Inequality Over the Life-Cycle: U.S. vs Europe*

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Abstract

I document that (i) the mean and dispersion of pre-tax labor earnings grow faster over the life-cycle in the U.S. than in some European countries; (ii) these facts are largely driven by individuals with at least a college degree. I study these differences in labor earnings inequality using a life-cycle model of human capital accumulation and elastic labor supply which features non-linear taxation, in conjunction with a college choice and complementary investments during college. The model economy accounts for the differential mean earnings growth patterns of individuals with and without a college degree in the United States, as well as the observed within-group inequality over the life cycle. In the model, non-linear taxation significantly suppresses pre-tax earnings, reduces college attendance, and investments during college. More generous subsidies and transfers for college exacerbate labor earning inequality. I find that differences in taxation and college subsidies alone account for 94% of the differences in mean earnings, and 80% of the differences in variance of log earnings over the life-cycle across the U.S. and European countries. To fully reconcile the model with data, the role of differences in initial conditions appear key.

Keywords: Life Cycle Models and Saving, Education and Inequality, Human Capital.

JEL codes: D15, I24, L26.

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1 Introduction

Inequality in labor earnings is higher in the U.S. cross-section than Europe, as measured by several indicators such as gini coefficient, share of earnings going to the top percentile, etc (Piketty & Saez, 2006; Guvenen *et al.* , 2014). One critical step in understanding earnings inequality in the cross-section is understanding the forces that shape inequality over the life-cycle. Specifically, one can ask, what are the determinants of life-cycle inequality in labor earnings? Are there significant differences in life-cycle inequality across the U.S. and Europe? How do these determinants interact with taxation and education policies? The goal of this paper is a quantitative exploration of these questions by studying life-cycle inequality in (pre-tax) labor earnings for males and the impact of labor market (tax) policies and higher education subsidies/transfers on college attainment and life-cycle earnings, using cross-country data, and focusing on the U.S., U.K., Netherlands, and France.

I document that the mean and dispersion in labor earnings grow fastest in the U.S., followed by the U.K., Netherlands and France (see figure 1).[1] For example, the growth in mean earnings between ages of 25 and 50 is a factor of 2.2 in the U.S., while it is only a factor of 1.5 in France. Differences in mean earnings mask the observed differences in the heterogeneity in earnings growth over the life-cycle across individuals. For instance, the variance of log earnings grows faster in the U.S. (40 log points), followed by the U.K. (30 log points) and Netherlands and France (both 20 log points). The increase in the variance of earnings indicates that as individuals age in the labor market, the differences in earnings across individuals grow and this growth is faster in the U.S. (see figure 4).

The second new fact that I uncover is that the differences in mean and dispersion of earnings over the life-cycle across the U.S. and Europe are driven by individuals with at least a four-year college degree (or its equivalent). Figure 2 shows that the mean earnings for those individuals without a college degree grow by a factor of 1.5 in "all" countries. Then, by definition, individuals with a college degree drive the differences in mean earnings across these countries. Variance of log earnings over the life-cycle show similar growth across all the countries for non-college individuals

[1] Guvenen *et al.* (2014) show similar results for these countries, though they leave out a quantitative exploration of them. Badel *et al.* (2018) show similar patterns across the U.S., Canada, Sweden, and Denmark. They do not however, make quantitative statements about the profiles.

(figure 5). This means that the bulk of the growth in dispersion is also due to college graduates.

Differences in life-cycle inequality across these countries are correlated with differences in taxation and education policies. First, I document that labor earnings taxation schedule is steeper in Europe than the U.S., by fitting a tax function to each country's labor earnings tax code.[2] The steepness comes from the fact that as earnings rise, the marginal tax rate on labor earnings increases and this increase in not uniform across these countries. For instance, moving a person from the mean earnings in the cross-section to three times this level increases her marginal tax rate by 8 percentage points in the U.S., while the increase in marginal rate is 12 pp in France for the same relative change in earnings. The ranking of countries in terms of life-cycle inequality coincides with steepness of the tax code, i.e. the steeper the tax schedule is, the smaller is the rise in life-cycle inequality in (pre-tax) labor earnings. A second salient policy difference is the share of public expenditure in overall college expenditure across these countries. The United States devotes the smallest share (39%), while France has the highest (80%). The overall college expenditure share in GDP and college attainment is higher in the U.S. than European countries. The above facts show a correlation between life-cycle inequality and taxation and education policies, but on their own, they fail to provide a quantitative assessment of the importance of each policy and their interactions for college attainment and life-cycle inequality across these countries. For that, I develop a model.

I construct a life-cycle model of human capital accumulation and elastic labor supply, which features uninsurable shocks to human capital and college choice. Individuals enter the model with heterogeneous learning abilities and initial stock of human capital and can accumulate more human capital over the life-cycle in potentially two ways: during college and while working. First, if they choose to go to college, they specialize in human capital accumulation, and invest consumption goods in the production of human capital. Second, if they do not go to college (start working from the beginning of life), or after college graduation, they invest in risky human capital as in Huggett *et al.* (2011). The heterogeneity in learning ability and initial human capital results in different education choices (whether to attend college and how much to invest during college) and different investments in human capital while working, which translate into different earnings trajectories over the life-cycle across individuals.

[2]This is consistent with other papers that study the taxation schedule across U.S. and Europe such as Guvenen *et al.* (2014), Duncan & Sabirianova Peter (2016), and Bick *et al.* (2019).

The model integrates a college stage into a life-cycle framework to capture intensive and extensive margins of college choice and its effects on life-cycle inequality. Individuals who choose to go to college prior to working, which provides them with a short period of rapid human capital accumulation, start working with an "endogenous" human capital stock. On the margin, those who did not choose college experience smaller growth in earnings over the life-cycle since rapid human capital accumulation during college "complements" the investments undertaken during the working life.

Steeper taxation schedule provides social insurance against uninsurable idiosyncratic labor earnings risk, while distorting labor supply and human capital investments.[3] Individuals with high learning ability, whose earnings grow faster, face high marginal and average taxes which discourages human capital accumulation. This distortion in human capital accumulation compounds the adverse impact of non-linear taxation through the classic labor supply channel. As a result, earnings grow slower over the life-cycle and the pre-tax earnings distribution becomes less dispersed. Since college investments complement human capital accumulation during the working life, higher non-linearity in labor earnings taxation lowers the value of college attendance. Those high ability individuals who still find college worthwhile to attend invest less during college as a result of steeper taxation. Therefore, the model naturally links tax policies with education choice along the extensive margin (college attendance) as well as an intensive margin (college investments).

In the model, a more generous college subsidies/transfers exacerbate life-cycle inequality. They make college investments "cheaper", which raise the value of attending college, and induce the marginal individual to attend college. Therefore, more individuals experience the rapid human capital accumulation during college (extensive margin), and while they are in college, they will invest more in human capital accumulation (intensive margin). This is especially true for inframarginal individuals with high learning ability who increase their investments during college significantly. As a result, the composition of the college graduates changes and the overall rate of growth in human capital in the economy increases. Faster growth in human capital accumulation results in higher average earnings growth over the life-cycle. Individuals with higher learning ability benefit the most

[3] Zhao (2017) finds that more risk averse individuals benefit more from progressive taxation in terms of welfare in a model with human capital, although elastic labor supply dampens the benefits. Cubas & Silos (2020) studies the effects of non-linear taxation and social insurance on occupational mobility in the U.S. and Germany.

from college subsidies/transfers and their earnings growth increases the most, which increases the growth in the dispersion in earnings over the life-cycle.

I find that the differences in the steepness of labor earnings taxation account for most of the observed variation in life-cycle inequality in the data. Differences in steepness of the labor earnings tax schedule account for 95% of the differences in the growth in mean earnings between ages 25-50 and 74% of the differences in overall growth in variance of log earnings over the life-cycle.[4] When differences in college transfers/subsidies are also considered on top of the differences in taxation, model generates 94% of the growth in mean earnings profiles and 80% of the growth in variance of log earnings. More generous subsidy/transfer from the government for college expenditure exacerbate life-cycle inequality as indicated by larger growth in the variance of log earnings over the life-cycle when differences in these expenditures are considered. On an aggregate level, my model accounts for 91% of the differences in cross-section gini coefficient across U.S., U.K., Netherlands, and France. Finally, model is consistent with the differences in aggregate annual hours worked between U.S. and Europe as emphasized by Prescott (2004).

Related Literature Current paper provides an integrated framework to study college attainment, human capital differences, and life-cycle inequality in labor earnings across the U.S. and Europe in a heterogeneous-agent model. This essentially relates it to a broad literature that exploit differences in labor market policies across the U.S. and Europe in order to explain differences in various aggregate outcomes such as hours worked, college attainment and quality of human capital, and earning inequality. Prominent examples include Prescott (2004), Ohanian *et al.* (2008), Rogerson (2008), and Bick *et al.* (2018) who study labor hours differences, Erosa *et al.* (2010), Schoellman (2012), Cubas *et al.* (2016), and Hendricks & Schoellman (2018) who focus on college attainment and labor quality differences, and Guvenen *et al.* (2014) and Zucman (2019) who focus on income inequality.

In terms of empirical analysis, Huggett *et al.* (2011) present life-cycle inequality facts for the U.S., while Badel *et al.* (2018) goes beyond the U.S. and include Canada, Sweden, and Denmark. My paper is the first paper to document life-cycle facts across the U.S., U.K., Netherlands, and France systematically and with similar methodology, and uncover the fact that inequality is driven

[4]These are averages across European countries, see section 7 for more details on each country's profile.

by individuals with a college degree. None of the papers that focus on life-cycle inequality make this point, including the above papers. Although the underlying data sources are different across these papers, they all find that life-cycle inequality varies non-trivially across countries.[5]

Several papers share similar modeling framework but focus on different questions. These include Heathcote *et al.* (2010), Huggett *et al.* (2011). Heathcote *et al.* (2010) study the implications of rising wage inequality in the U.S. over time and find that recent cohorts in the U.S. enjoy welfare gains from higher college premium and a more even division of labor within the household. Huggett *et al.* (2011) study lifetime inequality in the U.S. and conclude that about 2/3 of the rise in inequality over the life-cycle is due to endogenous human capital accumulation and the rest is due to idiosyncratic shocks to earnings.

Two closely related papers are Guvenen *et al.* (2014), and Badel *et al.* (2020). Guvenen *et al.* (2014) study inequality in the cross-section across U.S. and Europe and its relation to non-linearity of taxation schedule. They conclude that most of the differences in the cross-section gini coefficient can be accounted for by differences in non-linearity of labor earnings taxation. I find similar qualitative result, and go a step further to emphasize life-cycle inequality differences, and how endogenous choices for college and its interaction with labor market (tax) policies can exacerbate inequality. Badel *et al.* (2020) study optimal top marginal tax rate in the presence of endogenous human capital accumulation in the U.S. and find that the optimal top marginal tax rate is close to the current rate in the U.S. if human capital forces are taken into account. Although some modeling choices are shared with Badel *et al.* (2020), the focus of this paper on cross-country life-cycle inequality and college attainment and investments, separates it from the rest of the literature.

The paper proceeds as follows. Section 2 provides the empirical investigation of life-cycle inequality across the U.S. and Europe. Section 3 illustrates a simple life-cycle model of college choice to provide intuition about college selection. Section 4 presents the full model, while section 5 discusses parametrization. Section 6 illustrates the main mechanisms in the model. Section 7 presents the main results of the paper and discusses various channels through which model generates in-

[5] Most studies focus either on the U.S. or one country in general. See among others, Alvaredo *et al.* (2013), Piketty & Qian (2009) for China and India, Domeij & Flodén (2010) for Sweden, Blundell & Etheridge (2010) for Britain, Pijoan-Mas & Sánchez-Marcos (2010) for Spain, Fuchs-Schündeln *et al.* (2010) for Germany, and Jappelli & Pistaferri (2010) for Italy.

equality patterns observed in the data. Section 8 provides a discussion about various topics to put the paper in a broader perspective. Section 9 concludes.

2 Cross-country Inequality Facts

2.1 Earnings Inequality Over the Life-Cycle and College Attainment

Studying earnings inequality over the life-cycle requires microdata which includes reliable information on income and its sources, hours worked, and educational attainment. The sample should also be sufficiently large to include a proper number of low and high earners. For the United States, several microdata contain this information. The one that I am using is the Current Population Survey (CPS).[6]

For the European countries, the underlying microdata which includes all the above information, especially data on income, is the European Union Statistics on Income and Living Conditions (EU-SILC).[7] Although the sample size is smaller than CPS, this microdata contains sufficient information to study earnings inequality.[8] The reader can consult Appendix C for further information about EU-SILC.[9]

Each sample was restricted following the macro literature (Heathcote *et al.* (2010); Huggett *et al.* (2011), among others) by eliminating possible extreme observations. For example, individuals with positive hours worked but no income reported, and those who earn half the hourly minimum wage, were dropped. Also, those working in agriculture and public/government sector are excluded.[10] The age group is limited to 25-60 since I want the working individuals who most likely finished formal education, while avoiding late-life decisions about the timing of retirement.[11]

[6] Flood *et al.* (2018).

[7] EU-SILC (2004-2016).

[8] See table B.3 for information about the sample size in each country.

[9] Since I do not have access to panel data for Europe, I chose CPS for the U.S. instead of PSID. Also, observations in PSID are selected non-randomly on earnings, see Gouskova (2014).

[10] It is not entirely clear how much of the farm income is labor earnings and how much is capital. Also, most farmers are considered sole proprietors/self-employed which are excluded in my study. Government/public sector earnings structure is arguably different from the private sector and hence these individuals are dropped.

[11] This age group is a good approximation for the United States, but for European countries where the timing and duration of college is different from the U.S. may pose a problem. I have decided to stick to this formulation since I want to be consistent in my empirical investigation and there is not one choice that fits all countries.

The definition of labor earnings is real total wages and/or salaries from individual's employer.[12] This means that I am excluding any business income that is a result of self-employment. The reason is that it is not clear which share of business profits is labor earnings and which part is capital income. Also, self-employed individuals consist a small share of the working population (around 10% in the U.S. and less in Europe). Finally, there is a lot of discrepancies between reported income from self-employment in the surveys and what is reported to the Internal Revenue System in the U.S.[13]

For generating the desired statistics of inequality, I focus on the period 2005-2016 in each country and calculate each statistic for each age groups (5-year bins) and each year. For example, mean_{act} is the mean earnings of individuals in age group a, which belong to cohort c, at time t. I then impose that this statistic is driven by age, cohort and time effects, and nothing else. Of course, these three factors are linearly dependent, so I can only control by either time or cohort effects and then focus on the implied age effect using the following regression framework:

$$\text{statistic}_{act} = \beta_a a + \beta_t t + \epsilon_{act}. \tag{1}$$

The coefficient of interest is the vector β_a, which is "age effect", controlling for time effects. Similar regressions are possible while controlling for "cohort effects". Which effect is more important is not a settled debate (see Heathcote *et al.* (2005), Blandin (2018)), but in general, cohort effects are larger.

In what follows, workers are divided into two education groups. Those with at least a 4-year college degree or its equivalent, and those without. The first group is labeled "college" and the later "non-college". For a detailed treatment of educational levels in Europe and their U.S. equivalents, see Appendix C.

[12]Nominal earnings are deflated by each country's Consumer Price Index.

[13]This discrepancy is reported in table 7.14 in NIPA. For example, in 2016, the adjustments for misreporting on income tax returns on net profit (less loss) of nonfarm proprietorships and partnerships, plus payments to partners was 660 billion dollars.

Fact 1: Steeper Earnings Profile in the U.S.

The first statistic of interest for inequality over the life-cycle is simply the mean earnings. This statistic shows how earnings evolve over the life-cycle on average and it contains the effect of labor market experience and human capital accumulation over the working life. Figure 1 shows the difference in mean earnings over the life-cycle across the U.S., U.K., Netherlands, and France. Mean earnings profile is steeper in the U.S., followed by the U.K. and Netherlands. France has the flattest mean earnings profile among all four. For example, by the age 50, earnings increase on average by a factor of 2.2 in the U.S. relative to age 25, while in France, earnings increase by a factor of 1.5.[14]

Another fact that I uncover is that college graduates on average have steeper mean earnings profiles in all countries relative to non-college individuals. For instance, the earnings of college graduates in the U.S. increases by a factor of 3.1 between ages of 25 to 50, as opposed to a factor of 2.2 for both college and non-college individuals together. This reflects the fact that individuals with different education levels potentially experience different earnings profile over the life-cycle. In fact, as figure 2 shows, non-college individuals experience the same earnings profile over the life-cycle in "all" countries. On the other hand, figure 3 shows that college individuals drive the differences in mean earnings over the life-cycle across countries.

The differences in mean earnings can be a result of several factors. Individuals may select into different occupations with different earnings growth, which can be different across countries. For instance, if doctors are in higher demand in the U.S. than in France for any reason, and the supply of doctors are slower to adjust to this demand, then life-cycle earnings growth of doctors can be larger in the U.S. than France. If most of the professional occupations have a similar situation, then mean earnings profile over the life-cycle in the U.S. will be steeper than France.

Another reason for differences in earnings growth is labor market frictions. Assume that the supply of and demand for doctors are similar across U.S. and France, but longer administrative processes in France make the promotion of doctors in hospitals slower. Then we would observe that the earnings growth of doctors in the U.S. is mechanically faster. Widespread frictions of this sort

[14] Lagakos *et al.* (2018) find similar patterns in mean earnings profile over the life-cycle. Their focus is on work experience rather than age. Other papers that emphasize the cross-country differences in mean earnings over the life-cycle include Badel *et al.* (2018)

can slow down earnings growth across countries.

I argue in this paper that, from a human capital standpoint, steeper labor earnings taxation schedule lowers the incentives for investments in human capital which translates into slower earnings growth over the life-cycle. From the perspective of the model, a doctor in France has less incentive to spend extra hours in the medical school or the lab learning new techniques since any skill acquired will be taxed harder once turned into earnings. Across individuals, differences in college major and career path is interpreted as differences in initial conditions when starting adult life after high school graduation and differential investments decisions during adult life. Similar individuals across countries make different choices given the taxation and higher education policies which results in different mean earnings profiles for the whole cross-section and within education groups. A human capital framework would predict that college graduates are more distorted by steeper taxation schedule. This is backed by the evidence I uncover that the mean earnings of the individuals without a college degree looks almost identical across U.S. and the European countries.

Fact 2: Faster Growth in Variance of Log Earnings in the U.S.

The second statistic of interest is the variation in earnings. Individuals arguably experience different growth rates in life-cycle earnings and just focusing on the mean earnings profile masks this heterogeneity. On way to uncover this heterogeneity is by looking at the variance of log earnings and its evolution over the life-cycle.

Figure 4 shows that the variance of log earnings grows faster in the U.S. than European countries. First, the level of the variance is higher in the U.S. for all ages and it is followed closely by the U.K. Netherlands and France have smaller variance overall. Second, variance of earnings between ages of 25 to 60 grows by 40 log points in the U.S., followed by 30 log points growth in the U.K. The growth in the Netherlands and France is about 10 log points.[15]

Another notable feature in the above figure is that the main part of the growth is concentrated early on in the life-cycle. U.S. and U.K. both experience faster growth until the age of 35 and this is true in Netherlands and France between the ages of 30 to 45.

Similar to the mean earnings profile, most of the rise in variance of log earnings in concentrated

[15] Guvenen *et al.* (2014) show qualitatively similar results, though they control for cohort effects and the underlying sample and time-period is different.

among individuals with a college degree, as shown in figures 5 for non-college, and figure 6 for college individuals. Both college and non-college graduates face increasing variance over the life-cycle in all countries with the U.S. having the largest initial level and overall growth. The profiles are steeper in all countries for college graduates and the main concentration of growth is early on in the life-cycle.

Going back to the example in the previous part, a doctor in the U.S. invests more in her human capital over the life-cycle than a construction worker. This is arguably because of the nature and opportunities available for human capital accumulation in the two occupations. Thus, the difference between the earnings of the two widens as these individuals age. Within individuals without a college degree, variance of earnings can rise. For instance, a construction worker's earnings may experience less growth than a commercial pilot. But the variance of earnings arguably grows faster among individuals with a college degree (doctor vs art curator). The differences in life-cycle growth in the variance of log earnings across these countries can be interpreted as different incentives for human capital accumulation across heterogeneous individuals. If individuals with higher potential earnings growth are more distorted in France than in the U.S., then the life-cycle growth in the variance would be slower in France.

Fact 3: Larger Growth in the Gini Coefficient in the U.S.

Other statistics of inequality over the life-cycle show similar qualitative patterns; the growth in the U.S. is higher than Europe and it is concentrated among college graduates. For example, the gini coefficient, which has been used extensively for studying cross-section inequality, is another indicator of the variation in earnings over the life-cycle. Huggett *et al.* (2011) document the gini coefficient over the life-cycle in the U.S. This is the first paper that goes beyond the U.S. for this statistic.

Figure 7 shows the gini coefficient over the life-cycle in all countries. The initial value is normalized to zero to emphasize the growth. It shows that similar to the variance of log earnings, gini coefficient grows faster in the U.S. over the life-cycle followed by the U.K., Netherlands, and France. The ranking of the countries do not change, whether I use the variance of log earnings or the gini coefficient. Most of the growth in all countries happens before age 40, and most of the life-cycle growth is concentrated among individuals with a college degree.[16]

Together, the above three facts show that earnings inequality over the life-cycle grows and this growth is faster in the U.S. than in Europe. Earnings grow faster on average in the U.S. over the life-cycle, but this growth is masking different growth rates across individuals. In other word, individuals do not experience similar growth rates, and so both variance of log earnings and the gini coefficient grow over the life-cycle. This pattern of rising inequality through life is present in all countries, but both levels and growth rates are larger in the U.S. Education subgroups follow the same qualitative patterns, but life-cycle inequality is mainly driven by college graduates.

Fact 4: College Attainment and Investments Are Higher in the U.S.

The previous facts show that the segregation based on college is important for earnings inequality patterns across these countries. It should be noted that there are critical differences in college attainment rate and expenditure between U.S. and European countries. Table 1 shows summary statistics about college across these countries. U.S. has the highest share of college attainment among working individuals (35%), while France has the lowest share (25%). Total expenditure for college (tuition, research, amenities, etc) from both public and private sources as a share of GDP is the highest in the U.S. (2.6%), while the share of this expenditure that comes from public sources (taxes) is the lowest in the U.S. (39%).

What the differences in the college attainment and investments across these countries show is that (1) the composition of individuals who choose college is different, and (2) college has a differential effect on human capital formation across these countries. The goal of the paper is to quantify to what extent different policies (taxation, higher education subsidies/transfers) are contributing to these differential selection and investment patterns which lead to differences in life-cycle inequality across these countries.

[16] See figures A.1 and A.2 for non-college and college gini coefficient respectively.

2.2 Fact 5: Labor Earnings Taxation Is Less Steep in the U.S.

In general, European countries have steeper labor earnings tax schedule (Guvenen *et al.* , 2014; Duncan & Sabirianova Peter, 2016).[17] I document the same fact within the model using a tax function first introduced by Benabou (2002), and estimate the relevant parameters.

As an illustration, consider figure 8 which shows the marginal tax rates for labor earnings based on the multiples of mean earnings in each country. For instance, an individual who earns the mean earnings level in the U.S. faces a marginal tax rate of 30%. To understand the differences in the steepness of the tax schedule, note that moving an individual who earns the mean earnings level, to three times the mean earnings level increases her marginal tax rate by 8 percentage points in the U.S. Similar relative change in the level of earnings in France results in 12 percentage points increase in the marginal tax rate.

The differences in the steepness of the labor earnings schedule creates different distortions in these countries. Individuals with a potentially high earnings growth (e.g. college graduates) face the high marginal tax rates relatively early in the life-cycle. As a result, they are more distorted and reduce their human capital investments more. College choice amplifies this effect since steeper taxation lowers the value of attending college and the incentives to invest in human capital during college and all subsequent periods.

All of these empirical facts point to a role for differential growth rates in earnings over the life-cycle within each country, but with different magnitude across them. For understanding the underlying mechanisms for differential growth rates within and across countries, I develop a human capital model of earnings growth over the life-cycle and exploit policy differences in taxation and higher education. Before presenting the full model, I show how college selection depends on individual characteristics that shape human capital accumulation over the life-cycle and how policy changes can impact this margin.

[17] See OECD (2011) for more details.

3 A Simple Model of College Choice

In this section, I present a simple two-period model of college choice in order to show how changes in taxes can shift college selection and investments during college. This model is helpful for building intuition about different margins at play for college selection and human capital investments. The basic argument is the same in the full model in section (4). What is important here is how the individual makes college choice. The details of the derivations are in Appendix E.

Consider an individual who lives for two periods. The individual can potentially work in both periods, or she can go to college in period one and accumulate human capital while only work in the second period. There is no channel to increase human capital besides college and there is no human capital depreciation. I assume for simplicity that the only taxation system is a flat rate labor tax (τ). Individuals discount future at rate (r), which equals the real interest rate. This implies a discount factor $\beta = \frac{1}{1+r}$. There is a rental rate per unit of human capital so that the labor earnings of an individual with human capital (h) equals (wh). There are no shocks to earnings.

The individual has three state variables at the start of period one: learning ability (a), initial human capital (h_0) and disutility for college (η). Higher learning ability means higher marginal return on investment in human capital during college. The utility cost of attending college captures the psychic cost of exerting effort during college. The individual compares the present discounted value of going to college $V^C(a, h_0, \eta)$ and not going to college $V^{NC}(a, h_0, \eta)$ and if $V^C > V^{NC}$, she chooses college. Otherwise, she does not choose college.

If the individual goes to college, she will have access to a technology to increase her human capital. This technology uses her initial human capital, and investments in terms of consumption goods to produce new human capital. There is complementarity between initial human capital and investments in this technology as follows:

$$h_1 = h_0 + a h_0^{\phi} d^{\nu}, \quad \phi, \nu > 0, \quad \phi + \nu < 1, \tag{2}$$

where (d) is the amount of investments in terms of consumption goods. The individual has to borrow this amount in order to fund her college education. There is a government that subsidizes college expenditure at rate g_d and provides a fixed transfer during college in the form of a grant, denoted by $\bar{d}$.

Solution to the problem of the individual consists of a cutoff value for disutility for college (η^*), so that if $\eta < \eta^*$, individual chooses to go to college in the first period, and above that cutoff, she works in both periods. The cutoff value for the disutility for college is given by:

$$\eta^* = 2\log\left(\left[(\frac{1-\nu}{2+r})\left[1+\Big(\frac{wa\nu}{(1+r)(1-g_d)}\Big)^{\frac{\nu}{1-\nu}} h_0^{\frac{\nu+\phi-1}{1-\nu}}(1-\tau)^{\frac{\nu}{1-\nu}}\right] + \frac{\bar{d}(1+r)}{(2+r)wh_0(1-\tau)}\right)\right). \quad (3)$$

Also, the optimal investments during college is given by:

$$d = \Big(\frac{aw\nu h_0^{\phi}}{(1+r)(1-g_d)}\Big)^{\frac{1}{1-\nu}}(1-\tau)^{\frac{1}{1-\nu}}. \quad (4)$$

Equation (3) can be used as the basis of analyzing college choice and the impact of taxation in this simple setup. First, higher ability individuals have higher cutoffs and are more likely to go to college. This is intuitive since ability increases the marginal return of investments during college. This means that higher ability individuals also invest more if they choose to go to college as is evident from equation (4).

Second, higher initial human capital decreases the cutoff point which means that these individuals are less likely to choose college. The reason is that when the initial human capital is high, it is very costly to forgo the earnings in the first period and attend college, given that the marginal return to investment in college is diminishing. These two forces together decreases the likelihood of attending college when initial human capital increases. However, if the individual makes it to college, she will invest more since there are complementarities between initial human capital and investments during college.

Third, a more generous college subsidy rate (g_d) and grants ($\bar{d}$) will result in larger cutoff which means individuals are more likely to go to college. The reason is that the investment in human capital during college is "cheaper" since the subsidies are more generous and there is also a fixed transfer which can be used for college expenditure or consumption. Working in the first period means that the individual does not get this transfer. As a result of more generous subsidy rate and transfers, individuals are more likely to go to college on the extensive margin, and college expenditure increases on the intensive margin, as shown in eqution (4).

Finally, an increase in the tax rate (τ), decreases the likelihood of choosing college. The reason is that higher taxes decreases the marginal benefit of investments in college since a higher share of the new stock of human capital is now taxed. This means that if the individual attends college, she invests less during college (see equation (4)), which results in lower level of new stock of human capital (h_1). This stock is now taxed at a higher rate, which reduces the incentive to attend college.

The above model illustrates that higher taxes results in lower college attendance, lower expenditure during college, and higher average ability for those who attend college. I explore the above forces in a more realistic setup with college, work, and retirement stages of life along with progressive taxation and college subsidies in the next section.

4 A Model of Human Capital Accumulation and College Choice

The economy is populated by a measure one of individuals. Each individual starts her economic life at the end of high school at age j_h. The individual decides to go to college or start working right away. If the individual goes to college, she has to stay there for 4 periods, and after that enters the labor market at age j_w. All individuals retire at age j_r and die after 20 periods of retirement at age j_d. All of these ages are exogenously fixed.

Individuals have an innate learning ability (a) which is fixed over the life-cycle. Their stock of human capital at the end of high school that encompasses all the childhood investments by parents until the end of high school is denoted by (h_0). Individuals accumulate human capital (h) and borrow/save using a risk-free asset (x) at a real interest rate (r). Human capital encompasses both general human capital such as health, and specific human capital such as sector specific skills and on-the-job training. The earnings of an individual during the working life is determined by her labor supply, her human capital, which is subject to a stochastic shock, and a rental rate (w). There is a natural borrowing constraint, namely expected future earnings. Individuals can accrue debt so long as they can pay back the debt with interest using their future earnings.

The asset level of all individuals upon high school graduation is assumed to be zero. This assumption rules out parental savings for college and/or general transfers from parents to children.[18] In a human capital model similar to mine, Ionescu (2009) showed that leaning ability and initial human capital are much more important for college choice than parental wealth.

The human capital accumulation is determined by the choices of the individual. It depreciates at the rate (δ_h) every period until death, so tht the individual should make investment decisions for her human capital. The individual has access to two types of technologies that allow for human capital accumulation. During working life, individual can invest time and accumulate human capital according to a Ben-Porath technology[19] as follows:

$$h_{t+1} = (1 - \delta_h)h_t + a(h_t s_t)^{\phi}.$$

Here, s is the amount of time that the individual invests in the production of new human capital. This technology uses the learning ability, (a), and the current stock of human capital to produce new human capital. The economic interpretation is that during the working life, individual accumulates human capital in the form of gaining experience and/or learning on the job. The learning ability of the individual is an important factor in this technology. An individual with higher learning ability has a larger marginal gain from investing time in production of human capital. Therefore, she can accumulate more human capital than an individual with a lower ability, holding the current stock of human capital and time investment fixed.

Another technology that is available to the individual for human capital accumulation is during college. This technology differs from the previous one in that the individual needs to invest time and consumption goods in order to produce new human capital during college. I assume that the individual does not work during college and all of her time endowment (normalized to one) is used for human capital production. The law of motion of human capital during college is

$$h_{t+1} = h_t + a h_t^{\phi} d_t^{\nu}.$$

Here, (d) is the amount of goods that the individual invests during college periods. The learning

[18]This assumption is for the sake of simplicity since finding the distribution of assets at the start of adult life is difficult in the data, and even if I find this distribution from other sources for the U.S., it is generally not available for the European countries.

[19]See Mincer (1997) for a review of the history and evolution of this technology specification.

ability of individuals plays an important role here as well. Individuals with high learning ability have higher marginal benefit of investments during college. Therefore, they value college more and one in college, they are going to invest more for human capital production. This means that the gains from college attendance is heterogeneous across individuals. The only way to invest goods during college is to borrow from future earnings. Therefore, individuals with higher learning ability and higher initial human capital (after high school graduation), who have enough future earnings and can borrow against that, enter college.

Individuals are subjected to taxation of consumption, labor earnings (non-linear schedule) and returns on assets (capital income tax).[20] The tax rates and functional forms are presented in section 5. All individuals pay flat rate consumption (τ_c) and capital income taxes (τ_k), while working individuals pay labor earnings taxes as well.[21]

At the beginning of economic life, the individual decides whether to go to college or not. So the life-cycle path is either of the form college-work-retirement for college graduates or work-retirement for individuals with no college education. Figure 9 summarizes the structure of the life-cycle in the model. I present the problem of the individual in a recursive format starting from the retirement period and moving backwards to the high school graduation. In what follows, subscript j represents the individual's age.

4.1 Retirement

The state variable of the individual aged (j) is her assets (x). The individual makes consumption (c) and savings (x') decisions during the retirement periods. There is no human capital accumulation and her human capital depreciates each period. The terminal value for the individual states that at the last period of life, the individual consumes all of her assets since there is no bequest motive. Learning ability and the level of human capital are not relevant for the retirement periods. Government-funded social security transfers are denoted by (ss). These transfers are not dependent on the earnings history of the individual for simplicity.

[20] These taxes differ across countries and I study their quantitative importance later on.

[21] If the individual is borrowing, she will not pay capital income tax. This tax is only relevant if she is saving and has positive capital income.

$$V_j(x) = \max_{c,x'} \Bigg[u(c) + \beta V_{j+1}(x') \Bigg] \tag{5}$$

$$(1+\tau_c)c + x' = (1 + r(1-\tau_k))x + ss,$$

$$V_{j_d}(x) = u(x),$$

$$j \in \{j_r, \ldots, j_d\}.$$

4.2 Working

The state variables of the individual ages (j) are her learning ability (a), human capital stock (h), asset holdings (x), and the shock to the stock of human capital (z).The individual makes consumption (c), savings (x'), and labor supply (l) decisions. She also makes a choice about time investment (s) for production of human capital, which results in the next period's human capital (h').

$$V_j(h,x,z;a) = \max_{c,l,s,x',h'} \Bigg[u(c,l,s) + \beta \mathbb{E} V_{j+1}(h',x',z';a|z) \Bigg] \tag{6}$$

$$I = wzhl$$

$$(1+\tau_c)c + x' = (1 + r(1-\tau_k))x + I - T(I),$$

$$h' = (1-\delta_h)h + a(hs)^{\phi},$$

$$V_{j_r}(h',x',z';a) = V_{j_r}(h',x';a),\ \forall z,$$

$$j \in \{j_w, \ldots, j_r - 1\}.$$

The terminal value states that at the last period of working life, the individual starts the next period in retirement for all possible future values of the shock. In the above formulation, labor earnings is defined as $I = wzhl$, where (w) is the rental rate of human capital in the labor market, (z) is an idiosyncratic, age-independent, and *iid* shock to the stock of human capital, (h) is the stock of human capital, and (l) is labor supply.

The idiosyncratic shock represents uninsurable labor earnings risk. A negative human capital shock can occur when a worker loses firm- or sector-specific human capital following job termination. A decline in health (disability) is another example of negative human capital shock. In this case, both general and specific human capital might be lost. Internal promotions, bonuses, and upward movements in the labor market are examples of positive shocks to human capital.

Human capital investments in this formulation represent on the job training. They are also the vehicle for propagating the *iid* shocks to the stock of human capital in the model. A large literature that estimate the statistical models of earnings posit that there is a stochastic and persistent shock component to earnings that is important for various policy analysis. In a human capital model, *iid* shocks will result in a similar stochastic component of earnings. In other words, even though the shocks are *iid*, they propagate in the model in a way that earnings shocks look like an autoergressive process or a more sophisticated stochastic process to an econometrician. This point was emphasized in Huggett *et al.* (2011) where a similar shock process in a human capital model generates income processes estimated in other empirical work such as Guvenen (2007).

While working, individuals are subject to a non-linear labor earnings tax, $T(I)$. The non-linear taxation means that as the earnings of the individuals increases, the marginal tax rate on labor earnings goes up. The non-linear schedule distorts the individual's incentives beyond labor supply decision and affects human capital investments. Since the marginal cost of time investment is not changing under non-linear taxation (it is a direct utility cost), but the marginal benefit of an increase in future earnings decreases with higher marginal tax rates, non-linear taxation depresses human capital investments.[22]On the other hand, non-linear taxation provide valuable social insurance by lowering the marginal tax rate when individual experiences a negative shock.

Whether the benefits from non-linear taxation dominates the distortionary effects of this taxation schedule is a quantitative question that I will address in section 7.

4.3 College

The state variables for an individual age (j) in college is her learning ability (a), her human capital stock (h), and her asset holdings (x), and disutility for college (η). During college, the individual

[22]Other papers that emphasize the distortionary effects of non-linear taxation for human capital accumulation include Huggett *et al.* (2011), Guvenen *et al.* (2014), and Badel *et al.* (2020), among others.

makes consumption (c) and savings (x') decisions, along with goods investments (d) for production of human capital. She invests all of her available time for full specialization in human capital production. This means that the individual cannot work, and there is no depreciation of human capital during college.

The individual incurs a utility cost (η) of college attendance. This cost reflects the idiosyncratic psychic cost of studying, learning new skills, etc, during college.[23] In order to smooth consumption, individual has to borrow while in college against her future earnings. Thus, individuals with sufficiently high future earnings and low disutility for college will choose to attend college. For simplicity, the individual borrows at the same capital market interest rate. So, there is no student loan program with a different interest rate and repayment schedule.[24]

Government contributes to college expenditure through two channels. The first is a subsidy program which subsidizes private expenditure in college at the rate g_d. This subsidy reflects scholarships and tuition subsidies for college students. The second is a fixed transfer, $\bar{d}$, to individuals in college in the form of a grant. This grant is capturing expenditures on stipends, health insurance, housing allowances, bus passes, etc, that can be used for consumption, saving, or spent directly on human capital production. The subsidy program and grants constitute public expenditure in college. In reality, part of the public expenditure may not directly benefit college students, but indirectly influence their human capital accumulation through better facilities and higher quality of classes/labs. Finally, there are no uncertainty about college graduation, which means that every individual who enters college will graduate.

The problem of an individual during college is given by:

$$V_j(h, x; a, \eta) = \max_{c,d,x'} \left[u(c) - \eta + \beta V_{j+1}(h', x'; a) \right] \tag{7}$$

$$(1 + \tau_c)c + (1 - g_d)d + x' = (1 + r(1 - \tau_k))x + \bar{d}$$

[23] In order to better match some observable moments regarding college choice and investments, the inclusion of a utility cost of college attendance is very desirable. See for example, MacDonald (1981), Card (2001), and Hai & Heckman (2017) among others. In my setup, the distribution of this parameter helps with matching the college share in the data.

[24] For a treatment of student loan programs and their implication for college choice, graduation rates, and so on see Ionescu (2009), Ionescu (2011), Chatterjee & Ionescu (2012), and Ionescu & Simpson (2016), among others.

$$h' = h + ah^{\phi}d^{\nu}$$

$$V_{j_w}(h', x'; a, \eta) = \mathbb{E}V_{j_w}(h', x', z'; a),$$

$$j \in \{j_h, \ldots, j_w - 1\}.$$

The production of new human capital during college means that the individuals who attend college start working with an “endogenous” initial condition, rather than the exogenous draw they had when graduated from high school. This points to complementarities between college investments and human capital accumulation while working. Individuals who attend college can accumulate human capital much faster than those who do not, since college requires investments in the form of consumption goods. Therefore, a high ability individual who goes to college, starts working with a much higher stock of human capital than she otherwise would have if she did not attend college. She enjoys higher earnings after college and potentially a higher growth in earnings since returns on human capital investments while working are increasing in the level of human capital.

Individuals who go to college forgo earnings during the time in college and accrue debt, but they will have potentially high earnings in the future, which makes college worthwhile. Therefore, if there is a change in the environment that shrinks future earnings, the composition of college graduates and their investments during college will change.

It should also be noted that human capital in college is not risky. The reason, aside from simplicity, is not theoretical, but rather empirical. Any strategy to identify shocks to earnings relies on observed earnings, wages, hours, etc. It is true that students in the real world work during college, but given the type of jobs they can get while in college (mostly minimum-wage jobs), their human capital is not arguably as relevant for their earnings as later in life when they are not in college anymore, and on a career path. Therefore, shocks to human capital during college are ruled out theoretically. Graduation risk is also ignored to keep the model simple, though it is possible to add that to the current setup. Given that the facts are driven by individuals with a college degree, the model only allows for college completion.

4.4 Educational Choice

The life-cycle choice for an individual with a high school degree is to choose whether to go to college or not by comparing the life-cycle value of college path V^C and non-college path V^{NC}:

$$V(a, h_0, \eta) = \max\{V^C, V^{NC}\} \tag{8}$$

4.5 Technology

There is a stand-in firm that demands capital and labor for production of the consumption good using a constant returns to scale technology. Physical capital depreciates at rate (δ). The capital is the total assets in the economy and the labor is the total human capital supplied to the labor market.

4.6 Stationary Competitive Equilibrium

The definition of a steady-state stationary competitive equilibrium is standard. It consists of decision rules, population measures, and factor prices such that, given factor prices, decision rules are optimal, factor prices are competitive, and total taxes equals social security transfers, college subsidies/transfers, and government expenditure, and population measures are consistent with optimal choices. The formal definition of the equilibrium can be found in Appendix E.

5 Parametrization

Calibration consists of two steps. In the first step, I borrow some common parameters usually used in the literature and set them exogenously. The parameters governing demographics, technology, and the tax rates for consumption and capital income, are set in this way. The parameter governing the standard deviation of the shock to human capital is set to the estimate by Huggett *et al.* (2011). The depreciation of human capital is set to match the average decline in the hourly wage in the data towards the end of working life. The model implies that at the end of working life, human capital investment is essentially zero. This means that any decline in the hourly wage is due to depreciation of human capital. Given this set of parameters, I will set the rest in the second step to match some moments in the data. All the parameters except for the labor earnings tax schedule can be found in table (B.1).

5.1 Benchmark Model Functional Forms

Utility function:

$$u(c,s,l) = \begin{cases} \log(c) - \eta & \text{college} \\ \log(c) - B\dfrac{(l+s)^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}} & \text{working} \\ \log(c) & \text{retirement} \end{cases} \tag{9}$$

Production function:

$$Y = AK^{\alpha}L^{1-\alpha} \tag{10}$$

Initial conditions: Marginal distributions for learning ability and initial human capital are both Pareto-Log-Normal (PLN) distributions.[25]

$$\begin{aligned} a &\sim PLN(\mu_a, \sigma_a^2, \lambda_a) \qquad\qquad (11) \\ \log h_0 &= \beta_0 + \beta_1 \log a + \log \epsilon, \qquad \epsilon \sim LN(0, \sigma_\epsilon^2) \\ \eta &\sim \exp(\lambda_\eta) \end{aligned}$$

The random variable ϵ used in the above construction is independent of learning ability. The distribution for disutility of college is exponential. The distributions for learning ability and initial human capital are from the power law family, which feature fatter tails than other distributions. This is important for generating enough top earners in the model so that the earnings distribution matches sufficiently with the data. Given that the top earners are arguably more distorted by taxation, it is important quantitatively to generate enough top earners in the model.

[25] The way initial human capital is constructed from the learning ability results in a Pareto tail for its marginal distribution. For a formal proof, see Badel *et al.* (2020).

5.2 Demographics

An individual enters the model at a real-life age of $j_h = 20$, graduates from college at age $j_w = 24$ if she goes to college, retires at age $j_r = 60$ and lives up to age $j_d = 80$. The population growth rate $n = 0.01$ is set to the geometric average growth rate of the U.S. population over the period 1960-2015. Population fractions μ_j sum to 1 and decline with age by the factor $(1 + n)$.

5.3 Technology and human capital

U.S. national accounts data imply that capital's share, the investment-output ratio and capital-output ratio averaged $(0.4, 0.2, 3.2)$ over the period 1960-2015. I set α to match capital's share, and δ to be consistent with the investment-output ratio and the capital-output ratio, given n. I normalize A to one.

Finally, the value of the curvature parameter for the human capital production function is set to value $\phi = 0.6$, following Badel *et al.* (2020). This value is within the range of the estimates for this parameter in the literature.[26]

5.4 Taxation

There are different sources of taxes in the model. Consumption and capital income are taxed at a flat rate (τ_c), and (τ_k), respectively. There is also a non-linear tax system for labor earnings such that the marginal tax rate increases with earnings. The functional form for the non-linear taxation is the one used in numerous papers, (e.g. Benabou (2002); Storesletten *et al.* (2004); Guner *et al.* (2014)), and reasonably approximates the U.S. tax code:

$$I = wzhl,$$

$$T_f(I) = I(1 - \lambda(\frac{I}{\tilde{I}})^{-\tau}),$$

where $\tilde{I}$ is the mean cross-sectional income. Dividing by the mean is consistent with a balanced growth path since the average taxes will be unchanged if the earnings of all individuals are multiplied

[26] For a detailed discussion about the different estimates of this parameter, see Blandin (2018).

by a constant factor. The parameter (λ) governs the level of taxation, while the parameter (τ) governs the steepness of the tax schedule. This means that as τ increases, the marginal tax rate increases faster as earnings grow.

I need three pieces of information in order to estimate the parameters of the above tax function: (1) mean cross-sectional income, (2) individual's income, and (3) tax liability of each individual. For each country, I observe individual's income and so, I can calculate the mean cross-sectional income directly from the data. The part that cannot be calculated straightforwardly from the data is the individual's tax liability. In order to calculate that, I need to look at the tax code for each country and year and calculate labor earnings tax liabilities (federal, state, local, social security, etc) for each individual. I will rely on the programs provided by Bick *et al.* (2019) for calculating tax liability for each individual, which are basically simulating the tax code for the U.S. and some European countries.

In many countries, the tax code considers household as the unit of observation. Therefore, tax liabilities are calculated at the household level.[27] This is true for the U.S., France, and the Netherlands.[28] U.K. is the only country in my sample that is truly individual-based. This pose a challenge since the empirical facts and the model are based on only male earnings and countries differ in their respective tax unit.

I treat the taxes at the household level for all countries.[29] This means that all the required information for estimating the tax function are at the household level. In this way, I know the household income as well as the mean cross-sectional household income directly from the data. Bick *et al.* (2019) then gives tax liabilities for each household. Once I know these, I can look for parameters of the tax function so that the difference between what the tax function is producing and tax liabilities in the data is minimized.[30]

[27] Social security taxes are individual-based.

[28] Taxes in the Netherlands are individual-based. But part of tax code indicates a tax credit which is calculated at the household level. This nuance among others make the tax code in the Netherlands effectively household-based. For detailed information see OECD (2011).

[29] The interpretation of household-based tax parameters in the model is that each individual is part of a household and faces tax liabilities according to a household-based system. Of course, this affects the individual's decision if the other members of the household are also making similar human capital investment and labor supply decisions. For simplicity, I am abstracting from those and remain agnostic about household structure in the model.

[30] See Appendix C for more information about these estimations.

The country-specific parameters are presented in table 4.[31] The average taxes are smallest in the U.S. and the U.K., with the Netherlands having higher average taxes and France the highest. In terms of steepness, U.S. and U.K. are similar, with the Netherlands more progressive than them. France has the most progressive tax system among these four countries.

5.5 Preference Parameters

The parameters in the utility function are set to the values presented by Badel *et al.* (2020). The parameter governing the level of disutility of work is set to $B = 12.4$, while the parameter governing the labor supply elasticity is set to $\gamma = 0.6$. They calibrate these parameters to match the patterns of hours over the life-cycle in the data. Essentially, they regress the log of hours worked on the log of hourly wage (similar to MaCurdy (1981)) and match the coefficients of this regression in the model. Given the similar structure of the model for the working stage of individuals' life-cycle (endogenous and risky human capital with elastic labor supply), I set these parameters based on their calculations.[32] The amount of social security transfers during retirement is 40% of the mean cross-sectional income, which pertains to a replacement rate reported by Social Security Administration.[33]

5.6 Remaining Parameters

All the remaining parameters are chosen to match a set of data moments. These parameters are

1. mean of the distribution of disutility for college λ_η; 1 parameter,

2. distribution of learning ability and initial human capital; a total of 7 parameters,

3. human capital production parameter for college ν; 1 parameter,

4. subsidy rate for college, g_d; 1 parameter,

[31] As a robustness check, I estimated the tax function for the U.K. based only on male earnings and their tax liabilities. Compared to the household estimates, males face higher average tax than households as well as a slightly more steepness.

[32] The value for the Frisch elasticity is in the range estimated for macro models previously documented in the literature which feature endogenous human capital. For a more extensive discussion on Frisch elasticity see Blundell & Macurdy (1999), Domeij & Flodén (2006), and Keane (2011), among others.

[33] See Biggs & Springstead (2008) for alternative measures of replacement rates.

5. grant level, $\bar{d}$; 1 parameter,

6. discount factor β; 1 parameter.

There is a total of 12 parameters to be jointly calibrated. The mean of the disutility for college is governing the percentage of college graduates in the model, which is 35% in the U.S. over the period 2004-2016. The parameters for the initial distribution of ability and human capital are set to reproduce the mean and variance of log earnings for each education group.[34] The human capital production parameter is governing the expenditure during college in the model. It is set to reproduce the total expenditure during college as a percentage of GDP (both public and private). Based on OECD (2016), total expenditure on college education is 2.6 percent of the GDP in the U.S.[35]

The subsidy rate for college and the grant level are calibrated to produce two moments: (1) the share of public expenditure in total college expenditure, which is 38.6%, and (2) the share of public expenditure in the government revenue (2.9%).[36] Total government expenditure in 4-year colleges (excluding community colleges, vocational schools, etc) is available on the Department of Education website. These expenditures include all expenditures by federal, state, and local governments. Moreover, total government tax receipts are reported in National Income and Product Accounts (NIPA) table 3.2 for the federal government and table 3.3 for the local and state governments. Finally, the discount factor is set so that the model produces a capital to output ratio of 3.2.

5.7 Benchmark Economy

The results of the above calibration are summarized, for mean earnings, in figure 10 (all individuals), and for variance of log earnings in figure 11 (all individuals).[37] The model does an excellent job at matching the targeted moments for each education group. The mean earnings profiles are matched

[34] This constitutes 6 moments for mean earnings profile for each group (the first moment is a normalization), and 7 moments for each group for variance of log earnings. Together, there are $6 + 6 + 7 + 7 = 26$ moments to match.

[35] The value 2.6 is the average over 2005-2016. It excludes expenditure for community colleges and vocational/training schools.

[36] See table 1 for summary statistic for the U.S. higher education.

[37] For mean earning within education groups, see figures A.3 (non-college individuals), and A.4 (college individuals). For variance of log earnings within education groups, see figures A.5 (non-college individuals), and A.6 (college individuals).

almost perfectly, while the profiles of variance of log earnings are matched with lower precision. The mean and variance profiles for all individuals are matched very well, even though they were not directly targeted (the mean and variance profile of each education group were targeted for calibration).[38] The match will never be perfect since the number of parameters is less than the number of moments.

The benchmark economy features all the relevant statistics related to college perfectly relative to the data. Model generates a 35% share for college individuals, while the total expenditure (both public and private) for college in GDP is 2.6%. The share of public expenditure for college in total college expenditure is 38%, and the share of government revenues dedicated to college subsidies/transfers is 2.9%.

Figure (12) shows non-leisure time in the model and hours worked over the life-cycle from the data (annual hours), which was not targeted for calibration.[39] Both profiles are normalized to 100 at age 40. Hours worked over the life-cycle in the data follows a hump-shaped patterns whereas in the model, both labor supply and time investment for human capital accumulation are monotonically decreasing.[40]

Subsequently, there are additional moments that the model generates and are not targeted for calibration. One important moment is the relative earnings of college to non-college individuals (skill premium) over the life-cycle. Figure (13) shows the skill premium. Producing the skill premium is important since it incorporates the college decision, earnings levels and heterogeneous earnings growth over the working life across individuals. It basically summarizes all the relevant decision margins for generating a sensible earnings distribution. Even though none of these data moments are targeted by the calibration, the model still matches these moments closely.

Looking closer at the earnings distribution in the U.S., I check whether the model can generate

[38]The mean earnings profile for all is a weighted average of the profiles for each education group, with the weights being the share of each education group. Since the college share is matched perfectly, the mean earnings profile for all is unsurprisingly matched. The variance of log earnings profile however, is a nonlinear combination of the two education groups. The model does a good job since college graduates are driving the overall profile.

[39]Figures (A.7) and (A.8) show the hours profile for non-college and college individuals, respectively.

[40]The reason is that, in order to have a realistic capital to output ratio in a life-cycle setup where the only borrowing constraint is the expected future earnings, the discount factor has to be close to one ($\beta > 1/(1+r)$). Euler equation then implies that consumption is growing over the life-cycle. This means that the optimal labor supply has to decline if the growth in consumption is faster than earnings, which is the case here. Time investment in human capital declines monotonically over the life-cycle since individuals reap the benefits of human capital accumulation over shorter periods as they age. Therefore, they optimally invest less time over the life-cycle.

the percentage of earnings that flow to different quintiles of the earnings distribution, the cross-section gini coefficient, and the concentration of the earnings at the top. Panel A in table 2 shows these statistics for the U.S. which are calculated from the CPS. Model generates closely all sections of the earnings distribution, even though none of the statistics in this table are targeted by the calibration procedure. What is also important for my analysis is that the model generates a reasonable distribution of earnings for college and non-college individuals as well. Table 3 shows that the earnings distribution for each education subgroup follows the data closely. All the above gives external validity to the model that it can reproduce relevant statistics of the U.S. earnings distribution both at an aggregate level and for each education subgroups.

The last piece of evidence for the performance of the model that I present is related to the wealth distribution. Specifically, I define the wealth of an individual at any age as her asset holdings. I then look at certain quintiles of the wealth distribution and ask, how much of total wealth in the economy is held by each quintile? This shows how skewed the wealth distribution is in the model.

Kuhn & Rios-Rull (2016) document the distributional properties of wealth for U.S. households, based on the Survey of Consumer Finances (SCF).[41] I use their data to compare the model generated wealth distribution with the SCF data. Panel B in table (2) shows the comparison. The model does an excellent job capturing the distribution of wealth for each quintile as well as the wealth gini coefficient. However, the model fails to generate the concentration of wealth at the top. This is a known feature of life-cycle models that focus on labor earnings and goes back to Huggett (1996). The reason is that creating a realistic wealth distribution in the model requires more savings motive beyond consumption smoothing. One such motive can be saving for business operation and entrepreneurship.[42]

[41] Other papers that document wealth distribution in the U.S. and other countries include Piketty & Saez (2006), Saez & Zucman (2016), Piketty *et al.* (2017) and Zucman (2019). Most of the data used in these papers come from tax records in order to measure wealth inequality over time. For a more detailed account of wealth and income inequality in the U.S. since the 1950s, see Kuhn *et al.* (2020).

[42] See Quadrini (2000), Quadrini (2005), and Cagetti & De Nardi (2006), among others, for models of entrepreneurship and wealth inequality.

6 Model Mechanisms

One of the differences between the countries in section 2 is the difference in the steepness of the taxation system. Specifically, U.S. and the U.K. have similar steepness, while the Netherlands is a bit more steep. The steepest of all is France. Given that steepness in taxation schedule decreases the marginal benefit of human capital accumulation, but leave the marginal cost unchanged, it depresses investment in human capital as well as labor supply. Together, they cause smaller earnings growth and less variation in earnings at the top. The degree to which non-linear taxation can depress human capital accumulation in two hypothetical scenarios is studied in this section.

In the model, the parameter τ governs the steepness of the taxation system. Specifically, increasing this parameter means that the marginal taxes grow faster as the earnings increase. The benchmark calibrated value is $\tau = 0.13$. I increase τ to 0.15 and 0.17, while keeping other parameters constant.

Figures 14 shows the effect of increasing the steepness parameter on mean earnings of all individuals.[43] Not surprisingly, the steepness of the earnings profile declines. This is true for all individuals as well as within each education group. The main difference within each education group is that the college educated ones are affected more since they experience higher earnings growth rates on average and they hit the higher marginal tax rates more often than non-college graduates. Hence, the earnings profile for college graduates becomes less steep.

Figures 15 shows what happens to the variance of log earnings for all individuals.[44] The slower growth rate in earnings on average means that there is less variation in the earnings over the life-cycle. As a result, variance of log earnings grows slower as the tax system become more steep. The qualitative pattern is true for both education subgroups, although the college graduates are affected more as the high marginal taxes kicks in for these individuals more frequently relative to the non-college ones.

Given the above effects on earnings, it is not surprising that college selection and expenditure for college changes under different tax system. Table 5 shows the share of college graduates as well as total expenditure for college as a percentage of GDP. Higher progressiveness of the taxation system

[43] See figures A.9 and A.10 for the mean earnings profiles for non-college and college individuals, respectively.

[44] See figures A.12 and A.11 represent the variance profiles for non-college and college individuals, respectively.

lowers the benefit of human capital accumulation and hence, discourages college attainment. Once in college, the same effect depresses expenditure for human capital accumulation.

An interesting observation, which is consistent with the stylized facts in section 2, is that the variance of log earnings drops for the first age group. This happens through three channels: (1) the fact that less individuals go to college means smaller variance of human capital at age 25, which is the first year of working after college, (2) less investments during college implies that college graduates have smaller growth in human capital during college, and (3) higher marginal taxes because of the more progressive system depresses hours for all. Together, these three channels contribute to smaller variance of earnings in logs at age 25.

7 Policy Analysis

In this section, I use the model to study life-cycle inequality patterns documented in section 2 to see how much of the differences in the data is generated by the model under different policies. I consider U.S. and the European countries to be different from each other in two dimensions: labor earnings taxation, and college transfers/subsidies.

I move from the benchmark model that is calibrated to the U.S. in both dimensions to the European countries in two steps. In the first step, I change the relevant parameters for each dimension individually. In the second step, I combine them together and study their interactions. The first step shows that taxation differences go a long way for accounting for inequality differences. It also illustrates that increasing college transfers exacerbates inequality. The second step reveals that gains from more generous college transfers in terms of earnings growth are dampened by steep taxation schedule.

7.1 Only Taxation Differences

I change the taxation system by applying the pair (λ, τ) that was estimated in section 5 for each country, while keeping other parameters constant. I then solve and simulate the model and compare model produced statistics with data. In doing so, I keep the interest rate fixed, given that the European countries can be viewed as small open economies. This means that based on the production function and normalization of the TFP parameter, the rental rate for human capital is also constant.[45]

In the model, the parameter τ governs the degree of steepness of the taxation system. Specifically, increasing this parameter means that the marginal taxes grow faster as earnings increase. The benchmark model is calibrated with $(\lambda = 0.83, \tau = 0.13)$.

First row of table 6 summarizes the model generated profiles of mean and variance, respectively, after allowing for labor earnings taxes to differ across countries. The numbers for mean earnings are the share of overall growth in mean earnings between age 25-50 in the model relative to the data. The numbers for variance are the share of overall growth in variance between age 25-60 in the model relative to the data.

The table shows that considering only the differences in labor earnings taxation account for the bulk of the variations in the data. Model generates on average, 95% of the mean earnings growth, and 74% of the growth in the variance of log earnings across European countries.

Model does a good job of generating the mean and variance profiles for the U.K. which is not surprising given that the steepness of the tax system in the U.K. is very similar to the U.S. For France and Netherlands, however, model generates less growth in both mean and variance profiles. This means that the disincentives from higher marginal tax rates for potentially top earners are so large that the accumulation of human capital slows down a lot. As a result, inequality profiles become flatter than the ones observed in the data.

The other reason for the flatter profiles is related to college selection and change in composition of college graduates, which is presented in the first row of table 7. The numbers in this table are the share of college graduates and total college expenditure in GDP relative to these statistics in the data. Table shows that college choice is severely distorted under steeper taxation. On average, model generates 78% of the differences in college graduation and 86% of the total expenditure in GDP across European countries.

In all European countries, both the share of individuals going to college and the share of total

[45] European countries are considered small open economies. Therefore, I always fix the interest rate and TFP level for all of them at the benchmark calibration. This means that unless TFP level changes, the rental rate for human capital is fixed as well since a fixed interest rate and TFP level implies a fixed capital to labor ratio: $r + \delta = A(K/L)^{\alpha-1}$. In section 8, I discuss how changing the TFP level which translates into diffrent rental rate for human capital affect inequality patterns.

expenditure for human capital formation during college is smaller than the data. The exception is U.K. which is to be expected since taxation structure in the U.K. is almost identical to the U.S.

It should be noted here that U.S. and Europe differ in terms of the average duration of college degree. While in the U.S. it is customary to finish college in 4 years, college takes about 3 years in the U.K. and 4 to 5 years in the Netherlands and France. Some occupations also require degrees that take more than 4 years fulfill. For instance, medical and law school students spend more years to obtain proper college credentials for a potential future career. The model has a fixed number of periods for college which is 4. This means that a potential margin about the duration of college is missing. The distortionary effects of progressive taxation is more pronounced for individuals who spend more time in college accumulating human capital since their potential earnings growth is much faster after graduation. This means that model is generating a lower bound for the distortionary effects of non-linear taxation.

Given that college graduates in the data have steeper profiles and are important to reconcile the model with the data, it is of first order importance to consider differences in college subsidies/transfers across these countries. The next section focuses on this dimension.

7.2 Only College Subsidies/Transfers

In this section, only the parameters related to college stage is matched to each country and I find that increasing college subsidies/transfers increases earnings inequality. Specifically, I calibrate the subsidy rate g_d and grant level $\bar{d}$ to match the share of total college expenditure in GDP and the share of public expenditure in total college expenditure, while leaving the labor earnings taxation unchanged.[46]

The second row of Table 6 shows that country-specific college subsidies and transfers alone are not enough to reproduce the patterns observed in the data. The only country that is a bit closer to the data is the U.K. Even there, model fit becomes worse since U.K. spends less on college, both publicly and privately. The mean and variance profiles for the Netherlands and France are steeper than the data. The reason is that as college subsidies/transfers become more generous, the marginal individual finds it worthwhile to attend college since attending college is “cheaper”.

[46] For a brief treatment of higher education finances in the U.S. and Europe, see Appendix C.

Those potentially top earners who were already in college increase their human capital investments in college much more that the rest of the college individuals. As a result, the earnings of the top earners grow faster after graduation which increases the growth in mean and especially variance of log earnings over the life-cycle for the whole cross-section. As a result, college subsidies/transfers exacerbate earnings inequality.

7.3 Taxation + College Subsidies/Transfers

In this section, I combine taxation and higher education subsidies/transfers and study their joint effects for earnings inequality and show that the fit of the model is improved relative to previous sections. I already showed that the model can generate most of the variation in the data by country-specific labor earnings taxation alone. Given that inequality patterns in the data are driven mostly by workers with a college degree, selection for college is an important margin to consider. However, matching proper aggregate and public expenditure for college "alone" did not improve the fit of the model much.

The third row of table 6 shows the interaction of taxation differences and higher education subsidies/transfers. It is most informative if this row is contrasted with the first row of the same table. Comparing the rows of this table indicates that a more generous college subsidies/transfers provide more incentive for individuals to select for college, despite steeper taxation. Specifically, the marginal individual values college more since she can invest in college in a "cheaper" way. This cheaper way comes from the fact that investment in human capital production, d, is subsidized at a higher rate, and the amount of college grant, $\bar{d}$ is higher.[47] Together, they mean that the individual does not need to incur as much debt and can benefit from higher human capital during the working life even though the taxation system is more progressive. This is certainly true for the Netherlands and France, but in the case of U.K. lower overall college expenditure relative to the U.S. makes the fit of the model worse.

[47] When taxes become steeper, the private expenditure during college is depressed a lot. This means that in order to match the total college expenditure in GDP, the level of grants ($\bar{d}$) should increase. In the absence of an increase in steepness, the grant level goes down since more generous subsidy rate implies a lot of expenditure during college and the share of college expenditure in GDP would be too high. This means that if one only changes the college subsidies/transfers across these countries, she would find that college transfers in the Netherlands are smaller than the U.S. which seems counterfactual. Taxation differences correct this prediction of the model as well.

College subsidies/transfers improved the fit of the model for European countries in the presence of non-linear taxation since they induce more individuals to select for college. This is evident when comparing the first and third rows of table 7. Model now accounts for 94% of the growth in mean earnings and 80% of the growth in the variance of log earnings across countries.

8 Discussion

In this section, I discuss some results that are important in order to put the paper in a broader perspective. I first briefly discuss how the focus on life-cycle inequality relates to the cross-section inequality which has been the focus of many empirical papers. The model does a good job at generating cross-section gini in earnings across countries. I then study the role of TFP for accounting for life-cycle inequality across countries. Changes in TFP allows for full general equilibrium effects in the model and worth further analysis. I find that TFP differences only matter when taxation differences are present.

8.1 Life-cycle vs cross-section inequality

I showed in section 7 that the model does a good job of generating the differences in life-cycle inequality when differences in taxation and college subsidies/transfers are taken into account. What does this mean for cross-section inequality in labor earnings? In other words, can the model generate a realistic cross-section inequality? To answer this question, I look at the cross-section gini coefficient in labor earnings across U.S. and Europe from the data and compare them to model generated ones.

Table B.4 shows that the model generates almost all the variation in cross-section gini coefficient across these countries. For instance, the gini coefficient is 0.28 in the Netherlands in the data, and 0.25 in the model. This means that accounting for life-cycle inequality ultimately accounts for the observed differences in inequality at the aggregate level.

8.2 The Role of TFP

There is a large literature in macro development that emphasizes the role of TFP differences as the main factor for income differences across countries.[48] In this section, I explore this fact in the context of life-cycle inequality. Given that the emphasis of this paper is on human capital formation, which is also emphasized in the macro development literature,[49] it is worthwhile to think about how TFP differences is going to shape life-cycle inequality on the micro level as well as aggregate variables such as GDP and hours worked per worker at the macro.

8.2.1 Changing Only The TFP

In order to understand the role of TFP differences for life-cycle inequality, I calibrate the TFP parameter, A, for each country to match the GDP per adult relative to the U.S. in the data, which are documented in table B.5 from Penn World Tables. I then proceed by comparing the model generated earnings profiles with the data.[50]

The first row of table B.7 show that TFP alone is not of first order importance for generating life-cycle patterns in the data. Lower TFP will result in a lower rental rate for human capital in the market. This leads to lower return on human capital accumulation and lower value of college investments. Therefore, individuals will invest less in human capital overall which leads to flatter profiles for mean and variance of earnings. In a model with flat rate labor earnings taxation, changes in the rental rate would not change human capital investment decisions since earnings over the life-cycle would change by the same factor w. This is not true when non-linear taxation is present. Share of individuals with a college degree as well as overall expenditure in college also goes down as reported in table B.8.

[48]See Caselli (2005) for a review of this literature and the references therein.

[49]See Hendricks (2002), Erosa & Koreshkova (2007), Erosa *et al.* (2010), Schoellman (2012), Cubas *et al.* (2016), and Hendricks & Schoellman (2018) among others.

[50]The second column in table B.6 shows the TFP levels in this calibration. The U.K. has the lowest TFP level, while the Netherlands and France have higher TFP than the U.K. The reason TFP level in the U.K. is smaller than the other countries is that the GDP per adult in the U.K. is smaller relative to the hours worked. In other words, it looks like the aggregate hours worked is large in the U.K. relative to the Netherlands and France, but the GDP per adult is smaller. This implies a smaller TFP level (a proxy for productivity) in the U.K.

8.2.2 Taxation + College Subsidies/Transfers + TFP

For each country, I keep the taxation country-specific and calibrate the TFP level to match GDP per worker relative to benchmark (U.S.) as the data. College subsidy rate and grant level are recalibrated to match college expenditure in GDP and share of public expenditure in college.[51]

Second row in table B.7 shows how the model performs in producing inequality profiles. Lower level of TFP with fixed interest rate means a lower rental rate for human capital. As a result, investment in human capital has a lower present discounted value and individuals are less inclined for this investment. This is apparent specifically in the case of U.K. where a low level of TFP and rental price for human capital results in a flatter earnings profile and less growth in the variance of log earning. These changes in inequality is driven by a smaller share of college graduation in the U.K. as reported in the last row of panel B in table B.8. Similar thing happens in the Netherlands and France.

Accounting for differences in aggregate TFP alone is not of first order importance to reconcile the model with data in terms of GDP and average annual hours worked per adult. When TFP levels are country-specific and model matches the observed differences in GDP per adult across the U.S. and Europe, model cannot generate the observed inequality patterns. Only when differences in taxation and higher education subsidies/transfers are considered, TFP differences are amplified enough. This means that although TFP plays an important role for aggregate variables (GDP, hours worked, etc), it is not of first order importance for micro-level differences (life-cycle earnings inequality) across these countries.

Gdp per Adult and Aggregate Hours Worked Lastly, I document the performance of the model (with country-specific taxation and college subsidies/transfers) regarding GDP per worker and average annual hours worker per worker relative to the data.

Table B.5 shows GDP and hours worked per adult in 2005 in European countries relative to the U.S. from Penn World Table.[52] Netherlands has the highest GDP per adult, while France has the

[51] See table B.6 for the calibrated TFP levels.

[52] The reason I chose GDP per adult in the data not GDP per worker is that I do not want to pick up the effect of differences in labor force participation to be in the data. When I do a robustness check and choose GDP per worker in the data, the qualitative conclusion remains the same, and quantitative conclusion changes very slightly. See Appendix D for more details.

lowest annual hours worked among European countries. In the model, GDP per adult is simply output since the population size is one. Hours worked is non-leisure time which includes both labor supply and time investment in human capital production.

Figure A.13 shows that the model with fixed TFP but different taxation and college subsidies/transfers is doing a good job producing differences in GDP per worker relative to the data except for the U.K. With fixed TFP level and prices across these countries, U.K. looks somehow similar to the U.S. while the model generates less output in the case of the Netherlands and France.

A similar story about the hours worked in figure A.14 is true, with the U.K. looking similar to the U.S. in the model and hours worked in the model for the Netherlands and France are less than data. The two figures show that even though a combination of taxation differences and college subsidies/transfers are important to generate micro level inequality in labor earnings, the aggregate variables are still a bit far from the data.

Finally, in terms of aggregate hours, lower TFP level in the U.K. reduces aggregate hours worked, which deteriorates the fit of the model for the U.K. a bit. This is depicted in figure A.15. Average hours worked in the Netherlands and France goes down as well. Overall, the model on average can account for 85% of the differences in hours across U.S. and Europe. This version of the model accounts for all the differences in GDP per worker across U.S. and Europe as well as most of the differences in aggregate labor hours. These results are in line with other studies that connect aggregate hours worked with differences in tax rates such as Prescott (2004); Ohanian *et al.* (2008); Rogerson (2008); Bick *et al.* (2018).

9 Final Remarks

Overall the model account for 94% of the mean earnings and 80% of the variance profiles observed in the data. There are other differences in terms of taxation across these countries, namely consumption and capital income (wealth taxes). For future work, I will consider them as well so that a more comprehensive taxation differences across these countries is explored. These additional taxation differences may matter especially the consumption taxes which are high in Europe and matter for labor supply decision.

There are potentially other factors that can differ across countries that are left unchanged. One is the distribution of shocks. The shock process is assumed to be similar across individuals. This may not be true in the data for the U.S. and deserve more treatment. The propagation of shocks in the model is through human capital decisions, which are foundational for earnings inequality. Different shock processes change the decisions for college attendance and life-cycle human capital growth if the variance of the innovation to the human capital stock differs across education groups. This channel will be important to account for the cross-country facts since the shock process across countries may differ as well.

Another channel is the distribution of initial conditions, namely learning ability, initial human capital and disutlity for college. For future work, I will calibrate these distributions to match each country's mean earnings and variance profiles in the presence of taxation and college subsidies/transfers differences. I then study how these distributions differ from one another and what they imply about human capital formation earlier in the life-cycle, and other labor market conditions that are summarized in these distributions. For instance, if France has more unions which reduces the dispersion of earnings over the life-cycle, then I may find that the distribution of learning ability has a lower mean and less dispersion in France. This does not say anything about the innate ability of French people relative to Americans. Learning ability is a model object in a specific setup. It potentially summarizes other differences in the labor market besides taxation and college subsidies/transfers that are important for life-cycle earnings inequality.

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Table 1: Summary statistics for college graduation and expenditure

	(1)	(2)	(3)	(4)
Country	College share	College expenditure in GDP	Share of public expenditure in college	Share of college expenditure in government revenues
United States	35	2.6	38.6	2.9
United Kingdom	33	1.7	40.5	2.0
Netherlands	28	1.2	69.2	2.9
France	25	1.2	79.7	2.3

Note: All the numbers are in percentage. Government revenues include federal, local, and state government revenues. Any expenditure in vocational and training schools as well as community colleges that do not lead to a bachelor's degree are excluded from college expenditure. Source: OECD (2016).

Table 2: Earnings and wealth distribution

Panel A: Earnings Distribution	1st	2nd	3rd	4th	5th	Gini coef.	Top 5%	Top 1%
Data	2.6	7.0	12.6	21.3	56.5	0.4	27.2	10.7
Model	2.4	6.8	11.0	21.0	58.8	0.4	28.4	11.5
Panel B: Wealth Distribution								
Data	-0.5	0.9	3.9	10.7	85	0.8	60.4	34.1
Model	-0.8	0.6	3.2	8.2	88.8	0.8	47.0	11.7

Note: Quintiles of wealth and earnings distribution are reported. Data for earnings distribution are from the CPS and author's calculations, averaged over 2004-2016. Data for wealth distribution are from Kuhn & Rios-Rull (2016) for the same period.

Table 3: Earnings distribution for college and non-college individuals

	1st	2nd	3rd	4th	5th	Gini coef.	Top 5%	Top 1%
Panel A: Non-college								
Data	3.1	8.1	14.3	23.1	51.4	0.42	22.0	8.1
Model	2.9	7.9	13.5	24.2	51.5	0.41	21.1	8.8
Panel B: College								
Data	2.4	7.0	13.0	21.5	56.1	0.38	27.1	9.0
Model	1.8	6.8	12.4	23.3	55.7	0.38	26.8	9.4

Note: Quintiles of earnings distribution are reported. Data are from the CPS and author's calculations, averaged over 2004-2016.

Table 4: Country-specific labor earnings tax parameters

	United States	United Kingdom	Netherlands	France
λ	0.83	0.83	0.78	0.76
	(0.0003)	(0.0015)	(0.0032)	(0.0010)
τ	0.11	0.13	0.16	0.20
	(0.0002)	(0.0012)	(0.0019)	(0.0004)

Note: The standard errors are bootstrapped by 10% resampling for 1000 times, and are reported in parentheses.

Table 5: Selection for college for different progressive tax systems

	$\tau = 0.13$	$\tau = 0.15$	$\tau = 0.17$
Share of college (%)	35	31	27
Expend. for college in GDP (%)	2.6	2.0	1.3

Table 6: Inequality profiles under different policies

Policy	Mean Earnings			Variance of Log Earnings		
	U.K.	Netherlands	France	U.K.	Netherlands	France
taxation	0.98	0.93	0.93	0.89	0.79	0.53
college sub/tran	0.95	1.21	1.38	1.11	2.44	4.89
taxation + college sub/tran	0.91	0.96	0.95	0.81	0.89	0.67

Note: The figures for mean earnings show the share of growth in earnings between age 25 to 50 that is accounted by the model relative to data. For example, 0.93 in the first row for the Netherlands mean that 93% of the growth in mean earnings between ages 25 and 50 that is observed in the data is generated by the model. The figures for the variance show the share of overall growth in variance of log earnings that is generated within the model relative to data.

Table 7: College selection under different policies

Policy	Share of College Graduates			Expenditure in GDP		
	U.K.	Netherlands	France	U.K.	Netherlands	France
taxation	0.98	0.75	0.60	0.94	0.87	0.78
college sub/tran	0.95	1.45	1.49	1.00	1.00	1.00
taxation + college sub/tran	0.92	0.89	0.76	1.00	1.00	1.00

Note: The figures for both the share of college graduates and college expenditure in GDP are those statistics generated in the model relative to data. The data is reported in Table 1.

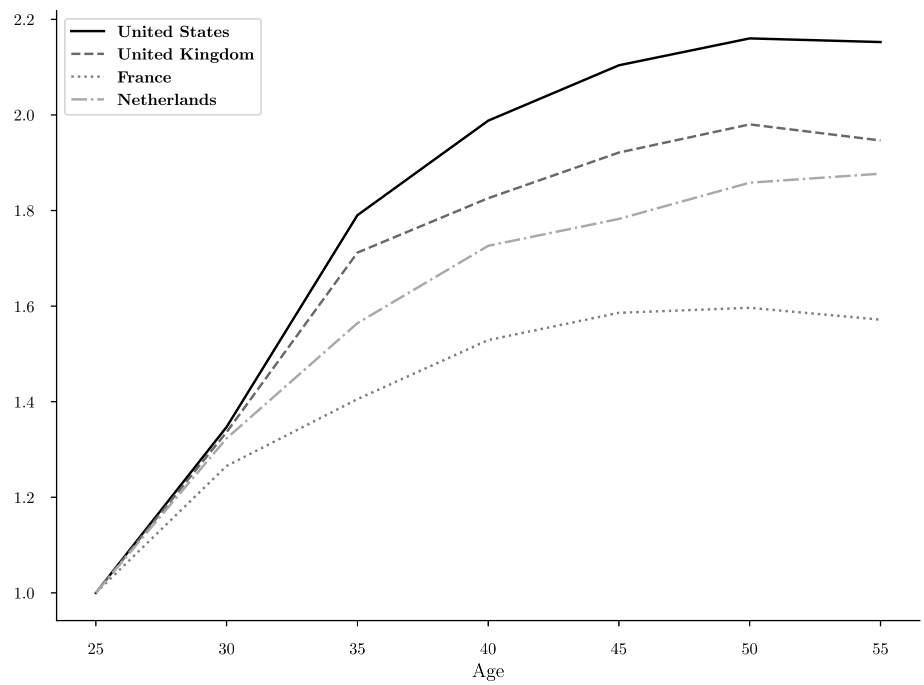

Figure 1: Mean earnings, individuals with and without a college degree, earnings are normalized to 1 at age 25.

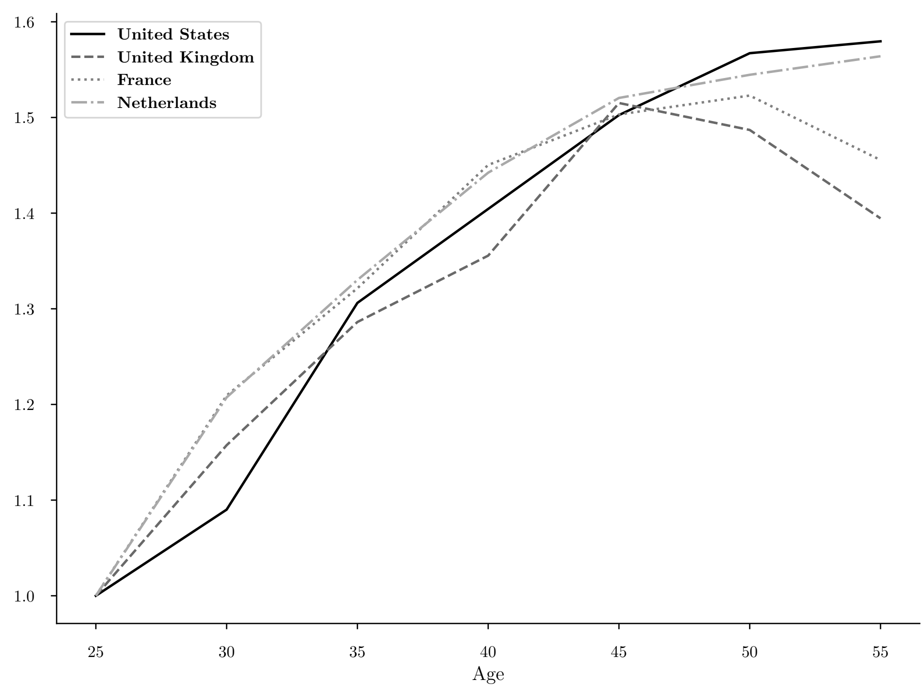

Figure 2: Mean earnings, individuals without a college degree, earnings are normalized to 1 at age 25.

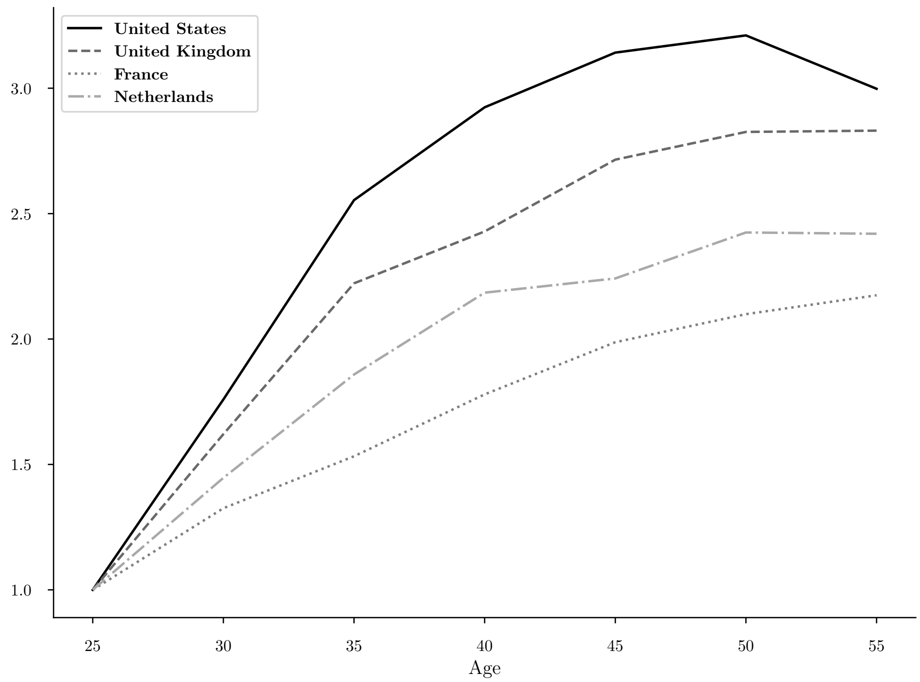

Figure 3: Mean earnings, individuals with a college degree, earnings are normalized to 1 at age 25.

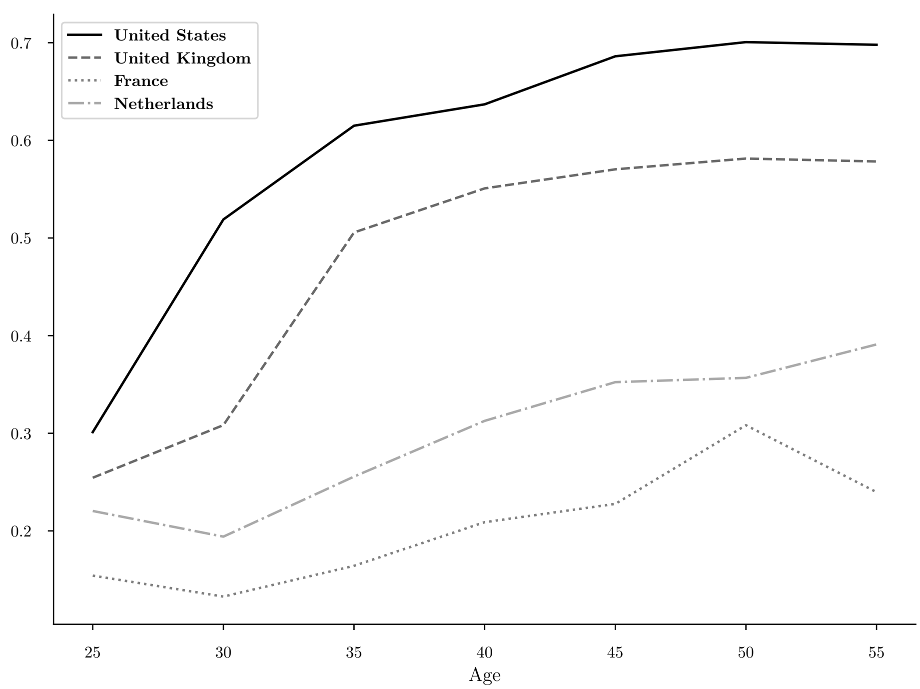

Figure 4: Variance of log earnings, individuals with and without a college degree.

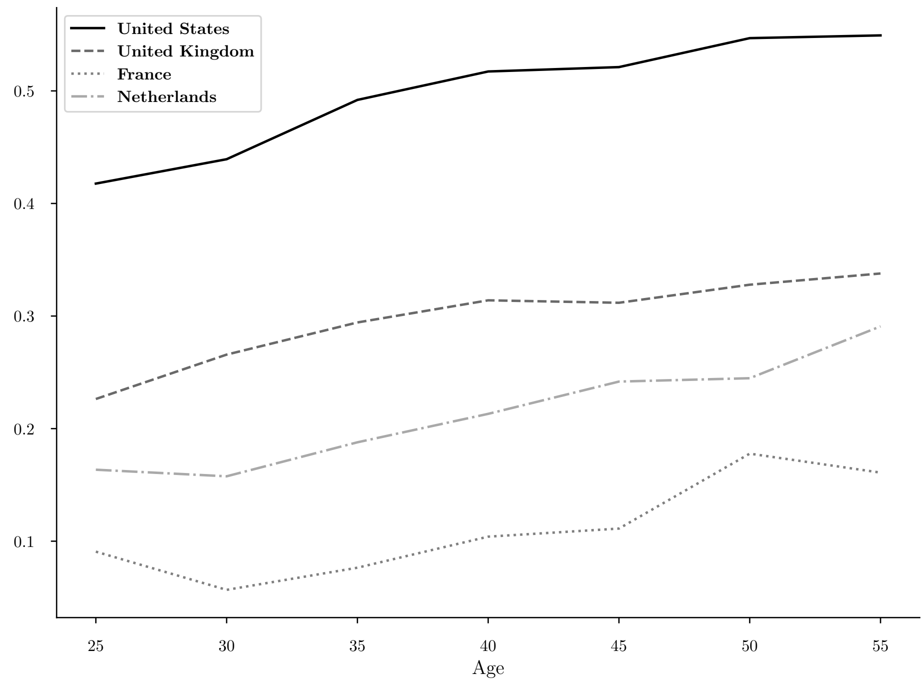

Figure 5: Variance of log earnings, individuals without a college degree.

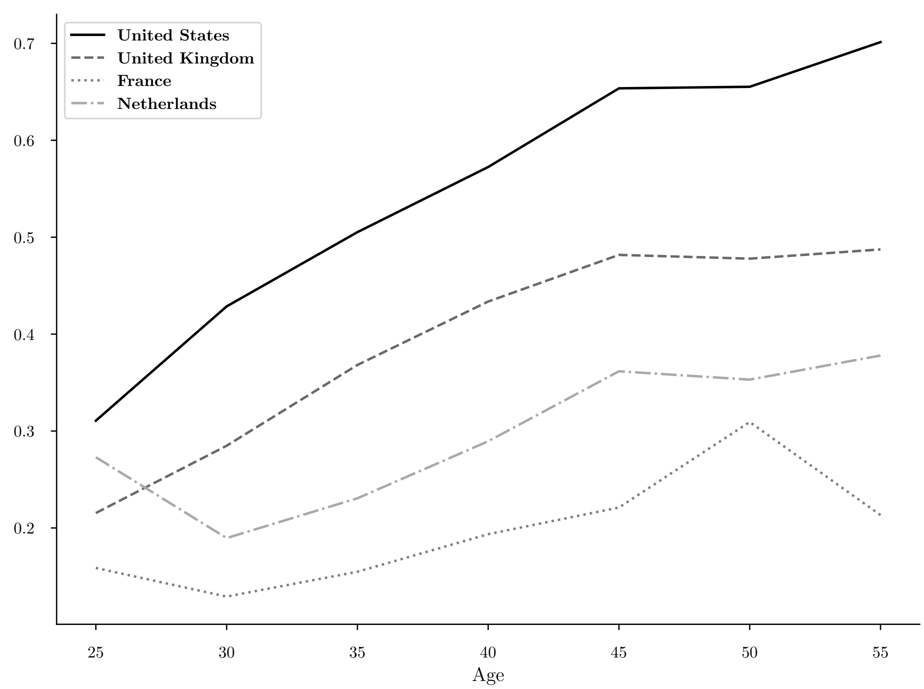

Figure 6: Variance of log earnings, individuals with a college degree.

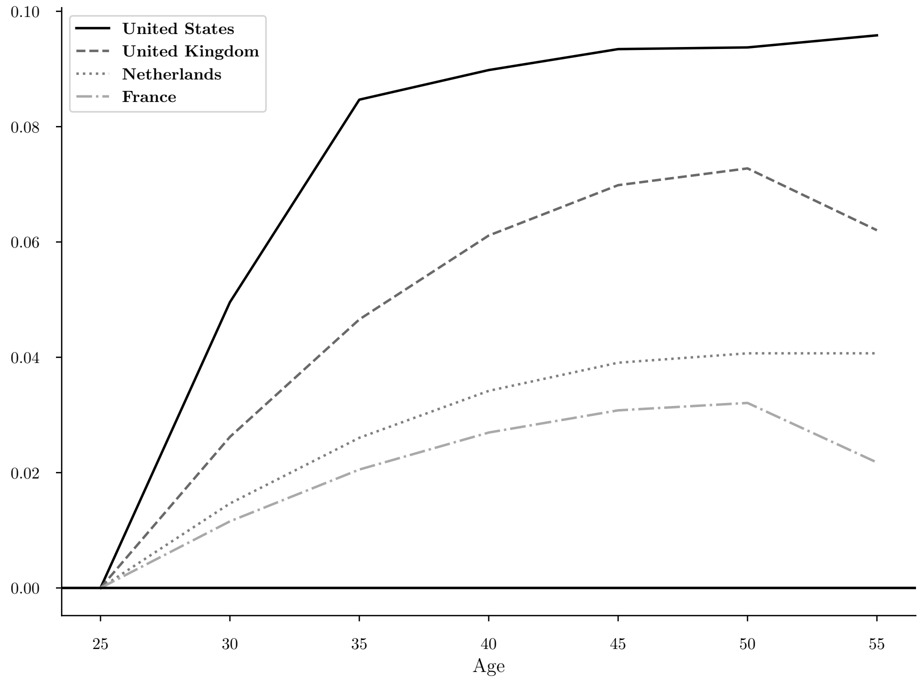

Figure 7: gini coefficient, individuals with and without a college degree.

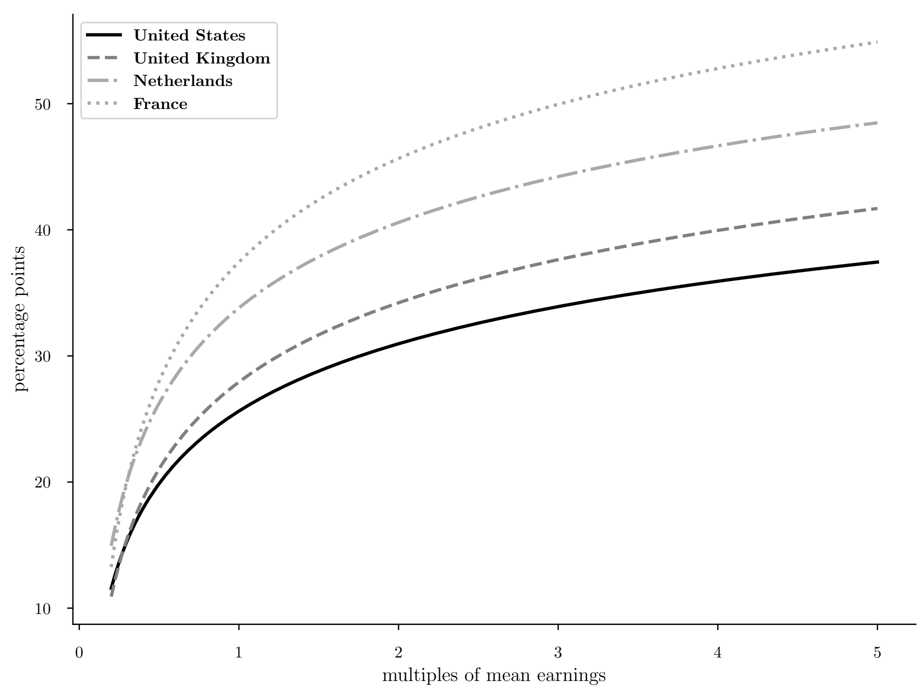

Figure 8: Marginal labor earnings tax rates based on multiples of mean cross-sectional income

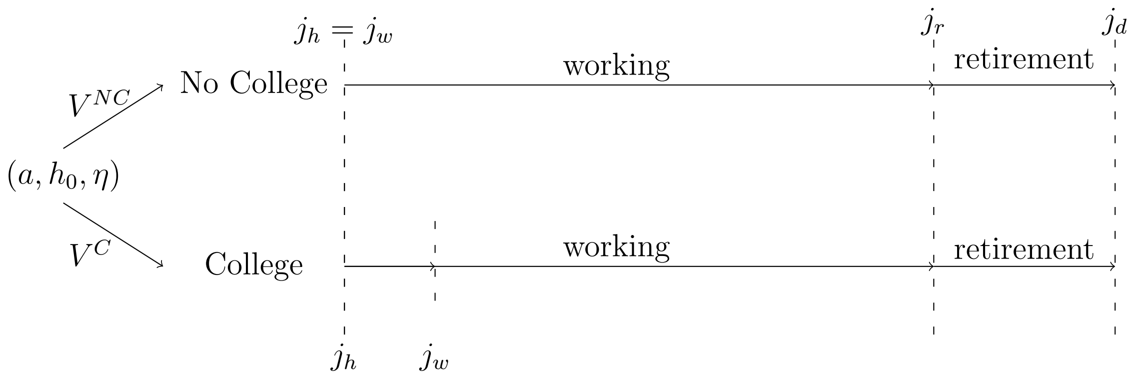

Figure 9: The life-cycle path of an individual in the model
Notes: j_h is the age of high school graduation, j_w is the age when individual start working, j_r is retirement age, and j_d is age of death.

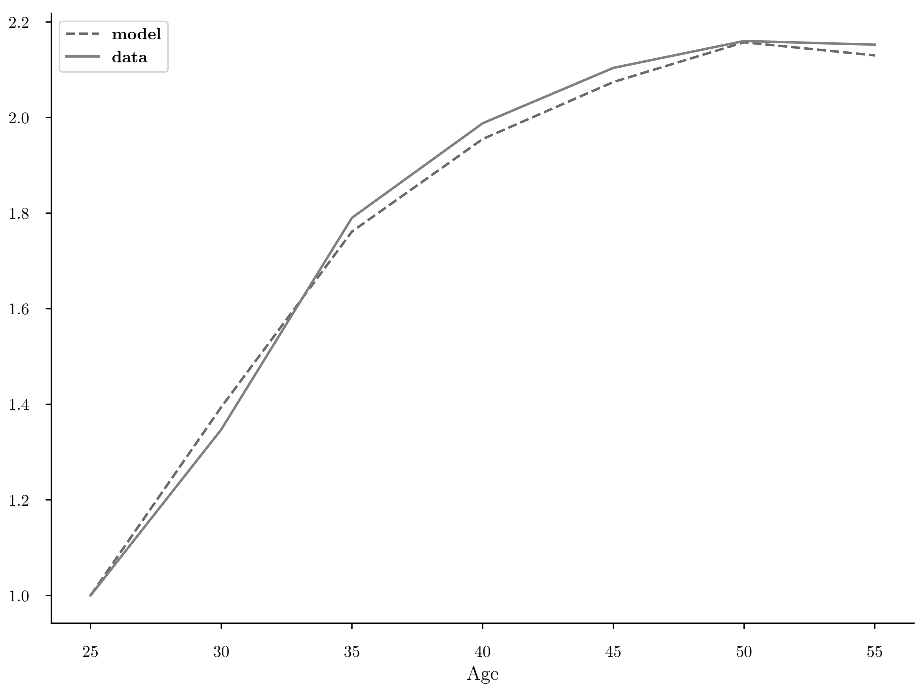

Figure 10: Mean earnings, individuals with and without a college degree, not targeted for calibration

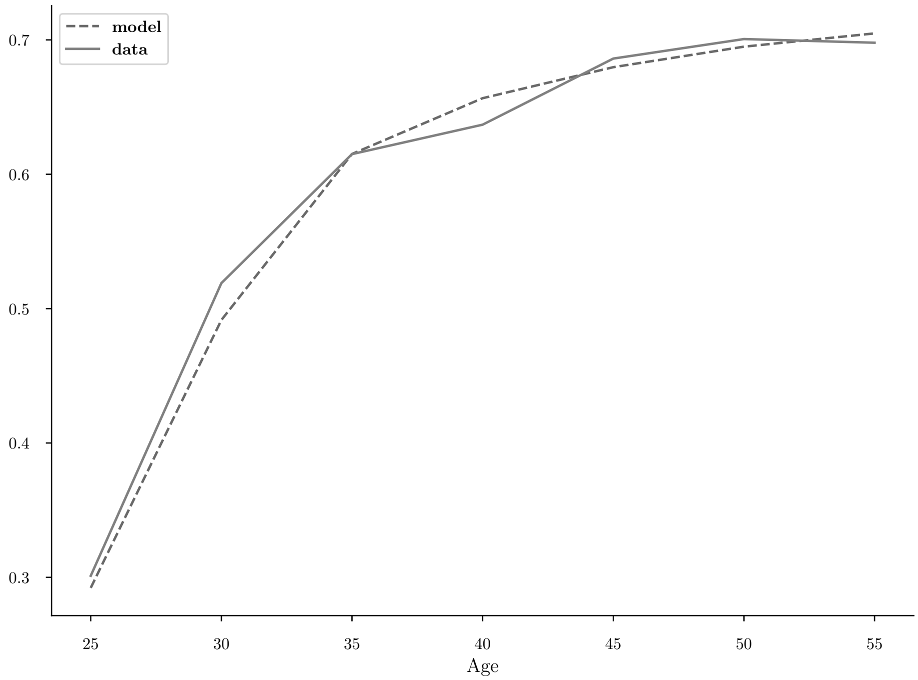

Figure 11: Variance of log earnings, individuals with and without a college degree, not targeted for calibration

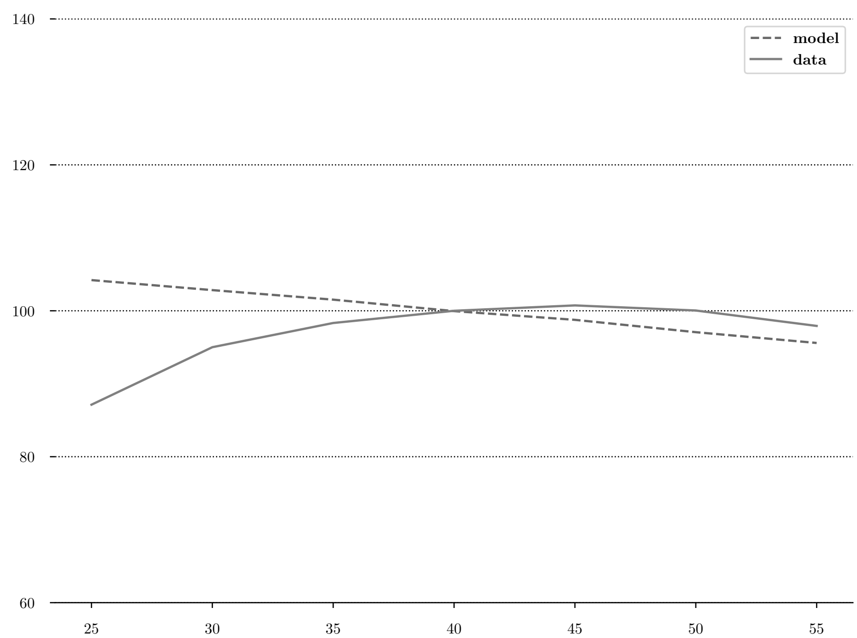

Figure 12: Hours worked over the life-cycle; data vs model (all individuals). Hours worked in the model is non-leisure time which includes labor supply and time investment for human capital accumulation.

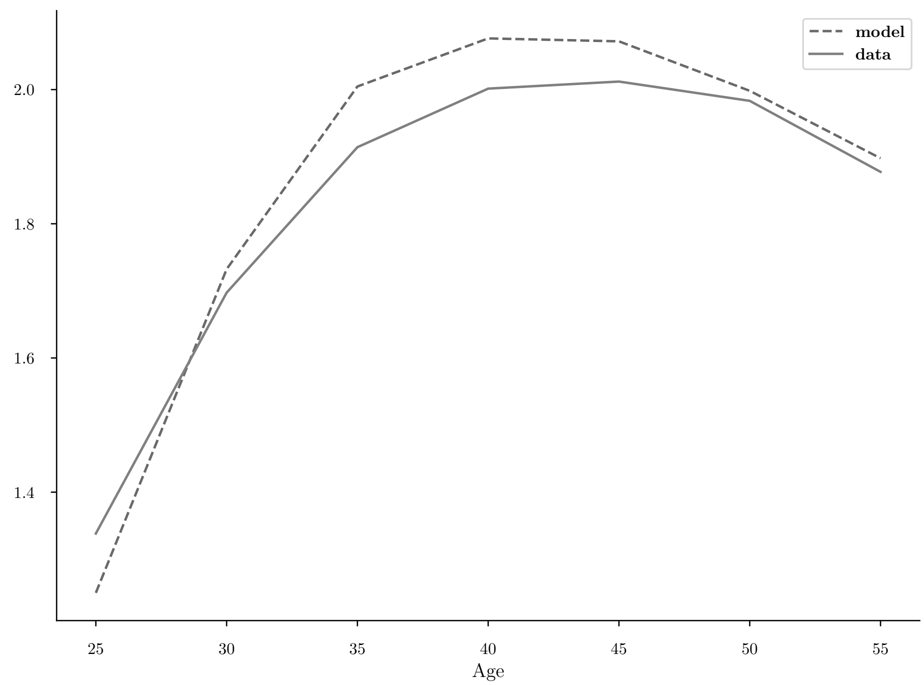

Figure 13: Skill premium, which is defines as the mean earnings of individuals with a college degree to those without one, not targeted for calibration

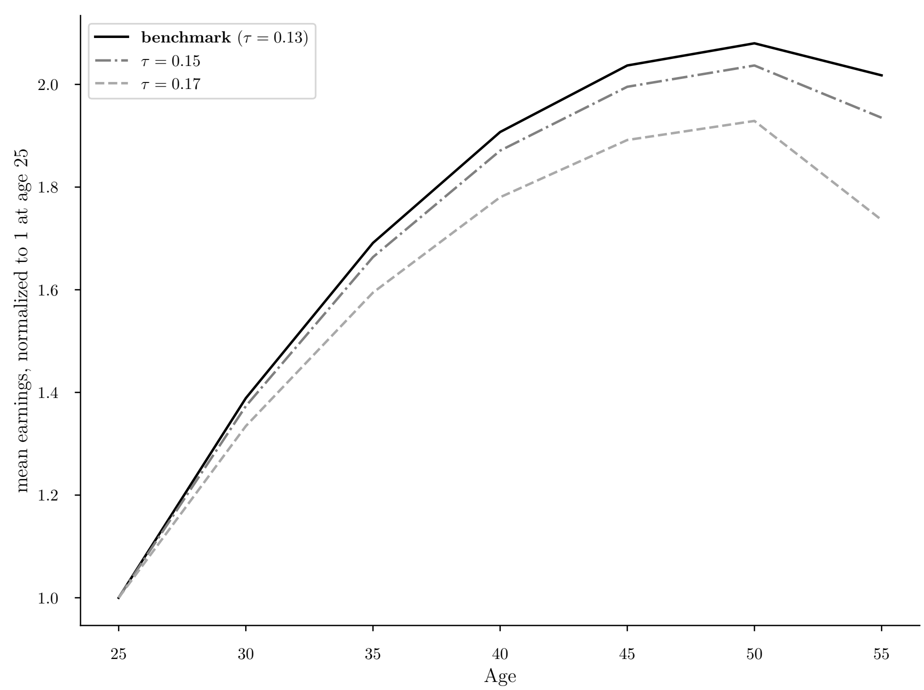

Figure 14: Mean earnings, individuals with and without a college degree, different progressiveness of the tax system

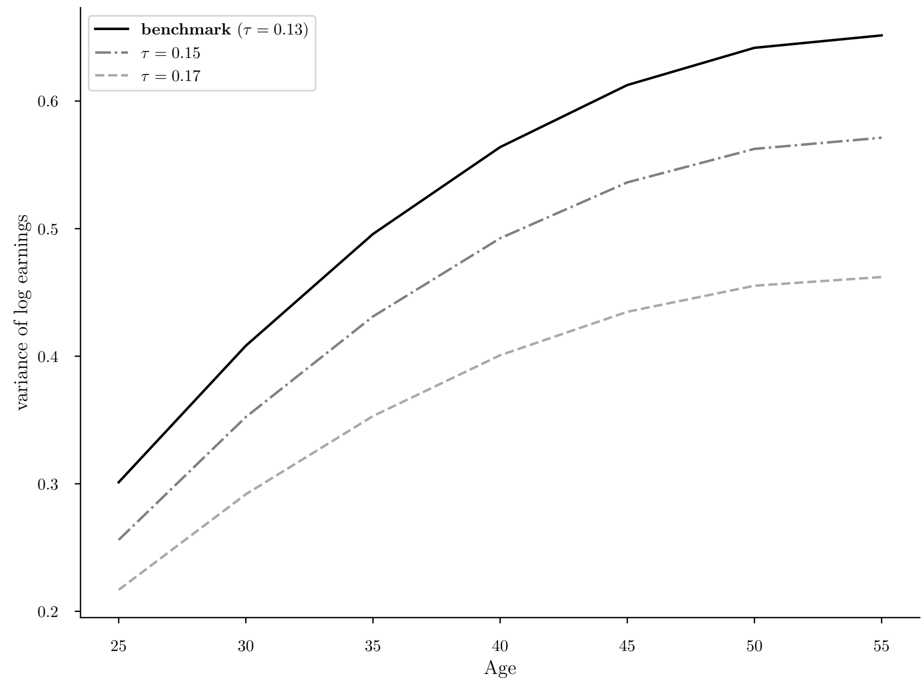

Figure 15: Variance of log earnings, individuals with and without a college degree, different progressiveness of the tax system

A Additional Figures

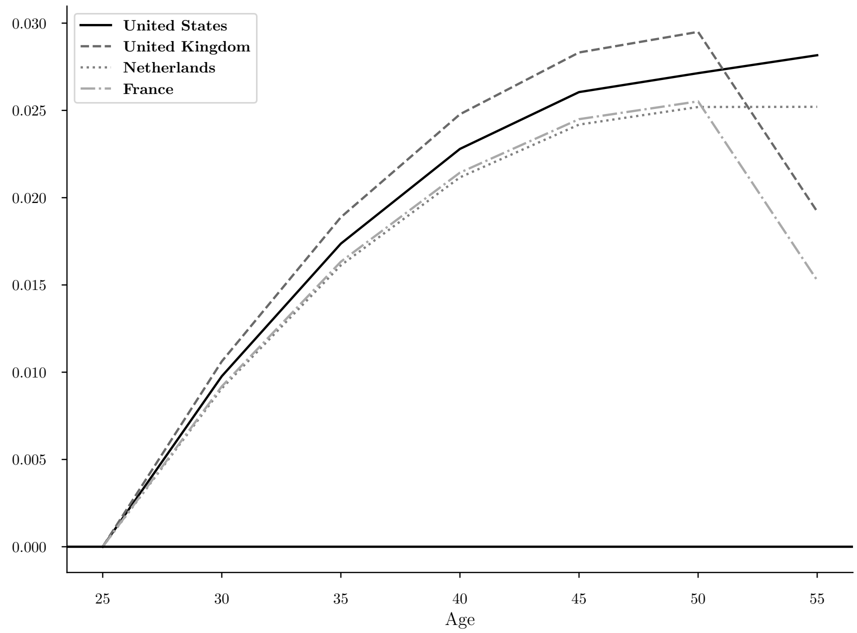

Figure A.1: gini coefficient, individuals without a college degree.

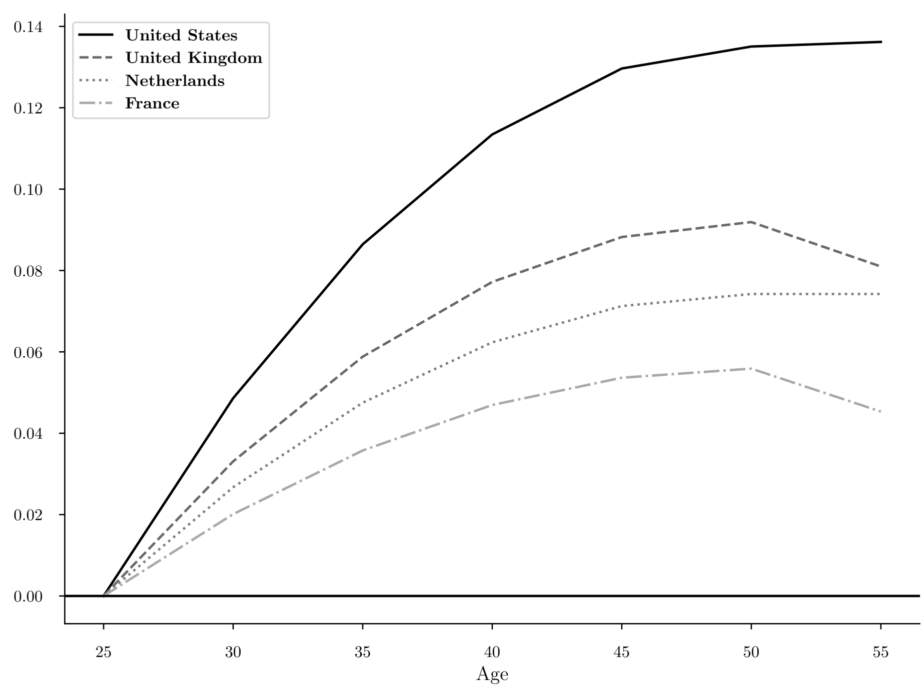

Figure A.2: gini coefficient, individuals with a college degree.

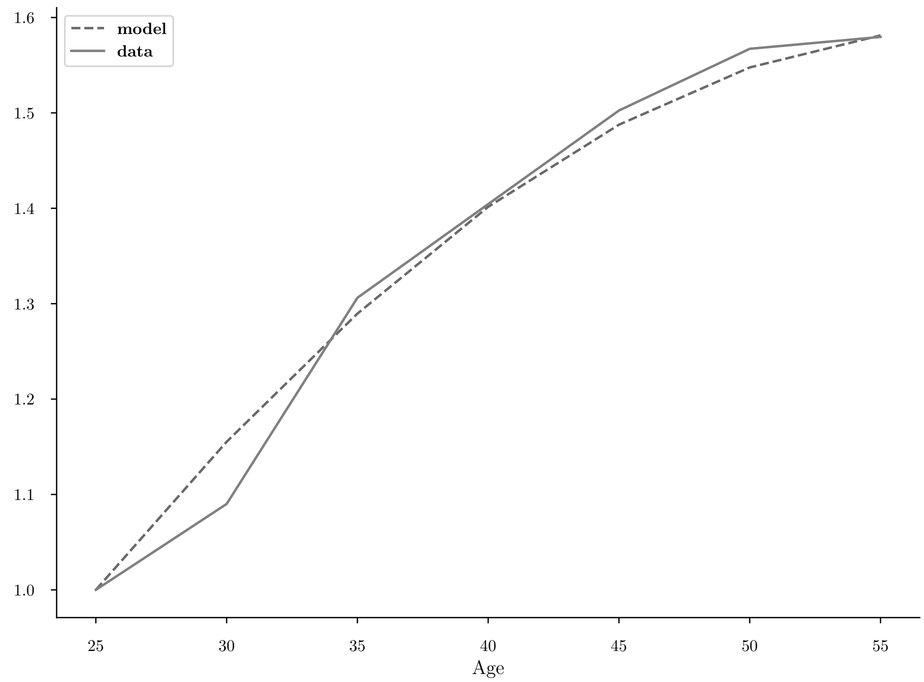

Figure A.3: Mean earnings, individuals without a college degree, targeted for calibration

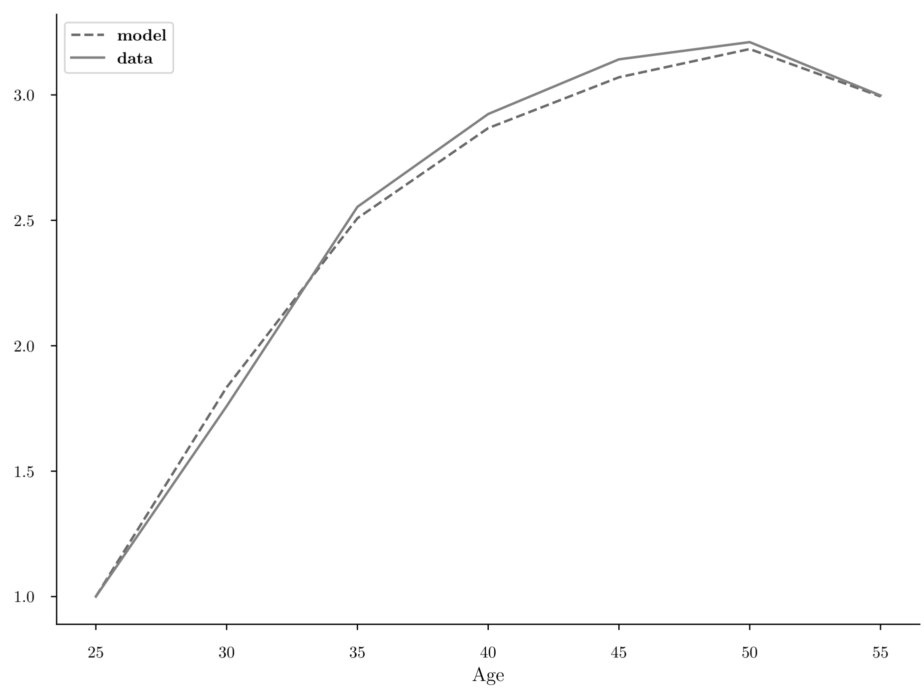

Figure A.4: Mean earnings, individuals with a college degree, targeted for calibration

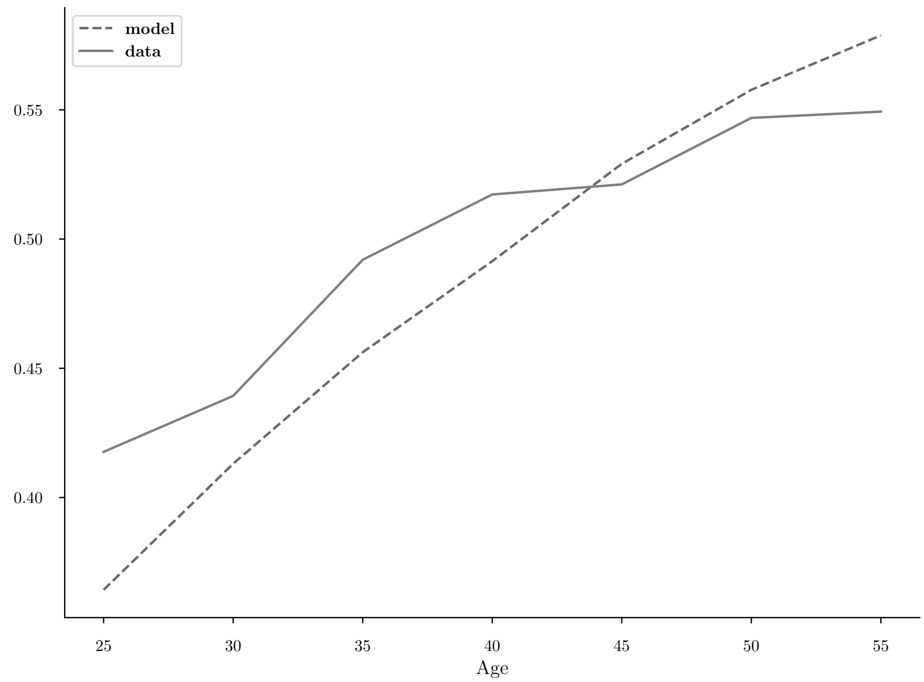

Figure A.5: Variance of log earnings, individuals without a college degree, targeted for calibration

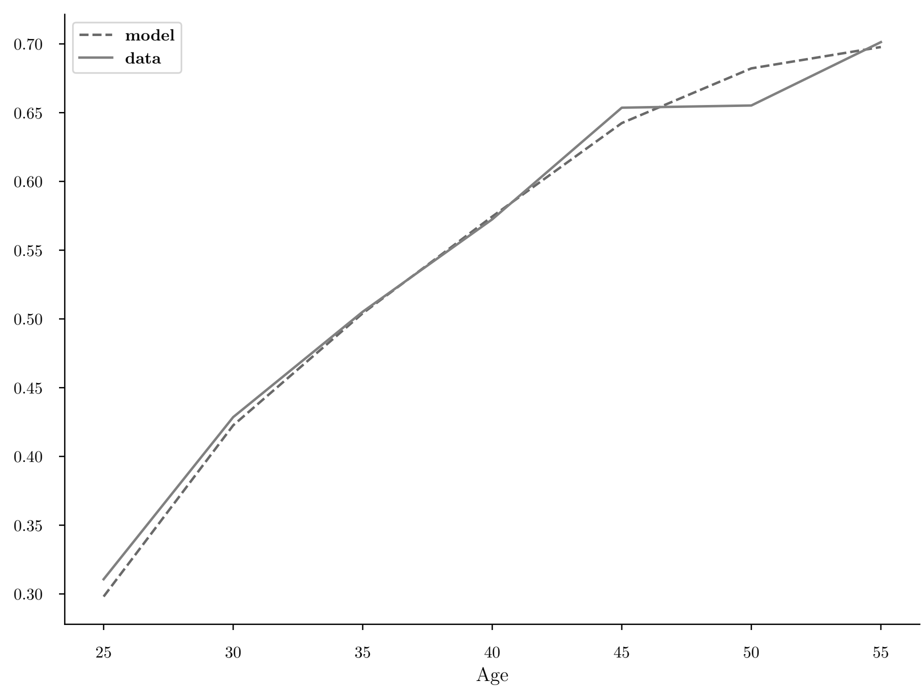

Figure A.6: Variance of log earnings, individuals with a college degree, targeted for calibration

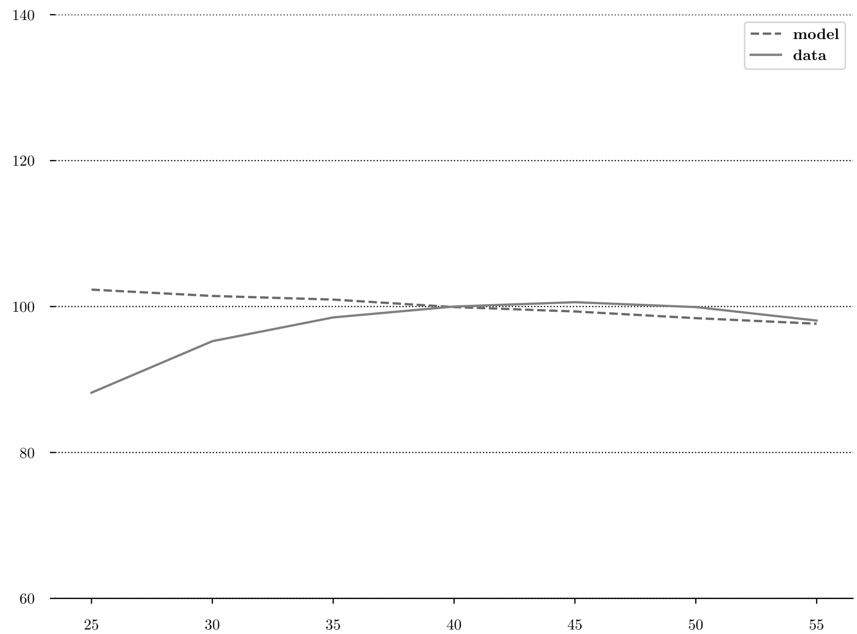

Figure A.7: Hours worked over the life-cycle; data vs model (non-college individuals). Hours worked in the model is non-leisure time which includes labor supply and time investment for human capital accumulation.

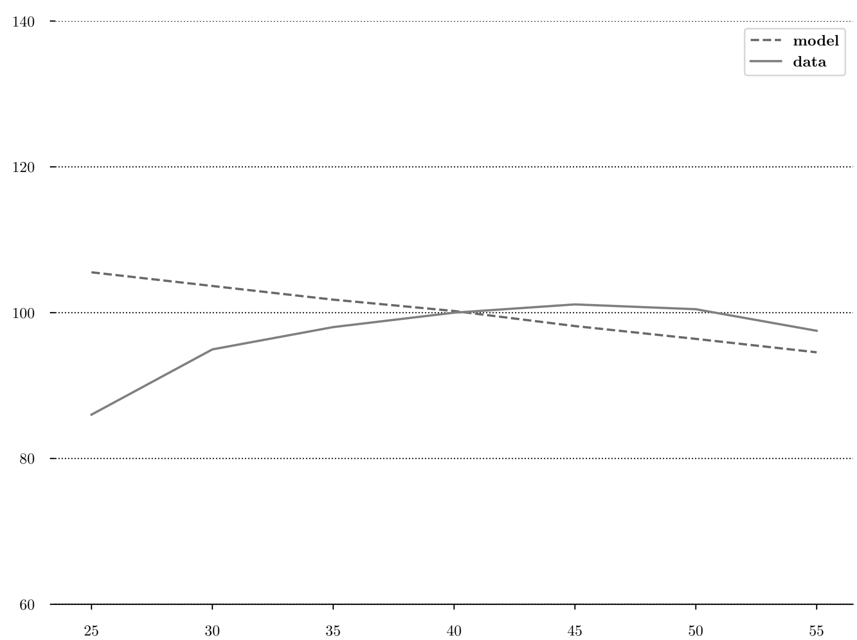

Figure A.8: Hours worked over the life-cycle; data vs model (college individuals). Hours worked in the model is non-leisure time which includes labor supply and time investment for human capital accumulation.

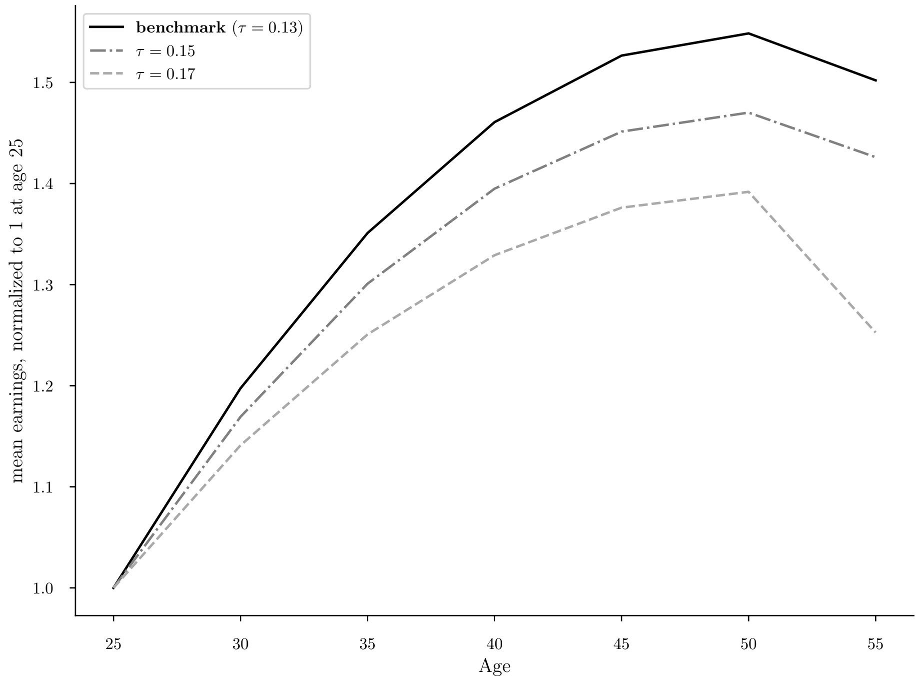

Figure A.9: Mean earnings, individuals without a college degree, different progressiveness of the tax system

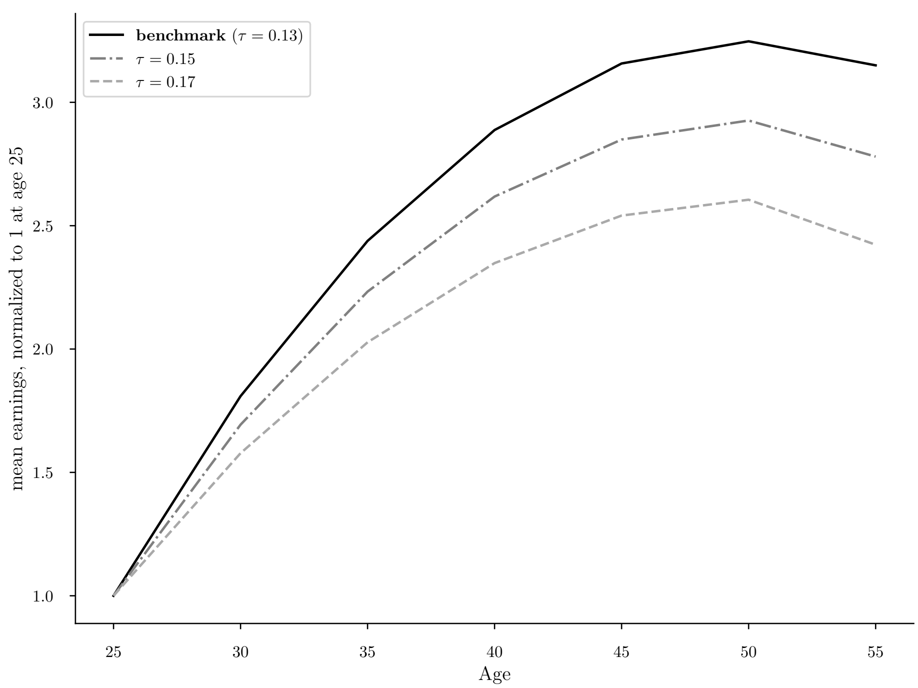

Figure A.10: Mean earnings, individuals with a college degree, different progressiveness of the tax system

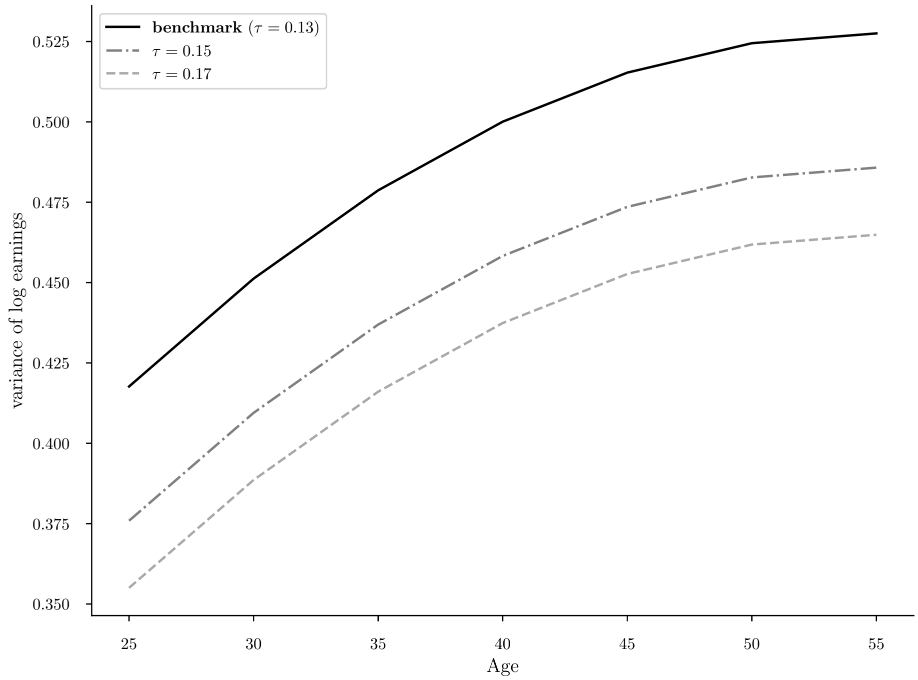

Figure A.11: Variance of log earnings, individuals without a college degree, different progressiveness of the tax system

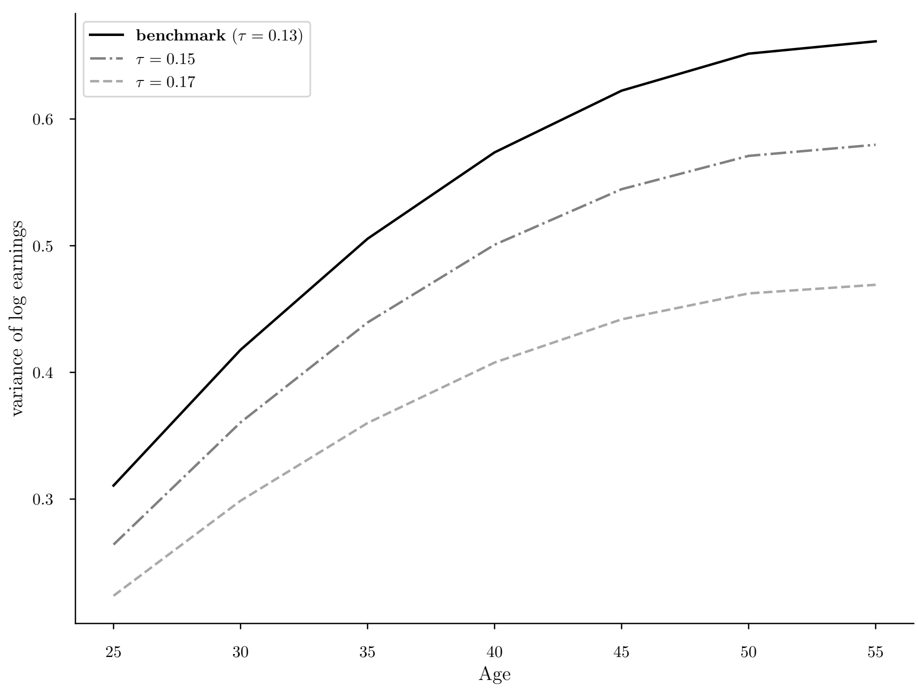

Figure A.12: Variance of log earnings, individuals with a college degree, different progressiveness of the tax system

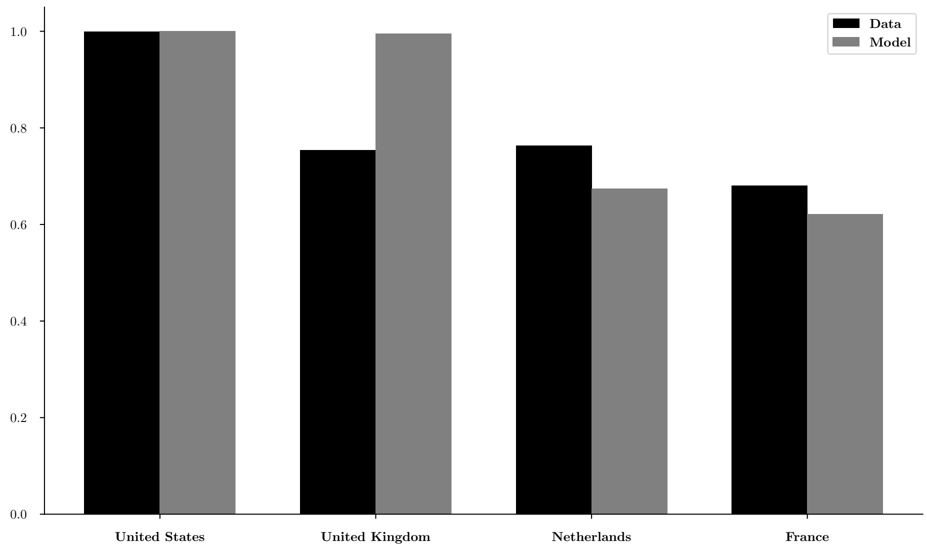

Figure A.13: GDP per worker (output) in the model (taxation + college subs/trans) vs. GDP per adult in the data.
Model and data for the U.S. are normalized to one. Differences in taxation and college subsidies/transfers are present. TFP level is normalized to 1 in all countries. Source: Feenstra *et al.* (2015).

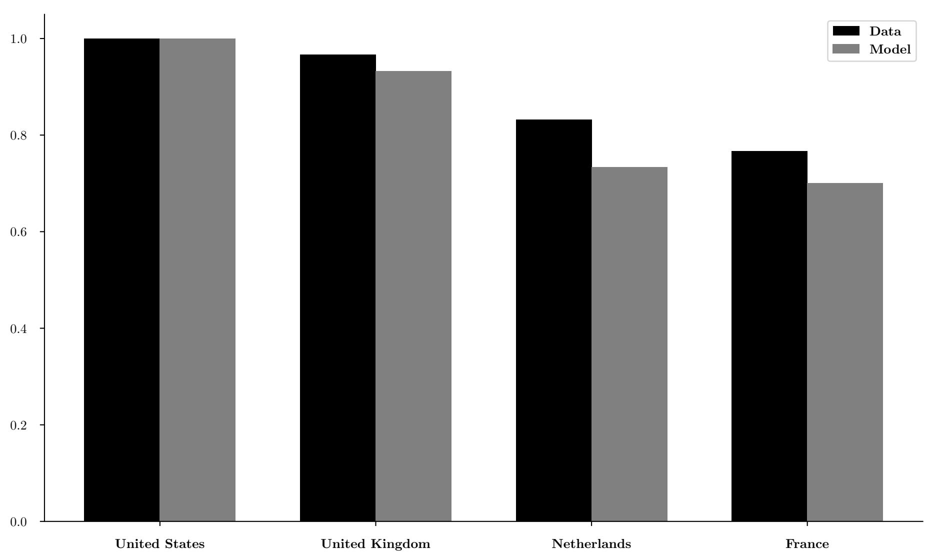

Figure A.14: Hours (non-leisure time) per worker in the model (taxation + college subs/trans) vs. average annual hours worked per adult in the data. Model and data for the U.S. are normalized to one. Differences in taxation and college subsidies/transfers are present. TFP level is normalized to 1 in all countries. Source: Feenstra *et al.* (2015).

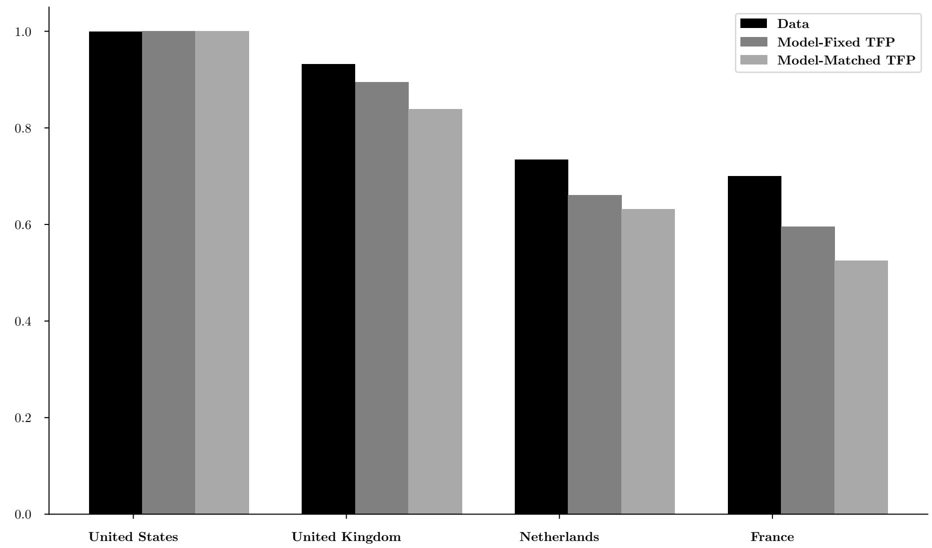

Figure A.15: Hours (non-leisure time) per worker in the model (taxation + college subs/trans + TFP) vs. average annual hours worked per adult in the data. Model and data for the U.S. are normalized to one. TFP levels are country-specific. Source: Feenstra *et al.* (2015).

B Additional tables

Table B.1: All parameter values

Parameter	Value
Technology	
α	1/3
A	1.00
Human capital	
ϕ	0.55
ν	0.16
δ_h	0.01
g_d	0.29
$\bar{d}$	2358.4
Utility	
β	0.985
B	12.40
γ	0.61
Shocks	
$z \sim N(\mu_z, \sigma_z^2)$	(0,0.111)
Initial conditions	
λ_η	160
$(\mu_a, \sigma_a^2, \lambda_a)$	(0.80,0.20,10.00)
$(\beta_0, \beta_1, \sigma_\epsilon^2)$	(5.20,0.15,0.22)

Table B.2: Parameters for the tax system

Tax source	Parameter	Value
Consumption	τ_c	0.10
Assets	τ_k	0.20
Progressive	(λ, τ)	(0.83,0.11)

Note: The consumption and capital income tax rates come from McDaniel (2011). The parameters for the progressive system are estimated.

Table B.3: Average sample size of 5-year age bins for each country over the period 2004-2016

Country	Size
United States	4425
United Kingdom	505
Netherlands	458
France	460

Table B.4: Gini coefficient of labor earnings for the whole cross-section, model vs data

Country	Data	Model
United States	0.39	0.39
United Kingdom	0.35	0.33
Netherlands	0.28	0.25
France	0.28	0.23

Note: Gini coefficients in the data are calculated for each year and averaged over the period 2005-2016. Model generated data are generated when differences in taxation and college subsidies/transfers are both considered.

Table B.5: Cross-country aggregate variables

Country	GDP per adult	Hours worked per adult
United States	1.00	1.00
United Kingdom	0.75	0.97
Netherlands	0.86	0.83
France	0.68	0.77

Note: All figures are for 2005, and the U.S. is normalized to one. Source: Feenstra *et al.* (2015).

Table B.6: Country-specific TFP level

Country	TFP only counterfactual	TFP with taxation and college subs/trnas
United States	1.00	1.00
United Kingdom	0.71	0.85
Netherlands	0.81	0.94
France	0.77	0.92

Note: U.S. is normalized to one.

Table B.7: The role of TFP for inequality profiles

Policy	Mean Earnings			Variance of Log Earnings		
	U.K.	Netherlands	France	U.K.	Netherlands	France
TFP	0.77	1.13	1.25	0.62	1.85	3.23
taxation + college sub/tran + TFP	0.84	0.95	0.93	0.71	0.83	0.61

Note: The figures for mean earnings show the share of growth in earnings between age 25 to 50 that is accounted by the model relative to data. The figures for the variance show the share of overall growth in variance of log earnings that is generated within the model relative to data.

Table B.8: The role of TFP for college selection

Policy	Share of College Graduates			Expenditure in GDP		
	U.K.	Netherlands	France	U.K.	Netherlands	France
TFP	0.72	0.92	0.88	0.65	0.73	0.69
taxation + college sub/tran + TFP	0.82	0.81	0.68	1.00	1.00	1.00

Note: The figures for both the share of college graduates and college expenditure in GDP are model generated relative to data. The data is reported in Table 1.

C Data Details

C.1 U.S. Data

The Current Population Survey (CPS) is the source of statistics on labor market for the U.S. government. It was designed to be representative of the civilian non-institutional population. There is a supplement applied in March called the Annual Social and Economic Supplement (ASEC) that extends the survey with detailed questions on income.

I follow the sample selection that is customary in the macroeconomic literature.[53] These criteria for sample selection are basically eliminating the extreme observations that are not precise enough especially for distributional studies such as the one carried out in this paper.

The age group is always 20-60, and they are grouped in 5-year age bin. All observations where a crucial value such as age, gender and education is missing are dropped. Also, if an observation reports positive labor earnings but zero or missing hours, it is dropped. The following criteria is used to further restrict the samples.

- Labor earnings: total wage and salary reported in CPS
- All earnings data are deflated by the price deflator reported in Flood *et al.* (2018).
- Agriculture workers, family workers and armed forces are excluded.
- Hours are restricted to at least 260 annual hours for age 30 and below, and 520 for above 30.
- Hourly earnings less than half of federal minimum wage are dropped.
- Mean, variance, and percentiles are calculated based on earnings levels and sample weights.

One important note is that the observations are not corrected for top coding. The reason is that this correction is not available for the European data since the top coding scheme changes from year to year, it is not uniform across countries, and the way it changes is not reported in the data documentation.[54] Hence, the data is treated as is and not corrected for any top coding.

[53] See for example Storesletten *et al.* (2004); Huggett *et al.* (2006); Guvenen & Kuruscu (2007); Heathcote *et al.* (2010); Huggett *et al.* (2011), among others.

[54] See Tormalehto (2017) for more detail about top-coding issue in Eu-SILC.

C.2 EU-SILC Data

The main source of data for the European countries is EU-SILC (2004-2016) which stands for the European Union Statistics on Income and Living Conditions. The general criteria for earnings and hours are the same as for the U.S. Observations with annual earnings less than half the effective minimum wage which are reported by EuroStat are excluded.

EU-SILC is an annual survey conducted by Eurostat in cooperation with the National Statistical Institutes (NSIs) of the European Union, European Free Trade Association (EFTA) and candidate countries. The goal of the survey is to collect comparable and reliable data on income, poverty, socio-economic and living conditions. This survey is the primary source of indicators on income by the Eurostat to evaluate progress towards EU policy objectives.

The EU-SILC is collected and harmonized under the coordination of Eurostat and NSIs. Harmonization means that Eurostat defines a set of target variables and defines a number of quality criteria regarding data collection. In most countries, the data collection is done via a survey, except for a few countries where administrative records are used.[55]

EU-SILC dtaa is seldom used in a cross-country study since it is a collection of surveys in different countries with potentially different form. However, Eurostat harmonizes most of the variables of interest for macroeconomists which include income data, education, and occupation data. For example, Hlasny & Verme (2018) uses EU-SILC to study variations in gini coefficient under different top-coding correction schemes.

C.3 Tax Data

In most countries, the unit of observation for tax purposes is the household. There is usually a primary earner and a secondary one and in some instances, there are more members of the household who draw an income. The main differences in the tax codes across countries are the tax brackets, marginal rates for each bracket, tax credits and their basis, and how the number of children affect tax liabilities of the household.

There are a few countries such as the United Kingdom where taxation is completely individual-

[55] See Roine & Waldenstrom (2010) for Sweden, Jantti *et al.* (2010) for Finland, and Aaberge & Atkinson (2010) for Norway.

based. There are other countries with individual tax system, but their tax code contain components such as tax credits that is based on the household, which makes their tax system hybrid. Netherlands is an example of that.

In order to estimate the parameters of the tax function in the main text, I used the tax system for each country and treated all of them as household based, even for the United Kingdom. In order to figure out the tax liabilities of each household, one needs to consult the tax code. This is done in a series of MATLAB programs by Bick *et al.* (2019). Therefore, for every household in the EU-SILC, I can recover the tax liabilities.

These tax liabilities take into account the structure of the household. For simplification, the household is disaggregated into three components: the principal earner, the secondary (spouse) earner, and the number of children. Given this structure, the programs look for the tax liabilities of the household in the tax code of the particular country and year. Of course, for the United Kingdom, the program calculates the tax liabilities separately for principal and secondary earner.

These tax liabilities include federal, state, local, and social security taxes for the U.S. and federal, and social security for European countries. I pool all the tax liabilities of the household together, and call that the taxes owed by the household. Total pre-tax income of the household is the sum of the income of principal and secondary earners. The income data constitutes only the wages, and I abstracted from business, asset, or other sources of income.

The estimation of the tax function is then a GMM estimator which chooses parameters of the tax function so that the difference between the tax liabilities for each household in the data and the one generated by the tax function is minimized. The standard errors are calculated by drawing 10% samples from the data and repeating for 1000 times. I also do a robustness check for the United Kingdom and focus on the principal's income and his tax liabilities, and re-estimate the parameters. In terms of progressivity, this does not change the tax function for the U.K. as much. The only major difference is that the average taxes are higher. These estimates are presented in table C.9.

Table C.9: U.K. with only individual tax (males)

	United Kingdom
λ	0.74
	(0.0018)
τ	0.14
	(0.0005)

Note: Standard errors are in parenthesis.

C.4 Higher education in Europe

In order to define levels of education uniformly across all countries, United Nations Educational, Scientific, and Cultural Organization (UNESCO) developed terms that have been agreed upon by all participating countries to address different levels of educational attainment. These levels, called the International Standard Classification of Education (ISCED) levels, are used to compile internationally comparable statistics on education.

The classification distinguishes between seven levels of education ranging from pre-primary to tertiary. International definitions of pre-primary, primary, and tertiary education are similar to the definitions used in the United States; however, lower and upper secondary education have slightly different meanings.

Pre-primary education (level 0), also called early childhood education, usually includes education for children aged 3-5, although in some countries, it starts as early as age 2 and in others continues through age 6. In the United States, pre-primary education includes kindergarten. Primary education (level 1) runs from about ages 6-11, or about first through sixth grades in the United States. Specialization rarely occurs in any country before secondary education.

Secondary education covers ages 11 or 12 through 18 or 19 and is divided into two levels: lower and upper secondary (levels 2 and 3). For the purposes of statistical comparability, the United States has defined lower secondary education as grades 7 through 9 and upper secondary as grades 10 through 12. In the United States, lower secondary education is the loose equivalent of intermediate school, middle school, or junior high school; however, in many other countries lower secondary education ends with an examination and constitutes the completion of compulsory education. Upper secondary education immediately follows lower secondary education and includes general (academic), technical, and vocational education, or any combination thereof, depending on the country. An upper secondary attainment level is roughly equivalent to a U.S. high school diploma.

Higher education, also referred to as tertiary education, includes three ISCED levels and is the equivalent of post-secondary education in the United States. Non-university higher education includes education beyond the secondary school level involving programs (e.g., vocational, community college, and junior college programs) that terminate in less than a 4-year degree. This type of education is at ISCED level 5. ISCED level 6 comprises education programs that lead to a 4-year undergraduate degree. These programs are typically located in universities and other 4-year institutions. The highest level, ISCED level 7, includes graduate and professional degree programs.[56]

Based on OECD (2007), post-secondary non-tertiary education straddles the boundary between upper secondary and post-secondary education from an international point of view, even though it might clearly be considered upper secondary or post-secondary programs in a national context. Although their content may not be significantly more advanced than upper secondary programs, they serve to broaden the knowledge of participants who have already gained an upper secondary qualification. The students tend to be older than those enrolled at the upper secondary level.

Tertiary-type A programs (ISCED 5A) are largely theory-based and are designed to provide sufficient qualifications for entry to advanced research programs and professions with high skill requirements, such as medicine, dentistry or architecture. Tertiary-type A programs have a minimum cumulative theoretical duration (at tertiary level) of three years' full-time equivalent, although they typically last four or more years. These programs are not exclusively offered at universities.

Conversely, not all programs nationally recognized as university programs fulfill the criteria to be classified as tertiary-type A. Tertiary-type A programs include second degree programs like the American Master. First and second programs are sub-classified by the cumulative duration of the programs, i.e., the total study time needed at the tertiary level to complete the degree.

Table C.10 presents a summary of the cross-walk between ISCED levels and their U.S. equiva-

[56] For the attainment indicators, a person is classified in the highest level for which they completed the last grade or degree for the level. For example, a U.S. student must complete grade 9 in order to attain a lower secondary education and 2 years of higher education (associate's degree) in order to attain a non-university higher education.

lents. For the purpose of sample selection and educational expenditure statistics, level 6 and 7 are defined as college graduate.

Table C.10: Cross-walk between ISCED levels and U.S. equivalent

ISCED level	Definition	U.S. equivalent
0	Preprimary	Kindergarten and below
1	Primary	1st-6th grades
2	Lower secondary	7th-9th grades
3	Upper secondary	10th-12th grades or first 3 years of vocational education
5	Higher education	Community or junior colleges or vocational technical institutes (non-university) leading to an associate's degree
6	Higher education	University or other 4-year education institution leading to a bachelor's degree
7	Higher education	A University or professional institute leading to leading to a master's or doctor's degree

Note: In order to define levels of education uniformly across all countries, this publication uses terms that were developed by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and have been agreed upon by all participating countries, but which might be unfamiliar to readers from the United States. These levels, called the International Standard Classification of Education (ISCED) levels, are used to compile internationally comparable statistics on education.
Source: NCES (2020).

C.4.1 United Kingdom

Tuition fee loans are available to cover the full cost of tuition fees and are paid directly to the institution. They are non-income assessed loans available to both full-time and part-time students, but part-time students must be studying for a minimum of 25% of their time to be eligible.

Maintenance loans are available to help with the cost of accommodation and other living expenses for full-time and part-time undergraduate students. The exact amount which can be borrowed varies, but the loan includes a non-financially assessed portion which all students who are eligible for the loan receive. It also includes a financially assessed portion which depends on household income (i.e. the combined total income of the student and his / her parents, or the student and the partner they live with); and a portion based on the student's place of residence (the family home, or away from home).

Repayment arrangements are the same for both tuition fee loans and maintenance loans. The threshold for when borrowers are required to start making repayments depends on when they studied their course. Any loan remaining after 30 years will be canceled. Payment is collected through the tax system. Student loans accrue interest from the date they are paid out up until they are repaid in full.

C.4.2 Netherlands

The Dutch government provides public aid. This covers student finance and benefits like healthcare and housing allowances. Student finance, or studiefinanciering in Dutch, is a 3-part financial aid package intended to help students with paying their tuition fees and student life. There are requirements you need to meet, with some students being eligible for all 3 components and some maybe one or two. The first is the loan or the tuition fee loan; the second is the supplementary grant, and the third is the student travel product.

Allowances are sums of money gifted to low-income citizens, or students, to aid with some of their living costs. Healthcare allowance is a monthly sum provided by the Dutch government to help cover your monthly health insurance bill. Similarly, the housing allowance is a sum to help with your monthly rent. As with student finance, there are specific requirements you need to meet.

Aside from student finance, there is the option of applying for a scholarship. A scholarship is like financial aid but it comes in the form of an award. Scholarships are usually given out by universities or other donors or institutions. Scholarships are also awarded based on specific criteria, like having certain grades or possessing certain qualities. Unlike a loan, scholarship money does not have to be paid back.

C.4.3 France

Grants are provided based on family or individual resources. Most students are entitled to a minimum grant. Any student receiving a state grant is automatically entitled to 100% reduction in tuition fees at state universities. Students are eligible for state-guaranteed loans of up to 15000 euros at a low interest rate. 70% of the amount loaned is guaranteed 10 years by the state. The loans are granted by commercial banks and require a further guarantee for the remaining 30%.

Fees for undergraduate studies are determined annually by the Education Ministry. Since 2007 universities may opt for an autonomous status. Autonomous universities have the ability to determine certain tuition fees. While undergraduate fees are capped at the level set by the Ministry of Education, post-graduate and doctorate studies may be set freely by the universities.

D Robustness Checks

to be completed ...

D.1 Mean and Variance Profiles Statistically Differ Across Countries

In this section, I show that the differences in mean earnings and variance of log earnings over the life-cycle are statistically significant using ANOVA analysis. This is also true for the college individuals. The profiles for non-college individuals for mean earnings are not different from a statistical standpoint (I reject the null hypothesis of similar profiles for all groups except for the mean earnings of the non-college individuals).

Table D.11: ANOVA table for mean earnings

	sum of squared errors	degrees of freedom	F statistic	$PR(>F)$
number of countries	0.593	3	3.605	0.031
Residual	1.096	20	-	-

Table D.12: ANOVA table for mean earnings, non-college individuals

	sum of squared errors	degrees of freedom	F statistic	$PR(>F)$
number of countries	0.015	3.0	0.226	0.877
Residual	0.435	20.0	-	-

Table D.13: ANOVA table for mean earnings, college individuals

	sum of squared errors	degrees of freedom	F statistic	$PR(>F)$
number of countries	3.056	3	5.287	0.008
Residual	3.853	20	-	-

Table D.14: ANOVA table for variance of log earnings

	sum of squared errors	degrees of freedom	F statistic	$PR(>F)$
number of countries	0.644	3	17.523	0.0
Residual	0.294	24	-	-

Table D.15: ANOVA table for variance of log earnings, non-college individuals

	sum of squared errors	degrees of freedom	F statistic	$PR(> F)$
number of countries	0.564	3.0	89.193	0.0
Residual	0.051	24.0	-	-

Table D.16: ANOVA table for variance of log earnings, college individuals

	sum of squared errors	degrees of freedom	F statistic	$PR(> F)$
number of countries	0.465	3	15.486	0.0
Residual	0.240	24	-	-

E Mathematical derivations

E.1 A simple model of college choice

Consider an individual who lives for two periods. The individual can potentially work in both periods, or she can go to college in period one and accumulate human capital while only work in the second period. There is no channel to increase human capital besides college and there are no human capital depreciation. I assume for simplicity that the only taxation system is a flat rate labor tax τ. Individuals discount future at rate r, which equals the real interest rate. This implies a discount factor $\beta = \frac{1}{1+r}$. There is a rental rate per unit of human capital so that the labor earnings of an individual with human capital h equals wh.

If the individual goes to college, she will have access to a technology to increase her human capital. This technology uses her initial human capital and investments in terms of consumption goods to produce new human capital. There is complementarity between initial human capital and goods investments in this technology as follows:

$$h_1 = h_0 + ah_0^{\phi}d^{\nu}, \quad \phi, \nu > 0, \quad \phi + \nu < 1, \tag{E.1}$$

where d is the amount of investments in terms of consumption goods. The individual has to borrow this amount in order to fund her college education. College expenditure is subsidized at the rate g_d, and the government transfers a fixed college grant $\bar{d}$ to the individual during college.

The individual has three state variables at the start of period one: learning ability a, initial human capital h_0 and disutility for college η. The last one is the utility cost of attending college that the individual incurs only if she chooses college in the first period. This cost captures the psychological cost of exerting effort during college. The individual compares the present discounted value of going to college $V^C(a, h_0, \eta)$ and not going to college $V^{NC}(a, h_0, \eta)$ and if $V^C > V^{NC}$, she chooses college. Otherwise, she does not choose college.

The problem of the individual if she chooses not to go to college is as follows:

$$V^{NC}(a, h_0, \eta) = \max_{c_0^{NC}, c_1^{NC}} \quad \log(c_0^{NC}) + \beta \log(c_1^{NC}) \tag{E.2}$$

$$\text{s.t.} \quad c_0^{NC} + \frac{c_1^{NC}}{1+r} = wh_0(1-\tau) + \frac{wh_0(1-\tau)}{1+r}.$$

The problem of an individual if she chooses to go to college is as follows:

$$V^C(a, h_0, \eta) = \max_{c_0^C, c_1^C, d} \quad \log(c_0^C) + \beta \log(c_1^C) - \eta \tag{E.3}$$

$$\text{s.t.} \quad c_0^C + \frac{c_1^C}{1+r} + (1-g_d)d = \frac{wh_1(1-\tau)}{1+r} + \bar{d}$$

$$h_1 = h_0 + a h_0^{\phi} d^{\nu} \tag{E.4}$$

Solving the above problem yields:

$$V^{NC} = 2\log(c_0^{NC}) \tag{E.5}$$

$$V^{C} = 2\log(c_0^{C}) - \eta \tag{E.6}$$

$$d = \left(\frac{aw\nu h_0^{\phi}}{(1+r)(1-g_d)}\right)^{\frac{1}{1-\nu}} (1-\tau)^{\frac{1}{1-\nu}}. \tag{E.7}$$

I can now find the cutoff for disutility η^* in terms of ability a and initial human capital h_0 that makes the individual indifferent for going to college. From the solution to both problems I know

$$2\log\left(\frac{c_0^C}{c_0^{NC}}\right) = \eta^*. \tag{E.8}$$

This means that if the individual satisfies $\eta < \eta^*$, she chooses college and otherwise, she starts working from the start of the first period. Therefore, the cutoff value depends on the ratio of consumption in the first period during college relative to no-college path. Solving for consumption functions, I get:

$$\frac{c_0^C}{c_0^{NC}} = \left(\frac{1-\nu}{2+r}\right)\left[1 + \left(\frac{wa\nu}{(1+r)(1-g_d)}\right)^{\frac{\nu}{1-\nu}} h_0^{\frac{\nu+\phi-1}{1-\nu}} (1-\tau)^{\frac{\nu}{1-\nu}}\right] + \frac{\bar{d}(1+r)}{(2+r)wh_0(1-\tau)}. \tag{E.9}$$

Combining with equation (E.8) yields the expression in the main text.

E.2 Solution of the Model

The algorithm to compute a steady-state equilibrium for the model with a taxation system (λ, τ) , given all model parameters, is outlined below.

1. Guess $(K/L, Tr)$. Calculate $r = F_1(K/L, 1) - \delta$, and $w = F_2(K/L, 1)$.

2. Solve the decision rules for every grid point for all stages of the life-cycle, both for college and non-college.

3. Simulate 10000 shock histories for every tuple of initial conditions (a, h_0, η) using the decision rules calculated in step 2.

4. Calculate $(K'/L', Tr')$ implied by the simulation. If $K/L = K'/L'$ and $Tr' = Tr$ up to a tolerance, then stop. Otherwise, update the guess and repeat 1-3.

E.2.1 Solving the decision rules for the working period

For the working period, the problem of an individual with or without college is as follows. The state variables are age, learning ability, human capital, assets, and the earnings shock. Let the vector of state variables be $\Theta = (j, a, h, x, z)$.

$$V(\Theta) = \max_{c,l,s,h',x'} \left\{ \log c - B\frac{(l+s)^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}} + \beta\mathbb{E}[V(\Theta')|z] \right\} \tag{E.10}$$

$$c = (1+r)x - x' + w(zh)l \tag{E.11}$$

$$h' = (1-\delta_h)h + a(hs)^{\phi} \tag{E.12}$$

The associated Lagrangian is

$$\mathcal{L} = \log c - B\frac{(l+s)^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}} + \beta\mathbb{E}[V(\Theta')|z] + \lambda[(1+r)x - x' + w(zh)l - c] + \mu[(1-\delta_h)h + a(hs)^{\phi} - h'] \tag{E.13}$$

The set of first order conditions are:

$$\frac{1}{c} = \lambda \tag{E.14}$$
$$B(l+s)^{\frac{1}{\gamma}} = \lambda w(zh) \tag{E.15}$$
$$\beta\mathbb{E}[V_x(\Theta')|z] = \lambda \tag{E.16}$$
$$\beta\mathbb{E}[V_h(\Theta')|z] = \mu \tag{E.17}$$
$$B(l+s)^{\frac{1}{\gamma}} = \mu a\phi h(hs)^{\phi-1} \tag{E.18}$$

The Envelope conditions are:

$$V_x(\Theta) = \lambda(1+r) \tag{E.19}$$
$$V_h(\Theta) = \lambda wzl + \mu[(1-\delta_h) + as(hs)^{\phi-1}] \tag{E.20}$$

Combining (E.14), (E.16), and (E.19), we get the consumption Euler equation:

$$\frac{1}{c} = \beta(1+r)\mathbb{E}[\frac{1}{c(\Theta')}|z] \tag{E.21}$$

Combining (E.14) and (E.15) gives the intratemporal labor supply equation:

$$B(l+s)^{\frac{1}{\gamma}} = \frac{w(zh)}{c} \tag{E.22}$$

From (E.15) and (E.17) we get

$$\lambda = \frac{B(l+s)^{\frac{1}{\gamma}}}{w(zh)} \tag{E.23}$$
$$\mu = \frac{B(l+s)^{\frac{1}{\gamma}}}{a\phi h(hs)^{\phi-1}} \tag{E.24}$$

Combining (E.18) and (E.20) with (E.23) and (E.24) we get

$$\frac{B(l+s)^{\frac{1}{\gamma}}}{a\phi h(hs)^{\phi-1}} = \beta\mathbb{E}\Big[\frac{wz'l'}{c'}|z\Big] + \beta\mathbb{E}\Big[\frac{B(l'+s')^{\frac{1}{\gamma}}}{a\phi h'(h's')^{\phi-1}}[(1-\delta_h) + as'(h's')^{\phi-1}]|z\Big] \tag{E.25}$$

For solving for the optimal choices, one can use the following algorithm:

- **Step 1:** Choose a value for s. That gives a value for h'.
- **Step 2:** Choose a value for x'. Together with a choice for h', we know Θ'. Using (E.21), we know c.
- **Step 3:** Knowing Θ', we can calculate the RHS of (E.25). Let's call this value Γ. This gives one equation in one unknown which is l:

$$l = \min\Bigg\{\max\Big\{\big(\frac{\Gamma a\phi h(hs)^{\phi-1}}{B}\big)^{\gamma} - s, 0\Big\}, 1\Bigg\} \tag{E.26}$$

- **Step 4:** Using the budget constraint, we can update the choice of $x' = (1+r)x - w(zh)l - c$.
- **Step 5:** Using (E.22), we can update the choice for s:

$$s = \min\Bigg\{\max\Big\{\big(\frac{wzh}{B}\big)^{\gamma} - l, 0\Big\}, 1\Bigg\} \tag{E.27}$$

With the updated choices in hand, we go to step 1, until all the equations are satisfied.

E.3 A Stationary Competitive Equilibrium

The economy has an overlapping generations structure. The fraction (μ_j) of age (j) individuals in the economy satisfies $\mu_{j+1} = \mu_j/(1+n)$, where (n) is the population growth.

At a point in time, individuals are heterogeneous in their age (j) and their individual state θ. The distribution of age (j) individuals across individual states θ is represented by a probability measure λ_j defined on subsets of the individual state space Θ. The individual state at age (j) is defined as:

$$\theta = \left(\overbrace{\mathbb{1}^c, h, x, z}^{\theta_1}; \underbrace{a, \eta}_{\theta_2} \right) \tag{E.28}$$

where $\mathbb{1}^c$ is an indicator function which equals 1 if the individual chooses the college path, and 0 otherwise. θ_1 consists of college choice, human capital stock, asset holding, and shock to the stock of human capital, and θ_2 consists of learning ability and disutility for college. θ_1 evolves based on optimal choices, while θ_2 is constant over the life-cycle.

Let $(\Theta, \Gamma(\Theta), \psi_j)$ be a probability space where $\Theta = \{0,1\} \times [0,\infty] \times (-\mathcal{X}, \infty) \times Z \times (0,\infty)$, $[0,\infty]$ is the state-space, Z is the support of shocks, $\mathcal{X}$ is the absolute value of the lower bound of natural borrowing constraint, and $\Gamma(\Theta)$ is the Borel σ-algebra on Θ. Thus, for each set Γ in $\Gamma(\Theta)$, $\psi_j(\Gamma)$ represents the fraction of age (j) individuals whose states lie in Γ as a proportion of all age (j) individuals. These agents then make up a fraction $\mu_j \psi_j(\Gamma)$ of all agents in the economy. The distribution of age j_h individuals is determined by the initial distribution over learning ability, initial human capital, and disutility for college. The distribution of age $\{j_h+1, \ldots, j_d\}$ individuals are then given recursively as follows:

$$\psi_{j+1}(\Gamma) = \int_{\Theta} P(\theta, j, \Gamma) \; d\psi_j. \tag{E.29}$$

The function $P(\theta, j, \Gamma)$ is a transition function which gives the probability that an age (j) individual transits to the set Γ next period, given that the individual's current state is θ. The transition function is determined by the optimal decisions.

The variables (K, L, C, T, SS, D) are aggregate quantities of capital, labor, consumption, taxes, social security transfers, and total subsidies/transfers for college. Finally, $T_j(\theta)$ is the total taxes paid by individuals at state θ at age (j).

Aggregate variables are calculated using individuals' choices:

$$K = \sum_{j=j_h}^{j_d} \mu_j \int_\Theta x_j(\theta) d\psi_j \tag{E.30}$$

$$L = \sum_{j=j_h}^{j_r-1} \mu_j \int_\Theta z_j(\theta) h_j(\theta) l_j(\theta) d\psi_j$$

$$C = \sum_{j=j_h}^{j_d} \mu_j \int_\Theta c_j(\theta) d\psi_j, \qquad T = \sum_{j=j_h}^{j_d} \mu_j \int_\Theta T_j(\theta) d\psi$$

$$SS = ss \sum_{j=j_r}^{j_d} \mu_j \int_\Theta d\psi_j, \qquad D = \sum_{j=j_h}^{j_w-1} \mu_j \int_\Theta \left(g_d d_j(\theta) + \bar{d}\right) \psi_j$$

Competitive equilibrium. A steady-state stationary competitive equilibrium is a collection of decisions $\{\{c_j, l_j, s_j, h_j, x_j, d_j\}_{j=j_h}^{j_d}\}$, factor prices $\{w, r\}$, government spending, taxes, social security transfers, and college subsidies/transfers $\{G, T, SS, D\}$, and distributions $(\psi_{j_h}, \ldots \psi_{j_d})$ such that

1. Agent decisions are optimal, given factor prices.

2. Distributions are consistent with individual behavior:

$$\psi_{j+1}(\Gamma) = \int_\Theta P(\theta, j, \Gamma)\ d\psi_j, \quad \forall j \in \{j_h, \ldots, j_d\}, \quad \forall \Gamma \in \Gamma(\Theta).$$

3. Competitive factor prices: $r = AF_1(K, L) - \delta$, $w = AF_2(K, L)$.

4. Government budget balances: $G + SS + D = T$.

5. Resource Feasibility: $C + (n + \delta)K + G = F(K, L)$.