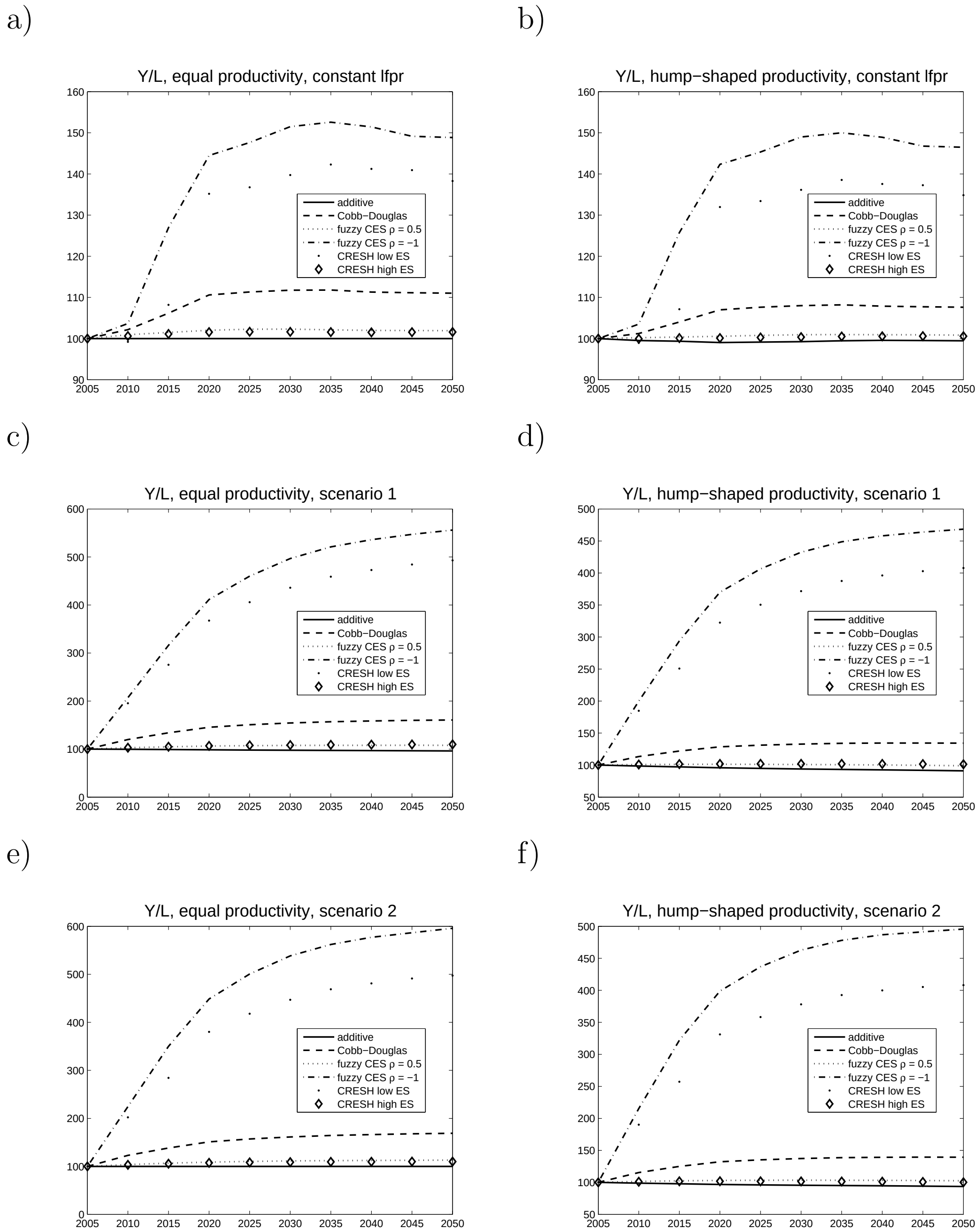


Figure 7: France, output per worker

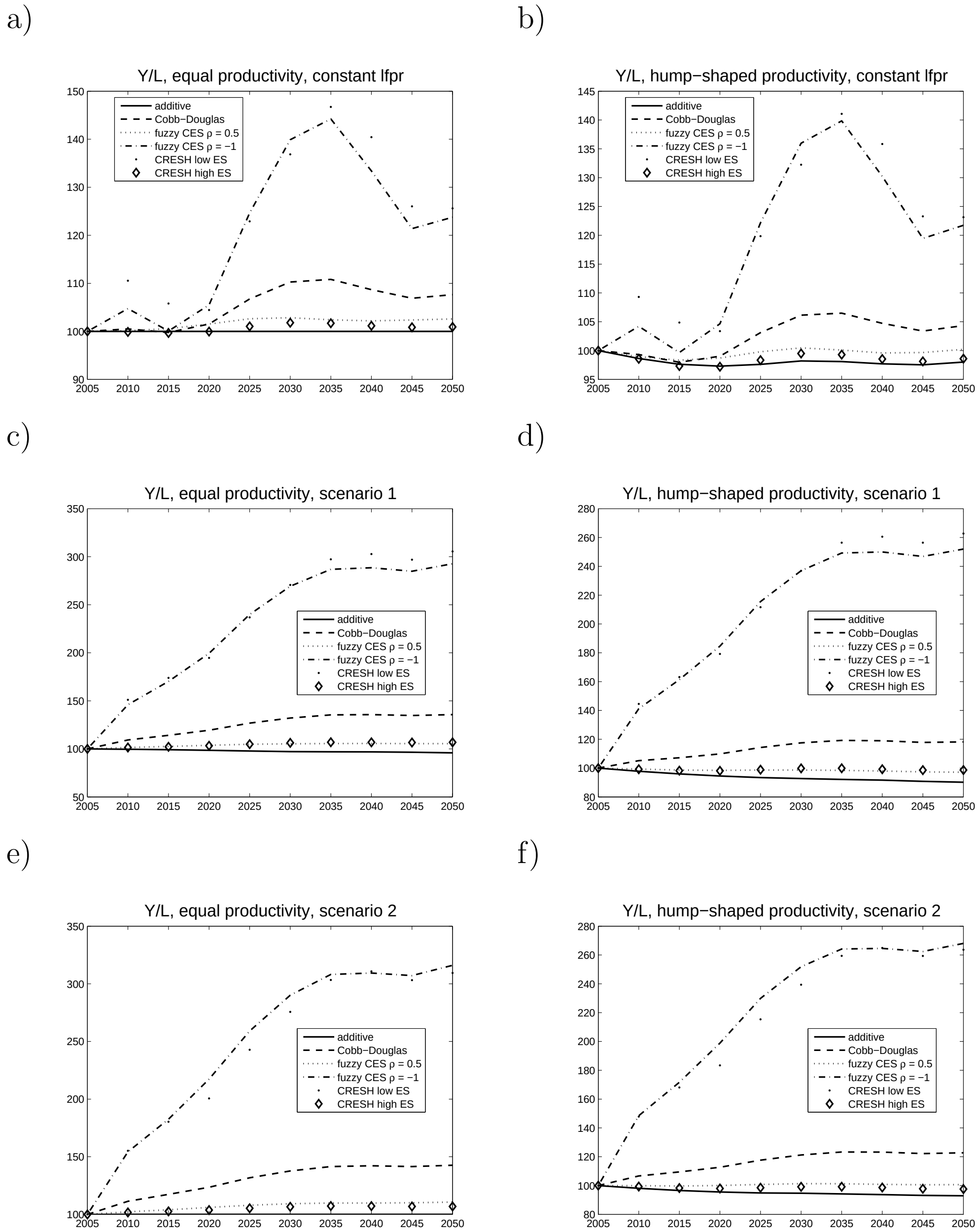


Figure 8: Germany, output per worker

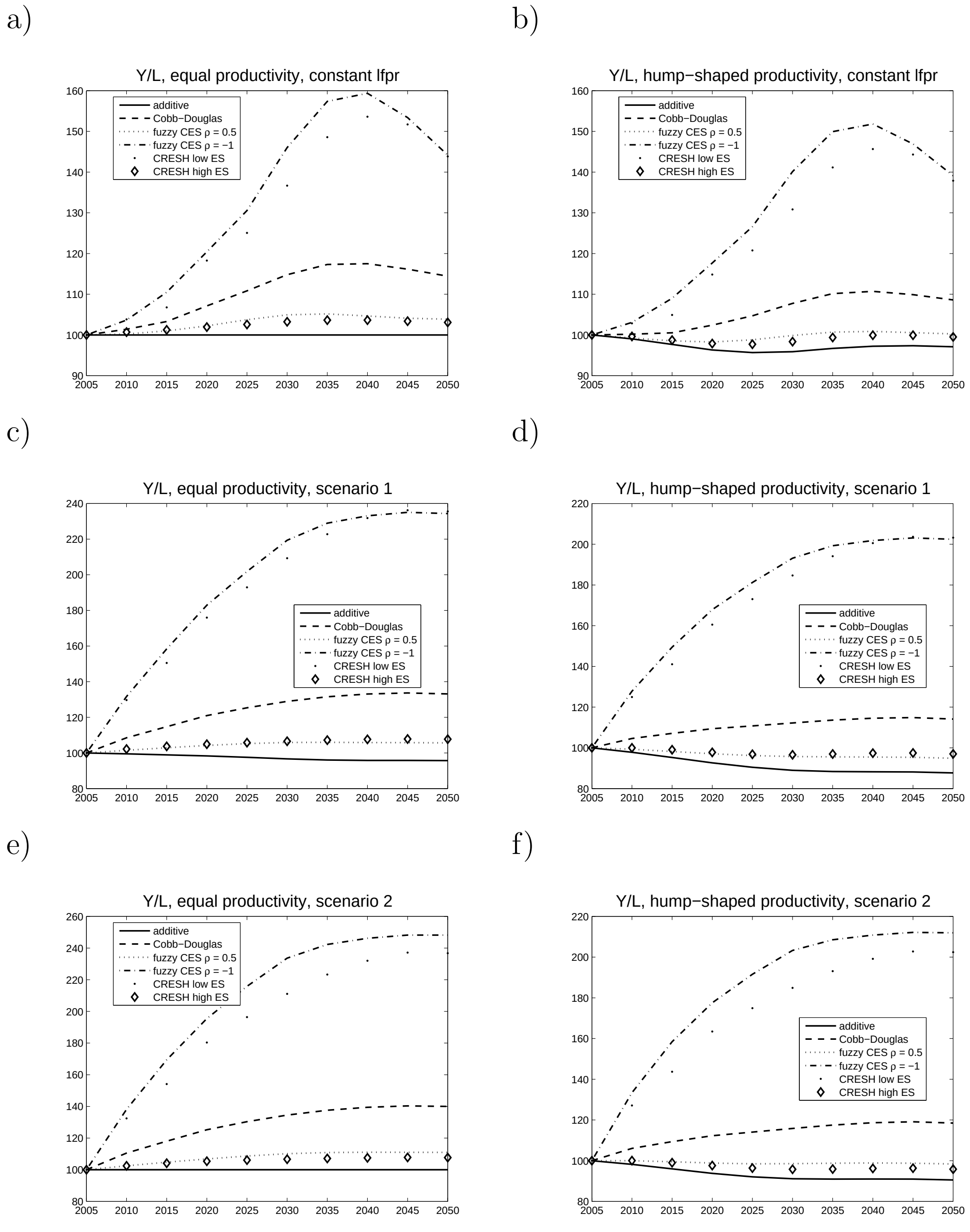


Figure 9: Italy, output per worker

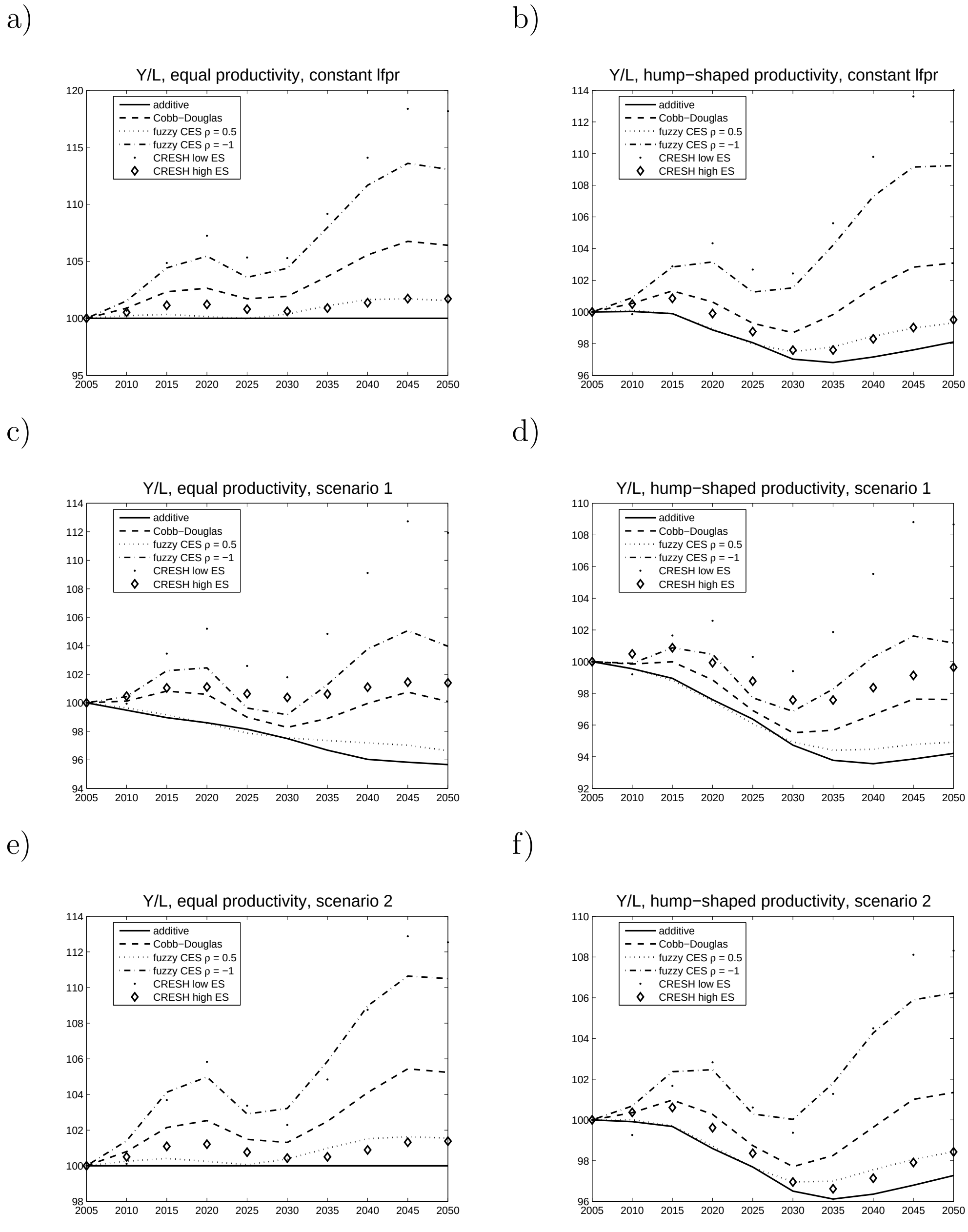


Figure 10: Japan, output per worker

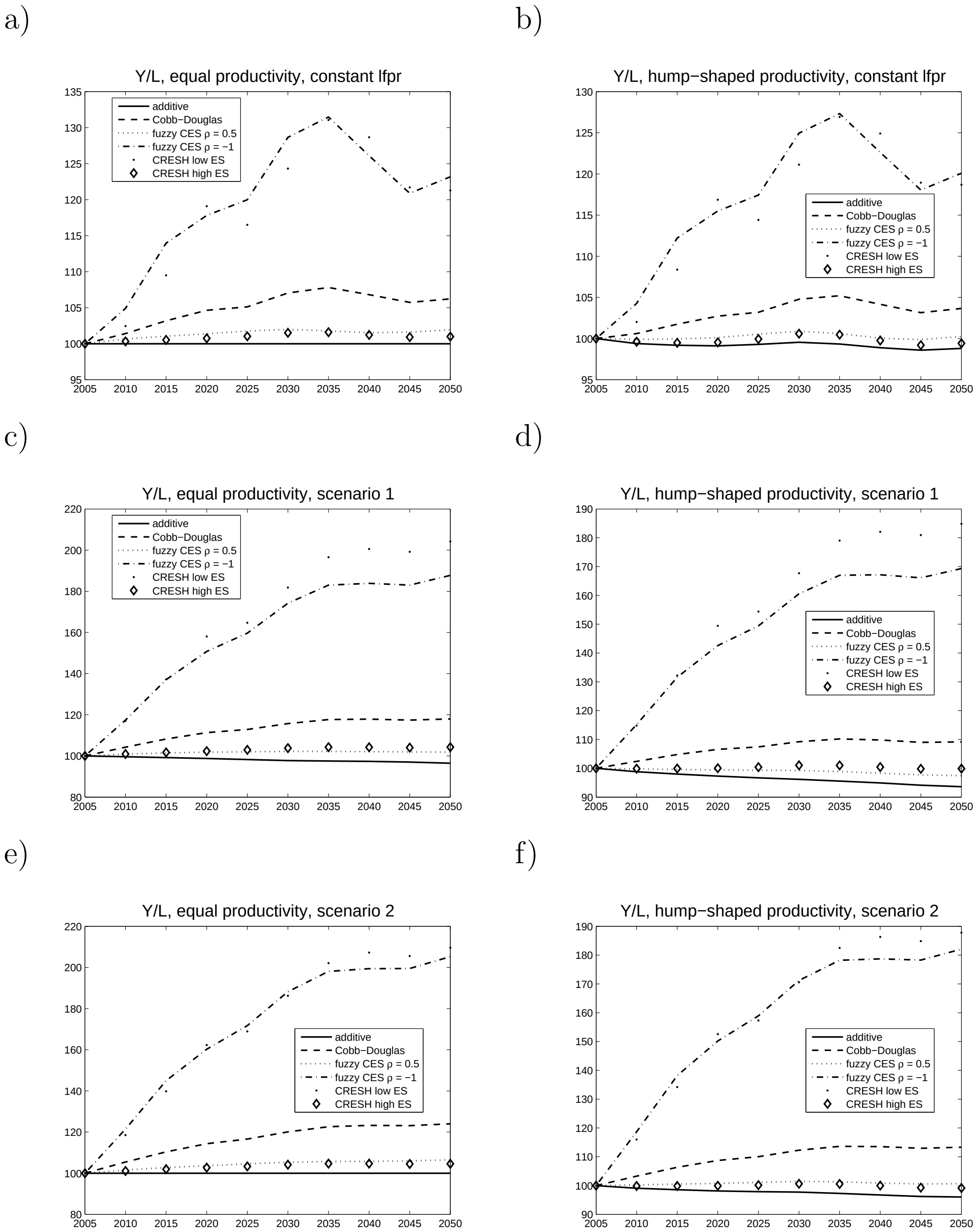


Figure 11: United Kingdom, output per worker

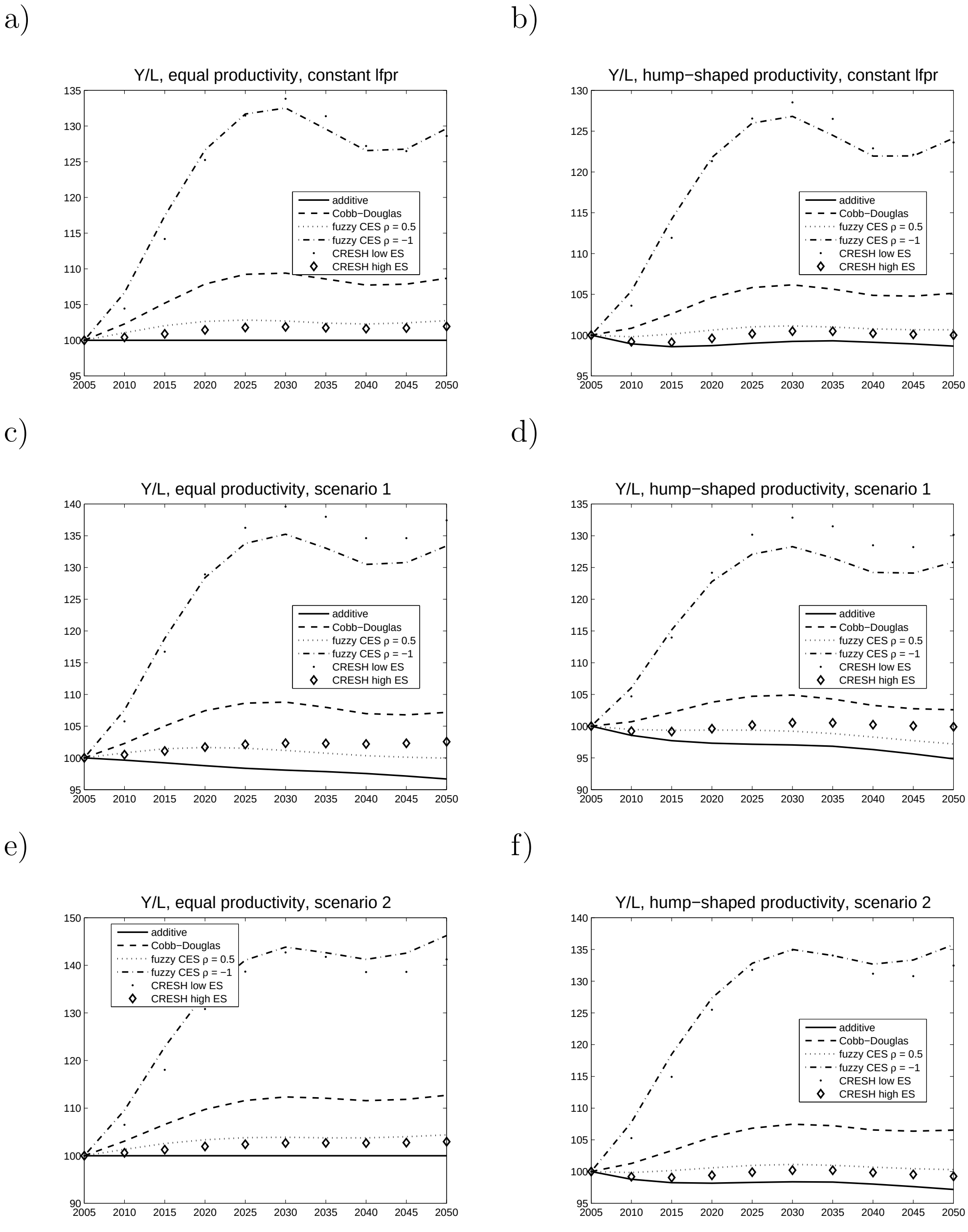


Figure 12: United States, output per worker

ag distribution generating a dividend in terms of labor productivity. Simulations suggest that the dividend is likely to be non-trivial and it is negatively related to the elasticity of substitution of workers at different ages.

Within our framework of a pure labor economy, changes in age specific productivity schedules have only a small impact on the projected labor productivity. Increases in labor force participation rates over the next five decades to levels currently observed in Nordic countries, have a rather pronounced impact. The efficacy of increasing labor force participation rates is contingent upon the scope of increase and the assumption that e.g. workers induced not to retire are good substitutes for younger workers (cf. McDonald and Kippen (2001)). A key question is definitely how firms will be able to adjust to shifts in the composition of the workforce that will result given the demographic projections and our alternative scenarios of labor force participation rates.

In summary, our paper aimed to show that issues on labor demand are central to the question how population aging will impact labor productivity. Scenarios on the future quantity and quality of labor supply as implicitly represented by our scenarios on the labor force participation rates and age productivity schedules, will in turn interact with the labor demand pattern. As argued above, the question on the degree of substitution of workers at different ages has been addressed before, but we need new empirical studies (most promising at the firm level) and new theoretical models that allow us to understand possible implications of population aging for the structure of labor demand. Furthermore, we need to extend our framework to include physical and human capital, factors which themselves will change in an aging society and will be complementary or substitutable to workers of different ages. To conclude with, we need to stress that our paper ignores equilibrium analysis and only indicates partial effects of population aging.

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A The effect of labor force aging on labor productivity in a stable population

The average value of an age-specific variable $x(a)$ over ages a_1 to a_2 in a stable population that grows at rate n and has a survivorship function $s(a)$ can be written as:

$$\bar{x} = \frac{\int_{a_1}^{a_2} x(a)s(a)e^{-na}da}{\int_{a_1}^{a_2} s(a)e^{-na}da} \tag{7}$$

The logarithmic derivative of $\bar{x}$ is then equal to

$$dlog\bar{x} = \frac{d\bar{x}}{\bar{x}} = (-A_x + A)dn \tag{8}$$

where A is the mean age of the population and A_x is the mean age associated with the characteristic $x(a)$.

If one limits the labor force participation to ages $[\alpha, \beta]$ it follows that $A - A_x$ is bounded in absolute values by $(\beta - \alpha)/2$, i.e., about 20 to 25 ages. Hence, a change of the population growth rate by 1 percentage point cannot have an aggregate impact of more than $20 - 25\%$.

B Output maximization with CES technology

Lam (1989, Section 3) considers a CES production function $Y = [\alpha L_1^\rho + (1-\alpha)L_2^\rho]^{1/\rho}$ which can be rewritten as $Y = L[\alpha\pi^\rho + (1-\alpha)(1-\pi)^\rho]^{1/\rho}$ with π denoting the proportion of the labor force in the young age group. It can be shown that for given values of ρ and α there exists a unique value of the share of the labor force in the young age group π that maximizes the value of total output, i.e., which equates the marginal products of the two ages of workers. More specifically, output per period attains a maximum when

$$\frac{\pi}{1-\pi} = \left[\frac{\alpha}{1-\alpha}\right]^\sigma \tag{9}$$

with $\sigma = 1/(1-\rho)$ denoting the elasticity of substitution between the young and old labor force age groups. From (9) it follows that if the two types of workers have equal productivity ($\alpha = 0.5$) output will be maximized when $\pi = 0.5$, i.e., when the age distribution of the labor force is uniform. If $\alpha \neq 0.5$, however, the elasticity of substitution will determine the division of labor that maximizes output. For instance, if $\alpha < 0.5$ the optimal value of π will be less than 0.5 since a greater proportion of older workers will be required to equate the marginal products of the two age groups. As the degree of substitutability increases, a higher ratio of older workers to younger workers is required to equilibrate their marginal products and the output maximizing value of π will decrease.

The above considerations can be applied to the labor demand function as given in (3). Denoting by π_x and π_y the share of the labor force in age group x and y, the output maximization condition is:

$$\frac{\pi_x}{\pi_y} = \left[\frac{\alpha_x}{\alpha_y}\right]^{\sigma}. \tag{10}$$

For an age-independent productivity schedule $\alpha_x = \alpha_y$ we obtain that $\pi_x = \pi_y$ for any pair of ages x, y. In other words, a uniform age distribution within the labor force ensures maximum output per worker.

In case of age-dependent productivity – for instance decreasing or hump-shaped – the optimal age distribution of the workforce will differ from the uniform age distribution. Formula (10) indicates that an optimal age-structure requires a higher share of those age-groups with higher productivity and a lower share of those with lower productivity.

C Parameters chosen in applying the CRESH function

HIGH elasticity of substitution

a_i	ρ_i	s_i		15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74
2	0.500	0.051	$15-19$												
2.2	0.545	0.084	$20-24$	1.65											
2.4	0.583	0.128	$25-29$	1.80	1.98										
2.6	0.615	0.132	$30-34$	1.95	2.15	2.35									
2.8	0.643	0.139	$35-39$	2.10	2.32	2.53	2.74								
3	0.667	0.161	$40-44$	2.26	2.48	2.71	2.93	3.16							
3	0.667	0.119	$45-49$	2.26	2.48	2.71	2.93	3.16	3.38						
2.8	0.643	0.100	50-54	2.10	2.32	2.53	2.74	2.95	3.16	3.16					
2.6	0.615	0.052	55-59	1.95	2.15	2.35	2.54	2.74	2.93	2.93	2.74				
2.4	0.583	0.025	60-64	1.80	1.98	2.17	2.35	2.53	2.71	2.71	2.53	2.35			
2.2	0.545	0.007	65-69	1.65	1.82	1.98	2.15	2.32	2.48	2.48	2.32	2.15	1.98		
2	0.500	0.003	70-74	1.50	1.65	1.80	1.95	2.10	2.26	2.26	2.10	1.95	1.80	1.65	

$\sum a_i s_i = 2.66$

LOW elasticity of substitution

a_i	ρ_i	s_i		15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74
0.6	-0.667	0.051	15-19												
0.66	-0.515	0.084	20-24	0.50											
0.72	-0.389	0.128	25-29	0.54	0.60										
0.78	-0.282	0.132	30-34	0.59	0.65	0.70									
0.84	-0.190	0.139	35-39	0.63	0.69	0.76	0.82								
0.9	-0.111	0.161	40-44	0.68	0.74	0.81	0.88	0.95							
0.9	-0.111	0.119	45-49	0.68	0.74	0.81	0.88	0.95	1.01						
0.84	-0.190	0.100	50-54	0.63	0.69	0.76	0.82	0.88	0.95	0.95					
0.78	-0.282	0.052	55-59	0.59	0.65	0.70	0.76	0.82	0.88	0.88	0.82				
0.72	-0.389	0.025	60-64	0.54	0.60	0.65	0.70	0.76	0.81	0.81	0.76	0.70			
0.66	-0.515	0.007	65-69	0.50	0.55	0.60	0.65	0.69	0.74 0.74	0.69	0.65	0.60			
0.6	-0.667	0.003	70-74	0.45	0.50	0.54	0.59	0.63	0.68	0.68	0.63	0.59	0.54	0.50	

$\sum a_i s_i = 0.88$