DEPARTMENT
OF ECONOMICS

Essays in Macroeconomics

Oliko Vardishvili

Thesis submitted for assessment with a view to
obtaining the degree of Doctor of Economics
of the European University Institute

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European University Institute
Department of Economics

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ო. ვარდიშვილი

To my siblings ♡
Nonika, Ia, Mariam, Luka

Abstract

In the U.S., 40% of students drop out of college. While dropout decisions may constitute an efficient response to students' discovering their low academic ability, they may be inefficient if an able student drops out due to adverse financial shocks. In my job market paper, *'The Macroeconomic Cost of College Dropouts'*, I investigate whether the observed dropout rates generate inefficiency by decomposing driving forces behind dropouts. I provide empirical evidence that the probability of dropping out of college is strongly associated with both ability and finances, even after controlling for other factors. I build a quantitative general-equilibrium overlapping generations model, where individuals face incomplete information on their academic ability and uncertainty about the generosity of financial aid. The model simulations show that uncertainty regarding ability is responsible for 20% of the observed dropout rates, while uncertainty regarding financial aid explains up to 53%. Pursuing a policy that eliminates uncertainty about the college aid would increase the social welfare by as much as 2.3%, benefiting both college graduates and non-college graduates. Such a policy is largely self-financing due to endogenous improvements in skill allocation and associated growth in GDP.

In my second project, *'Education Affordability and Income Inequality'* with F. Wang, we address the broad question of what explains the observed income inequality in the U.S. Different tax progressivity schedules are often named as the main factor that drive the difference in income inequality between the continental European countries and the U.S. (see Guvenen, Kuruscu, and Ozkan (2014), Holter (2015)). In this paper, we revisit the role of tax progressivity in shaping earnings inequality, taking into account another aspect that differs across these countries: the price of attaining a bachelor's degree. In the U.S., the price is much higher than in continental European countries. The OECD (2018) reports that the direct cost for students to attain a bachelor's degree constitutes $55000 in the U.S., while in Germany it amounts to $5000. Motivated by this observation, we study the role of education affordability in shaping earnings inequality in the context of an overlapping generations model where agents, heterogeneous in terms of learning ability, initial wealth, and productivity, decide whether to attend college, subject to borrowing constraints. After calibrating the model to the U.S. economy, we perform a number of counterfactual experiments. We find that the Gini coefficient for before-tax wage income would decrease by as much as 16.2 percent if the current education policy, the fraction of higher education costs borne by the U.S. government, were replaced with its German counterpart. On the other hand, we find that labor tax progressivity plays a less significant role in explaining earnings inequality. Besides, poor households with medium and medium-high abilities would benefit the most from this education reform. Apart from distributional gains, the hypothetical policy reform would also

boost macroeconomic activities by increasing labor productivity. Finally, analyzing the transitional dynamics shows that every new generation would be better off in terms of utilitarian welfare if the current education policy was replaced with its German counterpart.

In my third project, *'Larger transfers financed with more progressive taxes? On the optimal design of taxes and transfers'*, co-authored with Axelle Ferriere, Gaston Navarro, Philipp Grübener, we focus on the interplay between the two most important tools governments have at their disposal to reduce inequality - the income tax schedule and targeted transfers. Specifically, we study the optimal joint design of targeted transfers and income taxes. Within a simple heterogeneous-household framework, we derive two analytical results. First, higher transfers reduce the degree of optimal income tax progressivity. Second, optimal transfers are positive under mild conditions on primitives. This is due to both efficiency and redistribution reasons. Large transfers increase the fiscal burden for the government. Lowering marginal tax rates at the top incentivizes labor supply, which helps the government to raise sufficient revenue. Also, having the transfer in place provides some redistribution, reducing the need for higher tax progressivity. We then quantify the optimal tax-and-transfer system in a richer incomplete-market model with a realistic wealth distribution and unemployment risk. The model features novel flexible functional forms for progressive income taxes and means-tested transfers. Relative to the current U.S. fiscal system, our preliminary calibration suggests that the optimal policy consists of more generous means-tested transfers, which phase-out at a slower rate, together with less progressive income taxes.

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Contents

Chapter 1

The Macroeconomic Cost of College Dropouts

1.1 Introduction

Forty percent of full-time college students drop out before graduating. While dropout decisions may well constitute an efficient response to students discovering that they have low academic ability, they may be inefficient if talented students drop out due to adverse financial shocks. Distinguishing between these two reasons is important to design relevant policy measures: while the former does not leave much room for interventions, the latter can be tackled by well-targeted policy instruments with potentially large welfare gains. Most of the studies that address dropouts focus on the ability channel, and are silent on financial shocks at college. In this paper, using a quantitative framework, I study the role of financial constraints, on top of the ability, in college dropout decisions. First I provide empirical evidence that financial constraints are operational in college. Then, I use the macroeconomic model to decompose and quantify the forces behind dropouts. Finally, within the general equilibrium framework, I study the long-run efficiency and welfare implications of governmental policies that aim at decreasing dropout rates.

I first analyze a sample from the National Longitudinal Survey of Youth (NLSY) of 1997 to document that students with lower family wealth are not only less likely to enroll in college, but are also more likely to drop out before graduation. The fact that family wealth heavily influences not only the enrollment margin but also the dropout margin, even when controlling for ability, highlights that the financial situation of poor students may experience substantial volatility between academic years, which they can not self-insure against their family assets.

Indeed, using representative data from the Beginning Postsecondary Students Longitudinal Study (BPS), I show that up to 40 percent of the first-time, full-time students, who qualified for the maximum Pell grants in 2003-04 and satisfied all academic eligibility criteria to continue receiving full grants, lost the same amount during the following academic year. Yet, losing grants may have a larger negative impact on poorer students, as grants constitute a significant fraction of their total finances.

Based on these empirical findings, I ask the following questions: What fraction of the observed dropout rates can be explained by the volatility embedded in the current grant system? What remaining fraction arises due to other factors commonly examined in the literature, that is learning about academic ability and labor market opportunities?

To address these questions, I incorporate endogenous education decisions in a general equilibrium life-cycle economy. The framework features newborn individuals who make an enrollment decision based on their initial wealth, a prior belief about their ability, and an idiosyncratic productivity shock. The true innate ability determines the value of college, as it directly affects the probability of academic performance in college as well as future labor-market outcomes. Once in college, students reassess the value of college, as they (1) learn about their ability through their grades, (2) come across good labor market opportunities, and (3) observe grant amounts they qualify for in the upcoming period. The key modeling choice here that complements to the literature is that grants are a function of (1) a GPA and (2) an exogenous stochastic shock – capturing an opaque process associated with the reallocation of the grants.

Allowing for these channels has a decisive role to carefully decompose the dropout reasons. The first channel, the GPA–grant relationship, allows that a low GPA affects not only an individual's beliefs about her ability but also the individual's budget in line with the data. Therefore, the dropout decision might arise due to updated beliefs, due to a tightened budget, or a combined effect of these two. The second channel, the stochastic shock, is important to capture that a large fraction of academically-eligible students loses their grants, and therefore, they might drop out due to borrowing constraints. The absence of these channels would lead the role of uncertainty regarding ability to be overestimated, while the role of financial constraints be muted and therefore would result in misleading policy implications.

After learning about ability, observing the labor productivity, and the amount of grants, students may rationally decide to leave college if starting to work full time as a college dropout outweighs the option of staying in college.

College participation decisions are then integrated within an overlapping generations production economy. Therefore, individuals' education choices shape the college wage premium through general equilibrium wage effects, as college graduates are imperfect substitutes to both college dropouts and high school educated individuals in the representative firm's production function. Given that the college wage premium is a direct source of incentives for pursuing higher education, a general equilibrium framework is essential for an accurate evaluation of the long-run impact of large-scale educational policies.

I calibrate the model to match the key moments of educational attainment in the US, including college enrollment, completion rates, and the skill premium. I validate the model using the studies of Dynarski (2004), Dynarski (2008) and Scott-Clayton (2011) who, by means of natural experiments, measure the impact of an increase in subsidies on the enrollment and dropout margins. On both margins, my model generates quantitative and qualitative effects that are similar to this literature.

Using the calibrated model, first, I investigate the effects of adverse shocks at college on different wealth-ability groups. I find that having high initial wealth or high ability prior mitigates the pivotal power of an ability signal at college that makes dropout decisions optimal. Having a high ability prior can also partially mitigate students' sensitivity to adverse shocks. However, high ability asset-poor individuals remain vulnerable to the negative shocks to grant availability, as they cannot self insure themselves and consequently need to leave college.

Next, I disentangle the roles of ability, the uncertain nature of grants and productivity shocks in explaining the observed dropout rates. To isolate the magnitude of each dropout channel, I eliminate one at a time and quantify the resulting change in college participation margins. I find that eliminating both grants stochasticity and GPA requirements decreases college dropout rates by 53%, while eliminating one at a time reduces dropout rates by 28% and 25%, respectively. On the other hand, I find that learning about ability explains only 20% of the total dropout rates. The finding that a large fraction of students drops out due to the grant system defines a clear scope for policy intervention.[1]

Lastly, I consider potential governmental policies that target college dropout rates and quantify their effects on the skill distribution, income distribution, macro aggregates, and utilitarian social welfare function in the long run. A policy that eliminates uncertainty in grants increases productivity by 1.78%. Productivity increases for two reasons: (1) there are more skilled workers in the economy, (2) the ability composition of skilled workers improves, as the poor high ability individuals who were particularly vulnerable to the grant system now can afford to remain in college and graduate. The aggregate productivity results in higher output and higher

[1]Remaining 27% is explained by labor productivity shocks.

consumption. The welfare for newborns improves as much as 2.3%. This is due to the following three factors. First, the aggregate productivity gains directly translate into higher levels of average consumption. Second, the gap in skill prices decreases as the share of skilled individuals increases, and therefore the pre-tax income inequality decreases. Third, the elimination of the grants' stochasticity reduces uncertainty, which drives a further increase in the welfare of risk-averse individuals. Finally, I show that eliminating uncertainty in the current grant system is cost-effective for the government. Its overall spending in post-secondary education as a share of GDP decreases because of a more efficient allocation of talents.

Related Literature

There are several strands of literature this paper relates to. Firstly, it is related to the large empirical literature that studies family wealth-college success probabilities including Cameron and Heckman (1998), Carneiro and Heckman (2002), Cameron and Taber (2004), Belley and Lochner (2007). This paper contributes to this literature by documenting an increasing role of family wealth in college success, in line with Belley and Lochner (2007). Belley and Lochner (2007) analyze schooling outcomes at age 21[2] and they solely concentrate on the college enrollment margin, I complement their studies by examining schooling outcomes at late ages (the mid-30s), and examining both enrollment and graduation margins. This allows me to make more comprehensive conclusions about wealth-educational attainment relationships as well as make more comprehensive comparisons between the NLSY97 and NLSY79.

A growing literature studies the problem of dropouts, amongst them Hendricks and Leukhina (2017), Lee et al. (2015), Matsuda (2020) and Arcidiacono et al. (2016)). Most of them focus on learning about ability as a major channel to account for dropouts. I contribute to this literature by explicitly taking into account academic performance–grant relationship, as well as the fact that grants might get lost beyond academic reasons. Doing so enables me to examine carefully the role of financial constraints at college. Besides, I complement these studies by employing the general equilibrium framework, which is useful for policy analysis.

In the macroeconomic literature, Benabou (2002), Bovenberg and Jacobs (2005), Krueger and Ludwig (2013, 2016), Findeisen and Sachs (2015, 2016a,b), Abbott et al. (2013), Heathcote et al. (2017) study the importance of education policies on inequality and welfare from a macro perspective. However, they remain silent on the dropout margin. I complement this literature by carefully modelling various dropout channels, and quantify their implications on the overall macroeconomic efficiency.

[2] by the time of their research, the respondents were very young.

There are a set of papers that model dropouts as exogenous such as Caucutt and Kumar (2003), Akyol and Athreya (2005), Hanushek et al. (2004). Garriga and Keightley (2007) model endogenous dropping out decisions and quantifies the impact of increased subsidy rates on education attainment and macroaggregates. The sequence of papers Ionescu (2011) and Chatterjee and Ionescu (2012) address student loans in the presence of endogenous dropping out risk. As opposed to the last three papers, I allow for other channels than ability learning to play a role in dropping out decisions, specifically, uncertainty about grants, and the relationship between grants and academic performance (i.e. ability signals). Ozdagli and Trachter (2011) shows theoretically that, in accordance with the data, poorer students are less likely to graduate and are likely to drop out sooner than wealthier students. I rationalize their findings within the quantitative framework implemented employed in this paper.

The paper is organized as follows. In Section 1.2, I analyze representative, longitudinal samples of the youth of 1979 (NLSY79) and 1997 (NLSY97) in order to document that the financial background matters in ex-ante college completion probabilities. Then, using the Beginning Postsecondary Education data, I illustrate that there is a significant volatility embedded in the current grant system even controlling for academic eligibility, which might be unforeseen by students. In Section 1.3, I describe the model. Section 4 presents the calibration strategy. Section 5 examines the model's behavior and conducts validation exercises. Section 1.6 investigates how the dropping out decisions of distinct wealth-ability groups are shaped. Importantly, this section decomposes the relative importance of each channel in explaining observed dropout patterns in the US. Finally, Section 1.7 quantifies potential governmental policies that target at dropout rates and evaluates its impact on macroeconomic variables, welfare, and sorting.

1.2 Empirical Analysis

Recent policy recommendations argue that government policies should shift the focus on improving college preparedness of children coming from lower-income backgrounds, rather than expand federal student aid for the same income group. These policies are based on influential empirical papers examining the role of borrowing constraints in post-secondary education, such as (Cameron and Heckman (1998), Carneiro and Heckman (2002), Cameron and Taber (2004)). However, their conclusions are drawn from an analysis of a National Longitudinal Survey of Youth of 1979, when the cost of education was significantly lower, governmental Pell grants were covering seventy percent of college tuition, and ten weeks of full-time work was enough to earn annual college tuition fees. Consequently, low family income did not seem to be detrimental in college success probabilities at the time.

In this section, I show how at present students from economically disadvantaged backgrounds experience uninsured financial shocks at college, and how financial background has had an increasingly important role in predicting college success probabilities. Using the most recent NLSY97, I empirically document that family wealth positively affects the probability of college completion, even after controlling for ability and other family characteristics. For completeness, I also examine the NLSY79, confirming the previous findings that in the 80s, family wealth matters less, if at all, in college participation margins. Exploring why poorer students may drop out shows that their income source for college is grants – they constitute up to half of their total college budget. I further document that the grant system is characterized by substantial volatility. For example, 40% of academically eligible students lose maximum Pell grants, excluding dropouts. These results all pose a potential scope for policy intervention, investigated thoroughly in the quantitative part of the model.

1.2.1 The Role of Family Income on College Dropout Probabilities

To examine the family wealth–college participation relationship, I use two longitudinal datasets, the NLSY79 and the NLSY97. The NLSY79 sample consists of 12686 individuals born between 1957 and 1964, out of whom 6111 belong to a representative, cross-sectional sample, designed to represent the civilian segment of people living in the US in 1979.[3] At the time of the first interview, respondents' age ranges from 14 to 22. At the time of their last interview, in 2014, the respondents are between 49 to 58. Similarly, the NLSY97 surveys 8984 individuals, born between 1981 and 1984, out of whom 6748 are a representative, cross-sectional sample. From 1997 to 2011, the survey rounds were taking place annually and afterwards biannually. At the time of the last interview, in 2017, the respondents were 32 to 35 years old.

For this analysis, I employ the methodology implemented in Carneiro and Heckman (2002). Specifically, I divide each sample into three groups by their ability terciles,[4] and for each group, I regress a college participation margin (enrollment/dropout) on the family income quartile dummies, together with ex-ante family characteristics such as parental education, family structure, and type of household residence (urban/rural). This is formally specified in equation 1.1, where the outcome, Y, is an

[3] 5295 respondents are oversampled minorities such as Hispanic or Latino, Black, and economically disadvantaged non-Black/non-Hispanic. The remaining 1280 respondents were drawn to represent the population serving in one of the four branches of the US military. In my analysis, I solely concentrate on a cross-sectional sample.

[4] Ability is measured by AFQT test scores. See appendix A.1 for details.

indicator variable of college enrollment or dropout decisions. Afterwards, I examine the significance of the family income (wealth) dummies in explaining these college participation margins. In such specification, the sign and size of the coefficients of the family income dummies would inform the extent to which belonging to a lower income group affects college outcomes relative to the highest income group (i.e. the omitted category).

$$Y = \alpha + \sum_{k=1}^{3} \beta_k \text{Wealth}_{\{q1,q2,q3\}} + \beta_{4+} \text{ Family controls} + \epsilon. \tag{1.1}$$

For both datasets, I use representative respondents. I drop respondents with missing values of valid AFQT and family income as of the first survey date (or at the age of 17). I use parental education, place of residence, single-parent upbringing, and the number of siblings as control variables of family background. In all regressions, I control for gender and race. To conserve space, I provide a more detailed description of the control variables used across those two surveys in appendix A.2.

Tables 1.1 and 1.2 present the results of this strategy, where the estimated gaps by family wealth quartiles are measured relative to the top quartile, and adjusted for previously mentioned controls. Specifically, panel A in table 1.1 reports the gaps in college enrollment, and panel B reports the gaps in college dropout rates for the NLSY79 sample. Table 1.2 reports the same for the NLSY97, with taking into account the quality of the college. Specifically, panel A (B) presents the estimates on enrollment at (dropout of) a 4-year college, panel C (D) presents respectively enrollment at (dropout of) any college, i.e., without distinguishing between 2 and 4-year colleges.

A comparison of the two tables show that the estimated effects of family income, in fact, are significant for the younger cohort while they are generally insignificant for the older cohort. Table 1.1 shows that, for the NLSY79 sample, family income plays a small and statistically insignificant role in determining college attendance and completion. That is, none of the estimated coefficients are significant for the highest ability-lowest family income group. The estimated probability gap of dropping out of this group is 0.13 percentage points higher compared with their richest counterparts. Nevertheless, a joint F-test – in the last row of each panel – shows that the overall effects are insignicant, as I cannot reject the null hypothesis that all gaps are equal to zero. This finding is consistent with Carneiro and Heckman (2002), who shows that controlling for family background characteristics leaves family income redundant in explaining college participation margins.

In contrast to the older cohort, the role of financial background is instead more pronounced in the younger group. Panel A of Table 1.2 exhibits that the gaps in enrollment probabilities at a bachelor's degree between students from the bottom and top family wealth quartiles are quantitatively large and statistically significant almost for all ability groups. In the bottom ability – bottom family wealth group, individuals have 16 percentage points lower probability of enrollment at a 4-year college relative to bottom ability – highest wealth quartile family group. These gaps amount to 26 and 17 percentage points, respectively, for individuals with abilities in the middle and highest terciles. Not surprisingly, at the same time, it can be observed that the higher is the income group the lower the gap of college participation margins are relative to the default category.

Next, in panel B, Table 1.2, I examine dropping out probabilities of a bachelor's degree. The table shows that individuals from the middle ability tercile are affected largely by their family income: they are 40% less likely to stay enrolled in college than their rich counterparts. As for the highest ability group, their dropping out probability is still 12% more as compared to their rich counterparts. It worth noting that significant wealth effects on college dropout probabilities cannot be observed among poor and low ability students (second column of panel B, table 1.2). This can be explained by the fact that only a few students enroll at a bachelor's degree from the first ability tercile (67, 48, 34, and 38 individuals respectively from the lowest to the highest family wealth quartiles),[5] and therefore, the estimates for their dropping out probabilities (conditional on enrollment) are imprecise.

The fact that the role of family income is mitigated within the highest ability tercile group at all college participation margins (attendance, completion, two and four-year colleges) suggests that ability plays an important role in college participation margins. However, high ability is not enough to mute negative effects of low financial background in college success probabilities, as it appears in the early 80s.

The same qualitative relationship between family wealth and college outcomes takes place if we examine participation in any college (2-year and 4-year) rather than just 4-year college. This can be seen in panel C and panel D in table 1.2.

To conclude, analyzing the NLSY79 and NLSY97 databases shows that after controlling for the ability, the role of family income in the success of the post-secondary education has increased significantly over the years. Today coming from a low-level wealth background mechanically lowers the probability of college success, including both college enrollment as well as college graduation conditional on enrollment.

[5] In the bottom ability tercile, the number of individuals from the lowest to the highest family quartiles are respectively 155, 120, 69, and 61.

Table 1.1 – NLSY79 representative sample. Gaps in enrollment and completion of 4-year degrees (measured from the highest income quartile) conditional on parental education, number of siblings, urban, gender and race dummies.

	AFQT Tercile 1	AFQT Tercile 2	AFQT Tercile 3	All
		Panel A _ College Enrollment		
q1	0.0025	0.0236	0.03740	0.0842***
Std.Err.	(0.0501)	(0.0443)	(0.0310)	(0.0238)
q2	0.0141	0.0843**	0.0100	0.0976***
Std.Err.	(0.0490)	(0.0397)	(.0.0260)	(0.0218)
q3	0.0269	0.0127	0.0127	0.0424**
Std.Err.	(0.0494)	(0.0365)	(0.0221)	(0.0202)
All Gaps = 0	$F(3,1180) = 0.1034$	$F(3,1377) = 0.5258$	$F(3,1487) = 0.959$	$F(2,2876) = 16.4260$***
		Panel B _ College Dropout, Bachelor degree		
q1	0.0543	0.0810	0.1329***	0.1363***
Std.Err.	(0.0846)	(0.0575)	(0.0483)	(0.0329)
q2	0.0552	0.0026	0.0620	0.0666**
Std.Err.	(0.0836)	(0.0531)	(0.0402)	(0.0298)
q3	0.0171	0.0277	0.0409	0.0504*
Std.Err.	(0.0829)	(0.0464)	(0.0338)	(0.0261)
All Gaps = 0	$F(3,339) = 0.3148$	$F(3,768) = 0.7448$	$F(3,1269) = 6.3666$**	$F(3,2396) = 12.5304$***

Notes: Ability is measured by Armed Force Qualification Test (AFQT) scores. Within each ability tercile, I regress college enrollment (dropout) on family background and dummies of family wealth quartiles. All gaps are measured relative to the highest family wealth quartile within each ability tercile. q1(q2,q3) denotes gaps in enrollment (dropout) between quartiles 4 and 1 (2,3). Each of the first three columns in these tables represents a different AFQT tercile. The last column with the title "All" shows the gaps in college enrollment (dropout) for the whole population, without dividing it into different AFQT terciles. The last line of each panel presents a joint F-test that all gaps are equal to zero. *, **, *** denote statistical signifficance at the 10, 5, and 1 percent, respectively. The methodology is taken from Carneiro and Heckman (2002).

1.2.2 College Financing in NLSY97

To understand why family wealth remains a significant predictor of college completion probabilities in NLSY97, even contingent on enrollment, I next explore how students in this sample finance their education. In particular, I am interested in how poor students' financing options compare with those of their wealthy counterparts.

The NLSY97 survey groups the sources students use to finance their education into the following seven categories: family transfers for education purposes, family loans, financial assistance received from institutional sources such as grants or scholarships (henceforth grants), subsidized or other types of loans, work-study, employer assistance, and out-of-pocket payments. I express the students tuition expenditure across years in terms of 2000 US dollars, using the chain-weighted (implicit) price deflator for personal consumption expenditure, published by the BEA. Further details about the sources and the data cleaning procedures can be found in appendix A.1.

Figures 1.1 and 1.2 present, respectively, absolute values and relative shares of average college finances by family wealth. The amounts are broken down by main

Table 1.2 – NLSY97 gaps in enrollment across family wealth, dropout, 4-year or 2-year and 4-year colleges, conditioning on parental education, number of siblings, urban.

	AFQT Tercile 1	AFQT Tercile 2	AFQT Tercile 3	All
		Panel A – College Enrollment, Bachelor degree		
q1	-0.1604^{***}	-0.2676^{***}	-0.1728^{***}	-0.2845^{***}
Std.Err.	(0.0459)	(0.04918)	(0.0405)	(0.0267)
q2	-0.1668^{***}	-0.2239^{***}	-0.0359	-0.2162^{***}
Std.Err.	(0.0448)	(0.0437)	(0.0332)	(0.0241)
q3	-0.1518^{***}	-0.1154^{***}	-0.0469^{*}	-0.1227^{***}
Std.Err.	(0.0479)	(0.0410)	(0.0276)	(0.0227)
All Gaps = 0	$F(3,951) = 14.8261^{***}$	$F(3,1031) = 29.4676^{***}$	$F(3,1338) = 11.0536^{***}$	$F(3,3144) = 105.5945^{***}$
		Panel B – College Dropouts, Bachelor degree		
q1	0.1178	0.4016^{***}	0.1251^{**}	0.2550^{***}
Std.Err.	(0.1182)	(0.0716)	(0.0543)	(0.0396)
q2	0.1569	0.2630^{***}	0.0850^{**}	0.1662^{***}
Std.Err.	(0.1138)	(0.0618)	(0.0410)	(0.0333)
q3	-0.0691	0.1876^{***}	0.0382	0.0912^{***}
Std.Err.	(0.1192)	(0.0530)	(0.0333)	(0.0282)
All Gaps = 0	$F(3,175) = 0.4683$	$F(3,521)^{***} = 32.4386$	$F(3,916)^{***} = 6.6494^{***}$	$F(3,1636) = 42.0546^{***}$
		Panel C – College Enrollment, 2 year & 4 year		
q1	-0.1819^{***}	-0.1973^{***}	-0.0711^{**}	-0.2213^{***}
Std.Err	(0.0572)	(0.0429)	(0.0287)	(0.0250)
q2	-0.1370^{**}	-0.1417^{***}	-0.0202	-0.1471^{***}
Std.Err.	(0.0558)	(0.0381)	(0.0235)	(0.0225)
q3	-0.1661^{***}	-0.0974^{***}	-0.0162	-0.0909^{***}
Std.Err.	(0.0596)	(0.0358)	(0.0194)	(0.0212)
All Gaps = 0	$F(3,951) = 9.796^{***}$	$F(3,1031) = 20.0448^{***}$	$F(3,1138) = 3.9061^{***}$	$F(3,3114) = 65.7215^{***}$
		Panel D – College Dropout, 2 year & 4 year		
q1	0.1900^{**}	0.3243^{***}	0.1249^{**}	0.2410^{***}
Std.Err.	(0.0820)	(0.0580)	(0.0488)	(0.0331)
q2	0.2129^{***}	0.2409^{***}	0.0698^{*}	0.1851^{***}
Std.Err.	(0.0780)	(0.0504)	(0.0388)	(0.0288)
q3	0.0756	0.1527^{***}	0.0260	0.0890^{***}
Std.Err.	(0.0844)	(0.0463)	(0.0317)	(0.0257)
All Gaps = 0	$F(3,393) = 5.0246^{**}$	$F(3,774) = 32.1769^{***}$	$F(3,1045) = 5.9862^{**}$	$F(3,2236) = 105.5945^{***}$

Notes: Ability is measured by Armed Force Qualification Test (AFQT) scores. Within each ability tercile, I regress college enrollment (dropout) on family background and dummies of family wealth quartile. All gaps are measured relative to the highest family wealth quartile within each ability tercile. q1(q2,q3) denotes gaps in enrollment (dropout) between quartiles 4 and 1 (2,3). Each of the first three columns in these tables represents a different AFQT tercile. The last column with the title "All" shows the gaps in college enrollment (dropout) for the whole population, without dividing it into different AFQT terciles. The last line of each panel presents a joint F-test that all gaps are equal to zero. *, **, *** denote statistical significance at the 10, 5, and 1 percent, respectively. The methodology is taken from Carneiro and Heckman (2002).

sources: out of pocket payments, loans, grants and family aid.[6] In Figure 1.1, I can make four observations. First, out-of-pocket payments are an insignificant share of the total finances students have for college. Second, loans are increasing in family wealth (except the very last quintile). Third, grants are not clearly differentiated by family wealth. The gap in the amount of grants between the bottom and the top

[6]For ease of illustration, I drop the other sources since they constitute only minor fractions of total finances.

family wealth quintiles is only \$770. This is driven by generous merit-based scholarships at college, which are usually unconditional on family wealth. Fourth, parental transfers are sharply increasing in family wealth: the top family wealth quintile has 10 times more family transfers annually than the bottom quintile (\$7,572 and \$734, respectively).

Putting all sources together (see Table 1.3, row 6), financial inequality across different socioeconomic status students are at present, with the top wealth quintile youths having approximately 2 times more financial support relative to the bottom wealth counterparts (\$13,709 vs. \$8,163). However, the difference is more pronounced in a qualitative sense rather than a quantitative one. While some funding sources are guaranteed across academic years (e.g., parental transfers), others (e.g., Pell grants, subsidized and non-subsidized loans, and work-study awards, provided by the Federal Student Aid) are more uncertain. Students need to apply for them and renew their application for every academic year, which requires meeting the eligibility criteria throughout college, as well as undergoing the burdensome application process every year. As I will show later, this complicated procedure yields half of the academically eligible students to lose their grants halfway through college. This is discussed in detail in Section 1.2.3, while the Pell grants eligibility criteria are listed in appendix B.

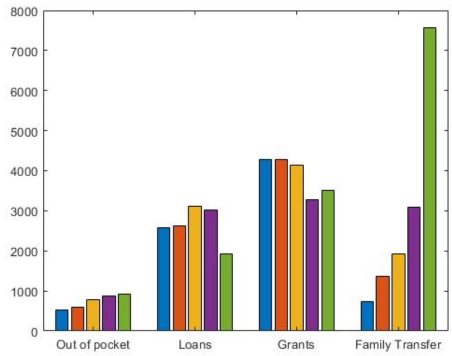
To get a better idea of which sources poor students rely the most on, Figure 1.2 visualizes the relative share of each source for each family wealth quintile. For poor students, the share of family contributions amounts to only 9%, while their major finances are grants (52%) and loans (31%). That implies that 91% of college finances for poor youths come from the 'external sources,' which I define as those involving – each college-going year – certain steps either to be qualified for, maintained, or earned. As for students from wealthier families, their main source of college finances are parental transfers (54%), followed by grants (25%) and loans (13%).

Table 1.3 – Summary Statistics of Selected Variables across Wealth Quintiles – NLSY97

	Bottom	Second	Third	Fourth	Fifth
Wealth (dollar)	-3718.5	19763	60234	136690	382240
	(43857)	(8470.4)	(14867)	(30262)	(143470)
Family Aid (dollar)	734	1364	1919	3099	7572
	(2070)	(1364)	(4134)	(4685)	(10652)
	(59.74 %)	(50.00%)	(36.40%)	(24.50%)	(14.43%)
Family Loans (dollar)	149	255	282	496	699
	(1335)	(1640)	(1521)	(2161)	(2960)
	(88.87%)	(84.47%)	(81.44%)	(77.04 %)	(76.38%)
Grants (dollar)	4285	4274	4147	3287	3515
	(6511)	(7001)	(6359)	(6286)	(6686)
	(28.70%)	(26.98 %)	(27.34%)	(34.79 %)	(38.33%)
Governmental Loans (dollar)	2578	2626	3111	3020	1928
	(4838)	(3891)	(4925)	(6589)	(4193)
	(0.45%)	(0.48%)	(0.58%)	(0.63%)	(0.80%)
Tot. Finances	8163	9238	10377	10702	13709
	(10514)	(11621)	(11270)	(12519)	(14634)
Hours (weekly)	20	17	17	14	13
	(15)	(17)	(13)	(11)	(11)
	(13.78%)	(11.54%)	(10.63%)	(14.13%)	(15.00%)
Ability (percentile)	40	47	55	63	69
	(26)	(26)	(26)	(24)	(24)
Piat (percentile)	34	39	45	51	58
	(25)	(26)	(27)	(26)	(27)
GPA (raw)	2.56	2.66	2.86	2.95	3.02
	(1.27)	(1.13)	(1.00)	(0.97)	(0.91)
Dist.	683	734	706	710	707

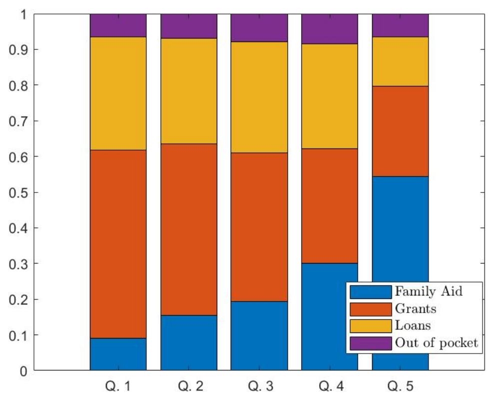
Notes: College finances, ability, GPA across family wealth quintiles. The second line shows the standard deviation of its mean, the third line shows the amount of students who get zeros.

Figure 1.1 – College Finances by Family Wealth and by Sources – NLSY97



Notes: Bars ordered according to students' family wealth, and divided by source used to finance college (out of pocket payments, loans, grants, and family transfers). Each bar represents annualized average amounts of dollars (in 2000 US dollars) from a given source. For the poorest (richest) quintiles, family transfers account for \$734 (\$7,572) of the total finances they have for college. Grants constitute to \$4,285 (\$3,515) of the total finances for the poorest (richest) quintile students. The average values are calculated for extensive margins of finance.

Figure 1.2 – Sources of Finances by Family Wealth – NLSY97



Notes: I divide students according to their family wealth quintiles. For each group, I calculate annualized average amounts they get from different sources to finance college, including family transfers, grants, loans, and out of pocket payments. For the poorest (richest) quintiles, family transfers account for 8% (50%) of the total finances they have for college. Grants constitute 52% (25%) of the total finances for the poorest (richest) quintile students.

1.2.3 Grants Uncertainty

The previous sections have shown that (1) poor students are more likely to drop out, even controlling for their ex-ante family characteristics and ability, and (2) that grants constitute a larger fraction in their college income. I now turn to examine how likely it is for college entrants to maintain the amount of grants they are qualified for the first year of a college degree. Yet, if maintaining subsidies is a challenge for students, we should expect this particularly to harm poor students' college persistence decisions, as they rely largely on the grants.

To do so, I examine the Beginning Postsecondary Student (BPS) data from the National Center of Education Statistics, which specifically surveys first-time students enrolled in postsecondary education institutions. The BPS follows respondents for a total of six years, interviewing students at the end of their first, third, and sixth year of college. Importantly, this survey is integrated with individual-level data from official records, including college entrance exam scores (from the ACT and College Board), financial aid information (from the FAFSA), and aid disbursement information (from the National Student Loan Data System). Finally, the BPS also provides detailed information on enrollment patterns and degree attainements.

Using this data, I am able to evaluate the actual fraction of students that not only qualify for and obtain a grant during their first academic year, but also maintain it throughout their studies. Working with non-restricted BPS data, I am able to track only need-based subsidies, such as Pell grants which are part of the federal financial aid system. However, I also discuss the patterns of merit-based grants following this section.

I examine the 2003-2004 cohort, restricting the sample to first-time, full-time students under age 22 and who enrolled directly into a 4-year degree college. Specifically, I investigate what fraction of students maintains the grants across years – both unconditionally and controlling for eligibility requirements, such as academic progress and labour income.[7] In this respect, it is important to specify that students meet the satisfactory academic progress when (1) they have a GPA higher than 2.00, and (2) accumulate a full-time number of credits (equal or more than 24 credit hours within the corresponding academic year). On top of that, I observe how much an individual earns in each academic year, which further affects grant eligibility.

Panel (a) in Table 1.4 describes the share of students maintaining the grants for their second academic year, i.e. in 2004-2005. The fraction refers to the recipients of the maximum Pell grants, computed according to the initial number of recipients during the first year. In the first column, unconditional shares are presented.

[7] Detailed requirements for getting and maintaining the Pell grants are outlined in appendix B.

The second column shows the share of academically-eligible students who maintained the maximum Pell grants. Finally, the third column shows the fraction of students maintaining the grants by restricting the sample only to those who were academically-eligible and also meet earnings requirements. According to column (1), approximately 57% of students maintained the maximum Pell grants from the first to second academic year, while around 16% lost it. This share increases to 65% if I control for academic progress requirements, and to 67% if I further control also for earnings. This suggests that academic progress requirements seems to be binding for a non-negligible share of students, while earnings do not play an essential role in explaining the loss of the Pell grants.

Panel (b) repeats the analysis by looking at the status of the grant in the third-year. Only 44% managed to successfully maintain the grants after two years, while 25% lost it completely. As seen 2004-2005 academic year, also in this case, controlling for academic progress plays a crucial role in maintaining the grant. Among those meeting the academic requirements only, 65% maintained the grants, while 9% lost them. Among those who meet these requirements only, 65% percent maintained the grants versus 9% who lost them completely. Finally, column (4) of panel (b) shows that the shares are robust to controlling for students' earnings as part of the Pell grants eligibility criteria.

Examining the representative BPS data indicates that both maintaining and losing the grants is not a straightforward process for students. We saw that controlling for academic progress requirements and financial background requirements only partially explain why access to grants decline over the years. It can also be that Expected Family Contributions (EFC) change between academic years, causing some to lose their grants. However, this does not seem to explain all remaining residuals, as the literature shows that parental wealth and income are quite stable across years. Hence, I argue that the reason why residual students lose their grants lies in the burdensome process associated with the reapplication.

To start the re-application process, each academic year, students are required to fill in the Free Application for Federal Student Aid (FAFSA), which is a thorough survey – with 121 different questions – on the financial status of both the student and her family. By means of the application, the grant authorities calculate the EFC, which exact amount is usually very hard to predict. Importantly, the thresholds of (1) parental income, (2) personal (past) earnings, and (3) bank account deposits at which the Pell grants start to diminish are not enclosed for the applicants. After the application is submitted, it takes up to 1-to-2 months for review and acceptance during which students need to promptly respond to emails so as not to impede the speed of the application process. Finally, 30 percent of initial applicants are selected to go through the verification step, in which they are required to provide additional financial documents. If they manage to complete this step successfully, they may qualify for the grants. This extensive bureaucracy associated with the continuation of Pell-grants might be the reason why many academically advanced students lose them already after 1 or 2 years, as noted in Table 1.4.

Merit-based grants are also not guaranteed between academic years. Indeed, a couple of micro-empirical papers show that they dwindle over the years even more rapidly than the Pell grants, and approximately half of students lose them eventually. For example, Carruthers and Özek (2016), by exploiting the Tennessee Education Lottery Scholarship, show that out of 40,000 students with the HOPE scholarships, 42% eventually lost them. They also find that losing financial aid weakens students' engagement in their post-secondary education, particularly at the extensive margin. Looking at graduates from a high school in Georgia in 1995, Henry et al. (2004) also document that 66% of all HOPE receipients lost their scolarship due to GPA checkpoints, and that losing the scolarship eliminated positive effects of the grants on graduation from four-year institutions, suggesting that losing merit-based scholarships might compromise the initial gains of subsidies on college participation margins. Using administrative data, Scott-Clayton (2011) exploits the effects of the PROMISE scholarship in West Virginia on college completion margins. The scholarship is a high-value award, worth an average of approximately \$10,000 over four years for those who initially qualify. She shows that approximately 25% of students lose the scholarship for a second year, and only 50% retain the scholarship for four years.

The evidence provided in this section, i.e., that a large share of students loses their grants either due to a GPA requirement or to an opaque reallocation process is extremely informative for my model. In light of this evidence, grants are assumed to vary over the college years. First, I allow grants to be a function of academic performance. Second, importantly, I allow the system of grants allocation to be subject to a stochastic shock. The latter is the way to account for the unexplainable fraction of students losing grants.

Accounting for the volatile nature of the current grant system in a model that aims at explaining observed dropout rates is, thus, extremely important. Neglecting it, in fact, would exclude the possibility of some students dropping out because of changes in their financial situation (such as losing a grant). Hence, without grants volatility, one might overestimate the role of beliefs in college continuation decisions. To see the intuition, let us consider a college choice model with constant grants and beliefs. In this setting, a low GPA interacts only with beliefs, and those with adequately low ability prior would drop out. While, in the real world, a low GPA also increases the risk of disqualification from grants, and consequently increases the incentive to drop out. Ignoring the relationship between those two would, therefore, lead to an upward bias of the importance.[8]

Table 1.4 – Percentage of 2003-2004 Students Who Received Full Pell Grants Again In Their Second and Third Year by Proportion of Pell Grants

Grants transition from 2003-2004 into 2004-2005			
	Unconditional	Controlling for academic progress	Controlling for academic progress and earnings
No Pell	16.02	9.37	8.67
Partial Pell	27.31	26.89	25.87
Full Pell	56.67	64.80	65.45
Grants transition from 2003-2004 into 2005-2006			
	Unconditional	Controlling for academic progress	Controlling for academic progress and earnings
No Pell	25.81	8.76	8.43
Partial Pell	30.49	29.69	30.39
Full Pell	43.70	61.55	61.17

Notes: Selected sample: Degree program in 2003-04 is Bachelor; students younger than 22; Recieved Pell Grants (More than $4,000); Controlling for academic requirements to maintain the grants: (1) Grade point more than 2.00; (2) Total credit hours more than 24. Meeting financial requirements: (1) Job 2004 - Earnings (include work study) less than $6,400.
Source: US Department of Education, National Center for Education Statistics, 2003-04 Beginning Postsecondary Students Longitudinal Study, Second Follow-up (BPS:04/09).

1.3 The Model Economy

I consider an overlapping generations general equilibrium model. The model economy consists of individuals that are heterogeneous with respect to age, wealth, learning ability, education, and labor productivity, firms that produce a final good by hiring labor and capital on competitive spot markets, and a government that operates a tax system and a pension system. The key innovation of the model is the two-period college stage. Individuals make two education-related decisions: first, whether to enroll in the college and second, whether to continue or to drop out of college. An individual's enrollment decision is based on her prior beliefs about ability and initial wealth. Once in college, a student can drop out, basing her decision on an ability signal (captured by college GPA scores), her labor market productivity, and novel to the literature, the grants available to her. Particularly, I model the second-period grant as a function of academic performance measured by the GPA as well as stochastic shocks. This is in contrast to the existing macro literature that

[8] Note that, as I do not have a longitudinal study of all types of financial aid, the standard deviation of the stochastic shock will be pinned down internally.

usually models grants as a constant share of the tuition costs over time. As demonstrated in the empirical analysis, grants vary from year to year and have a tendency to decrease over time, thus potentially affecting individuals' willingness to continue college. Furthermore, I model the working and retirement stages to account for the long-term gains of college attendance in life-time earnings and risk. These stages are key in assessing welfare consequences in the long-run and the transitional paths of the general equilibrium.

1.3.1 Demographics

Time is discrete, indexed by t, and it goes forever. At any point in time, the economy is populated by J overlapping generations indexed by $j = 1, 2, \cdots, J$, where J denotes the maximum age. Individuals survive from age j to $j+1$ with probability ϕ_{j+1}. For simplicity, I assume that the survival rate before retirement is equal to one; agents face a death hazard once they retire, i.e., $\phi_j \in [0, 1)$ for $j \geq j_r$, where j_r denotes the retirement age. Let N_t denote the initial size of the cohort that enters the economy in period t; N_t grows at a constant rate n, i.e., $N_t = (1+n)N_{t-1}$. Since the population growth rate is constant, and the age-specific survival rates are time-invariant, the relative share of each age cohort in the population is constant over time. To ease aggregation later on, I define m_j as the population size of the age cohort j relative to the youngest cohort alive in the current period:

$$m_j := \frac{N_{t-j+1}\left(\prod_{i=0}^{j-1} \phi_i\right)}{N_t}.$$

1.3.2 Timeline

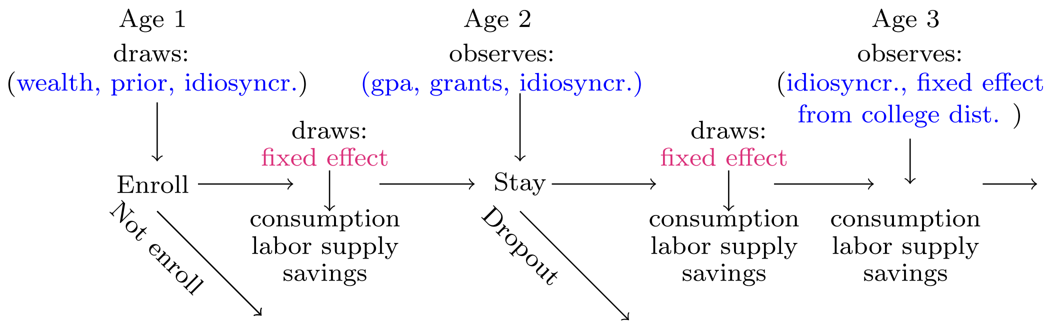
Before I describe the main elements of the model, I briefly review an individual's timeline over the life-cycle, with particular emphasis on the two-period college stage drawn in Figure 1.3.

Individuals enter the economy as high school graduates at age 1. They draw a prior on academic ability and an education-contingent initial wealth endowment,[9] based on which each individual decides whether to enroll into college or not. After enrollment decisions, they observe their productivity in the labor market and correspondingly make consumption-leisure-savings decisions. I allow working in college as 49% of US students do, as shown by the National Center of Education Statistics.

College lasts two periods. At the beginning of age 2, halfway through college, in-

[9]Initial wealth is an exogenous way of modeling parental transfers. Since my focus is on initial transfers for educational purposes, those who do not go to college receive zero initial wealth.

Figure 1.3 – Timeline of Schooling Decisions



dividuals reflect on their academic abilities, grant amounts, and labor productivity. In light of the incoming information, students update their beliefs on their ability and reassess the value of college. Based on their assessments, they either continue with a college education or drop out. After the college continuation decisions, individuals observe the remaining uncertainty on the labor market and make consumption-leisure-saving decisions accordingly. Those who remain in college are able to graduate. As of period 3, all individuals have finalized their education and earn their education-specific (high school graduate, dropout, or college graduate) wages.

Finally, after working for 24 periods, the individuals retire (i.e. at the age of 66 in the real world) and live on capital income and pension benefits. Individuals may live for 98 years. However, they face mortality risk after retirement, as discussed further below.

The rest of this section is organized as follows. First, I describe the belief system embedded in the model. Second, I describe the resource cost of college. Then, I will illustrate the household's life-cycle decisions in detail.

1.3.3 Beliefs about ability

An individual enters the economy with a normally distributed prior about her true (yet unobserved) ability e_i. The mean of the prior is given by $\mu_{e0,i} = e_i + \alpha_e + \epsilon_{e0,i}$. The parameter α_e is a general optimistic bias that one has about true ability, common to all individuals. Optimism is often named as a major determinant in college dropout decisions. Therefore, incorporating this element, allows the model to generate conservative dropout rates with respect to other dropping out channels that are novel to the literature.[10] Importantly, the noise $\epsilon_{e0,i}$ is distributed normally, $\mathbb{N}(0, \sigma_{e0}^2)$. This implies that an individual prior is given by with mean $\mu_{e0,i}$ and standard deviation σ_{e0}.

[10] Not allowing the optimism parameter would underestimate the role of beliefs in the dropping out decisions.

At the end of the first period of college, individuals get their GPAs. A GPA depends on heterogeneity, luck, and effort toward college. The first is captured by true ability, e_i, the second by the noise associated with grades, ψ_i, and the third is captured by one minus the time spent working in the labor market in period 1, $1 - l_{1,i}$. The assumption that working while in college may be detrimental to academic performance aligns with the large literature that isolates the causal impact of working hours on education attainment, including Scott-Clayton and Minaya (2016), Stinebrickner and Stinebrickner (2003), Wenz and Yu (2010), Darolia (2014), Bozick (2007). The GPA of an individual i is thus given by:

$$GPA_i = e_i + \lambda_l \max(l_{-1,i} - \underline{l}, 0) + \psi_i, \tag{1.2}$$

where $\underline{l}$ denotes the threshold amount of working hours that does not harm one's GPA[11] and ψ_i is the stochastic part of GPA. ψ_i is distributed normally with mean zero, and standard deviation $\sigma_{\psi,i}$. An individual who enrolls in college extracts a signal through GPA as follows:

$$\hat{S}_i = GPA_i - \lambda_l \max(l_{-1,i} - \underline{l}_i, 0). \tag{1.3}$$

Given the signal, she updates her beliefs in a Bayesian fashion given by equations (1.4) and (1.5). Since I assume that both the prior and the signal are normally distributed, the posterior distribution is also normally distributed, with mean $\mu_{e1,i}$ and variance $\sigma_{e1,i}$.

$$\mu_{e1,i} = \frac{\sigma^2_{\psi,i}\mu_{e0,i} + \sigma^2_{e0,i}\hat{S}}{\sigma^2_{e0,i} + \sigma^2_{\psi,i}} \tag{1.4}$$

$$\sigma_{e1,i} = \frac{\sigma^2_{e0,i}\sigma^2_{\psi,i}}{\sigma^2_{e0,i} + \sigma^2_{\psi,i}} \tag{1.5}$$

In the following, I suppress the subscript i wherever it does not arise confusion.

I assume that the variance of the prior, $\sigma^2_{e0,i}$, is the same across all individuals, i.e., given the latter, $\mu_{e0,i}$ is a sufficient statistic for capturing the distribution of the prior beliefs across individuals.

[11] That captures the empirical evidence that working for a few hours a week $(15-20)$ does not affect negatively on GPA accumulation (Bozick (2007)).

1.3.4 Resource Cost of College

In the first period, going to college entails a resource cost that is a fraction, ι, of the skilled labor wage rate, $w_{t,c}$. Let $z_1(a, \mu_{e0})$ denote the fraction of that cost, borne by the government in the first period in college. Grants are potentially both need-based, a, and merit-based, μ_{e0}. Note that the government observes the mean of the individual prior, as it is assumed to be shaped by high school grades. The direct cost of attending college in the first period for an individual is therefore $(1 - z_1(a, \mu_{e0}))\iota w_{t,c}$.

In the second period, students might lose their grants. This depends on their assets, and the stochastic shocks to grants, ζ, which is drawn from a normal distribution with a mean $\mu_\zeta = 1$ and a standard deviation σ_ζ. The stochastic shock is motivated by the empirical analysis in section 1.2, where I show that even controlling for a set of eligibility criteria, students still lose grants. To sum up, the second-period grant is captured by:

$$z_2\big(a, \zeta, GPA(l_{-1}, \hat{S})\big) = \begin{cases} z_1(a, \mu_{e0})\zeta & \text{if } \; GPA > \overline{GPA}, \\ 0, & \text{otherwise,} \end{cases} \tag{1.6}$$

where $\overline{GPA}$ is the GPA threshold, below which students are disqualified from grants. This means that for an individual, $z_1(\cdot) = z_2(\cdot)$ are the same if and only if (1) she receives a GPA higher than $\overline{GPA}$; and (2) gets a shock realization $\zeta = 1$.

1.3.5 Labor Productivity

Each individual is endowed with one unit of productive time per period. Labor productivity for an individual i at age j with education status s is denoted by:

$$h_{j,i} = \epsilon_j \cdot \exp\left(\theta_i + \eta_i\right), \qquad \text{where} \qquad \eta_i \in \mathcal{H}_s, \qquad \theta_i \in \Theta_s, \qquad s = \{h, d, c\}$$

The three elements are: (1) a deterministic, life-cycle productivity profile, ϵ_j, (2) a productivity fixed effect, θ_i, and (3) a stochastic component, η_i. The distribution of the stochastic component η_i is education-specific $\mathcal{H}_s$, where subscript s indexes for education level are: $s = h$ for high school graduate, $s = d$ for college dropout, and $s = c$ for college graduate. The idiosyncratic shock, η_i, is drawn every time an individual's education status changes, and follows an education-specific Markov process $\pi_s(\eta'|\eta)$ after college until retirement. Specifically, at age 1, all individuals draw from the distribution for high school graduates $\mathcal{H}_n$; at age 2, only those who have enrolled in college redraw η_i, from the distribution for college dropouts $\mathcal{H}_d$; at age 3, those who obtain a college degree redraw η_i from the distribution for high school graduates $\mathcal{H}_c$. The distribution of the fixed effect component θ_i is Θ_s, which depends on both education and one's true and yet unknown ability, e. Similar to the stochastic component η_i, everyone draws θ_i at age 1, and only those with an education status change redraw during college. Note that those who enrolled in college draw $\theta_i \in \Theta_n$ irrespective of ability. This assumption serves to eliminate learning about one's academic ability through the labor market. Once the education level is finalized (i.e. reaches college dropout or college graduate), θ_i remains fixed for the rest of the lifespan. Generally speaking, given ability e, the higher the education status, the higher is the probability of drawing higher θ_i.

1.3.6 Government

The government collects taxes on household consumption, capital income, labor income, so as to finance public expenditure G_t, and education subsidies. Consumption and capital income are taxed with flat rates, τ_c and τ_k, respectively. Following Heathcote et al. (2010b), I consider a potentially progressive labor income tax function:

$$\tau_l(y) = 1 - \lambda y^{-\lambda_m}, \tag{1.7}$$

where $\tau_l(y)$ is the tax rate at income level y, $\lambda_m > 0$ is a measure of the progressivity of the tax schedule and λ is a parameter that governs the average tax rate (for a given λ_m).

The pension system operates on a pay-as-you-go basis: it collects contributions from the current workers and distributes the revenues directly to the current pensioners. In period t, current workers contribute a fraction, τ_p, of their labor income to the pension funds, and current retirees receive a pension benefit that is proportional to their average life-time income: $pen_t(s,\theta) = \kappa_s w_{t,s} \bar{L}_t(s,\theta)$, where $\bar{L}_t(s,\theta)$ is the average labor supply, in terms of efficiency units, of working-age cohorts with the characteristics (s,θ), $\theta \in \Theta_s$. The budget constraint of the pension system is then given by:

$$\sum_{s\in\{h,d,c\}} \tau_p w_{t,s} L_{t,s} = \sum_{s\in\{c,d,n\}} \sum_{\theta\in\Theta_s} \sum_{j=j_r}^{J} pen_t(s,\theta) m_j(s,\theta), \tag{1.8}$$

where $m_j(s,\theta)$ is the relative size of age cohort j that falls into the skill category s and has a fixed productivity component θ.

Finally, the government collects the accidental bequests in the economy, and distributes them as initial wealth to the college-bound individuals. This assumption is a shortcut to allow parental transfers in the economy without explicitly modeling intergenerational transfers. The description of the government budget constraint is defined in equation (2.18), in section 1.3.9.

1.3.7 Firms and Production

Firms hire labor and capital on competitive spot markets to produce a final good. The final output is produced according to the standard Cobb-Douglas production function:

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha},$$

where A denotes total factor productivity, and α is a parameter that governs the elasticity of output with respect to capital.

I assume that workers come in two skill types: those with a college degree are referred to as skilled labor, the others (college dropouts and high school graduates) are referred to as unskilled labor. The two skills are imperfectly substitutable to each other, with the substitution parameter ϑ. Aggregate labor, therefore, can be formulated as follows:

$$L_t \coloneqq \Big(\upsilon(L_{t,h} + L_{t,d})^{\vartheta} + (1-\upsilon)L_{t,c}^{\vartheta}\Big)^{1/\vartheta}, \tag{1.9}$$

where $L_{t,s}$ denotes aggregate labor in terms of efficiency units in the different educational groups, s. The parameter υ is calibrated to match the college wage premium in the data.

Following Matsuda (2020), the assumption about only two skill types is motivated by the proportion of the firms that ask for a "High school degree", "Associate's degree," "Some college, no degree" or "Bachelor degree and higher." Torpey and Watson (2014) show only 5% of the total jobs require those education levels, implying most individuals with some college are employed in the jobs requiring only high school diplomas.[12]

Finally, with perfect competition and constant returns to scale of the production function, the size distribution of firms is indeterminate; without loss of generality, I assume the existence of a representative firm. The representative firm takes the wage rates of skilled, $w_{t,c}$, unskilled labor, $w_{t,h}$, and the interest rate, r_t, as given.

1.3.8 The Individual's Problem

Next I describe in-depth the life-cycle problem of an individual.

Decisions at age 1

[12] Another 6% percent of jobs requires postsecondary non-degree awards, which I do not consider in the model.

Before the consumption-leisure-savings decisions are made, an individual receives an education-contingent initial wealth $\{a_c, a_h\}$, observes an idiosyncratic productivity shock, η, and draws a prior belief μ_{e_0} about her innate ability. Given the state vector $(a_c, a_h, \eta, \mu_{e_0})$, she decides whether to enroll into college or not:

$$\mathbb{1}(1, a, \eta, \mu_{e_0}) = \begin{cases} 1, & W_c^1(a_c, \eta, \mu_{e_0}) > W_h^1(a_h, \eta, \mu_{e_0}), \\ 0, & \text{otherwise.} \end{cases}$$

The value functions $W_c^1(a_c, \eta, \mu_{e_0})$ and $W_h^1(a_h, \eta, \mu_{e_0})$ are the expected present values of life-time utilities, respectively, of going to college or not. It follows that the indicator function, $\mathbb{1}(1, a, \eta, \mu_{e_0})$, is equal to 1 when individuals find it optimal to attend college. The value functions are formally defined as follows:

$$W_c^1(a_c, \eta, \mu_{e_0}) = \mathbb{E}_{\theta' \in \Theta_h} V_c^1\big(a_c, \theta', \eta, \mu_{e_0}\big),$$

and

$$W_h^1(a_h, \eta, \mu_{e_0}) = \mathbb{E}_{\theta' \in \Theta_h | \mu_{e_0}} V_h^1\big(a_h, \theta', \eta\big),$$

where $V_c^1\big(a_c, \theta, \eta, \mu_{e_0}\big)$ and $V_h^1\big(a_h, \theta, \eta\big)$ are the expected present values of the life-time utilities of an individual who decides to enroll into or stay out of college, respectively. Note, a non-college value function, $V_h^1\big(a_h, \theta, \eta\big)$, does not take an ability prior as a state variable. This is because after drawing the fixed effect, beliefs become redundant. Furthermore, note that for enrolled individuals, the first period fixed effect is independent of ability. This assumption is necessary to avoid learning about the ability in the labor market.

After the enrollment decision at age 1, having drawn the fixed effect, θ, individuals solve a standard consumption-leisure-savings problem. For those who decide not to enroll, their recursive problem reduces to the standard consumption-leisure-savings problem defined in equation (1.14). Formulated recursively, the college-bound individuals' Bellman equation is as follows:

$$\begin{aligned} V_c^1(a_c, \theta, \eta, \mu_{e_0}) = \max_{a', c, l} \Bigg\{ & u(c, 1 - \xi(\mu_{e_0}) - l) + \beta \int_{\hat{S}} \int_{\zeta} \int_{\eta' \in \mathcal{H}_d} \\ & \max \Bigg(W_c^2\big(a'(a_c), \eta', z_2(a, \zeta, GPA(l, \hat{S})), \mu_{e_1}(\mu_{e_0}, \hat{S})\big), \\ & W_d^2\big(a'(a_h), \eta', \mu_{e_1}(\mu_{e_0}, \hat{S})\big) \Bigg) d\eta d\zeta d\hat{S} \Bigg\}, \end{aligned} \tag{1.10}$$

s.t.

$$(1+\tau_c)c + a' + (1 - z_1(a, \mu_{e_0}))\iota w_{t,c} = (1 + (1-\tau_k)r_t)a_c + (1-\tau_p)y - y\tau_l(y) + Tr,$$

$$a' \geq -\underline{\mathrm{A}}_1,$$

$$\mu_{e_1} = \frac{\sigma_\psi^2 \mu_{e_0} + \sigma_{e_0}^2 \hat{S}}{\sigma_{e_0,i}^2 + \sigma_\psi^2},$$

$$\sigma_{e_1} = \frac{\sigma_{e_0}^2 \sigma_\psi^2}{\sigma_{e_0}^2 + \sigma_\psi^2}.$$

The expectations are taken with respect to the distribution of the ability signals, $\hat{S}$, shocks to college subsidies, ζ, and the future idiosyncratic labor market shocks, η'. The continuation value for college-bound individuals is the maximum expected utility between two scenarios: (a) stay in college, $W_c^2\big(a'(a_c), \eta', z_2(\zeta, GPA(l, \hat{S})), \mu_{e_1}(\mu_{e_0}, \hat{S})\big)$, or (b) dropping out, $W_d^2\big(a'(a_h), \eta', \mu_{e_1}(\mu_{e_0}, \hat{S})\big)$.[13] Note that the a' depends on the parental transfers. Students know that they will get a_c if they remain in college, and they will get a_d if they drop out, i.e., they internalize the college-contingent transfers in their optimality conditions. Note that those who remain in college receive the same amount of transfers given in the first period, a_c, i.e., I assume that students do not face uncertainty regarding parental transfers. The GPA is formed by $\big(l, \hat{S}\big)$ and grants depend on $\big(a, \zeta, GPA(l, \hat{S})\big)$, as defined in equations (1.2) and (1.6), respectively. It follows that working while in college influences the eligibility of grants indirectly through grades. Finally, note that y defined as $y_1 = w_c h_{1,c}(\theta, \eta) l(1, a_c, \theta, \eta, \mu_{e_0})$ is earnings.

Decisions at age $j = 2$

At the beginning of period 2, students observe their GPA, the stochastic part of the grants, ζ, and an idiosyncratic part of the labor productivity process, η. GPA affects posterior beliefs about one's true ability, and, at the same time, affects grant allocation. The amount of grants is also affected by the stochastic shock ζ. Finally, the idiosyncratic wage shock, η, affects the budget constraint of the individual through wages and outside option of college as η follows a markov process if an individual drops out.

With the realized state vector $(GPA(l, \hat{S}), \zeta, \eta)$, an individual compares the value of college to the value of dropping out and optimally decides whether or not to stay

[13]Note that once an individual decides to drop out, the signal, $\hat{S}$, and the subsidies shock, ζ, become redundant.

in college. Formally, the decision is summarized as follows:

$$\mathbb{1}\big(2, a, \eta, z_2, \mu_{e_1}\big) = \begin{cases} 1, & \text{if } W_c^2\big(a'(a_c), \eta', z_2, \mu_{e_1}\big) > W_d^2\big(a'(a_h), \eta', \mu_{e_1}\big), \\ 0, & \text{otherwise,} \end{cases}$$

where

$$W_c^2\big(a'(a_c), \eta', z_2, \mu_{e_1}\big) = \mathbb{E}_{\theta' \in \Theta_d | \mu_{e_1}} V_c^2\big(\theta', \eta, z_2, \mu_{e_1}\big),$$
$$W_d^2\big(a'(a_h), \eta', \mu_{e_1}\big) = \mathbb{E}_{\theta' \in \Theta_d | \mu_{e_1}} V_d^2\big(a, \theta', \eta\big),$$

where $W_c^2\big(a'(a_c), \eta', z_2, \mu_{e_1}\big)$ and $W_d^2\big(a'(a_h), \eta', \mu_{e_1}\big)$, as defined above, are the expected present values of the life-time utilities of staying in college and dropping out, respectively. The probabilities are taken with respect to the fixed labor productivity shocks, $\theta \in \Theta_d$. It leads the indicator function, $\mathbb{1}\big(2, a, \eta, z_2, \mu_{e_1}\big)$, to take the value of 1 if the individual decides to remain in college.

The consumption-leisure-savings decision problem at age 2 for college-bound individuals is formulated as follows:

$$\begin{aligned} V_c^2\big(a, \theta, \eta, z_2, \mu_{e_1}\big) = \max_{a', c, l} \Big\{ & u(c, 1 - \xi(\mu_{e_1}) - l) + \\ & \beta \int_{\eta' \in \mathcal{H}_c} \mathbb{E}_{\theta' \in \Theta_c | \mu_{e_1}} V_c(3, a', \theta', \eta') d\eta \Big\}, \end{aligned} \tag{1.11}$$

$$(1+\tau_c)c + a' + (1 - z_2(a, \zeta, GPA(l_{-1}, \hat{S})))\iota w_{t,c} = (1 + (1-\tau_k) r_t)(a + a_c) + (1-\tau_p) y - y\tau_l(y) + Tr,$$

$$z_2\big(a, \zeta, GPA(l_{-1}, \hat{S})\big) = \begin{cases} z_1(a, \mu_{e_0})\zeta & \text{if } \; GPA > \overline{GPA}, \\ 0, & \text{otherwise,} \end{cases} \tag{1.12}$$

$$a' \geq -\underline{\mathrm{A}}_2. \tag{1.13}$$

For those individuals who decide to drop out, beliefs about their ability become redundant. Their recursive problem reduces to the standard consumption-leisure-savings problem defined in equation (1.14).

<u>Decisions at age $j >= 3$</u>

College graduates draw their wage components from the college wage distribution. From age $j = 3$ onward,[14] the problem of an individual with an education level

[14]For high school graduates, who never enroll, the optimization problem reduces to equation (1.14) from age $j = 1$, and for college dropouts their problem reduces to equation (1.14) from age $j = 2$ onward.

$s = \{h, d, c\}$ is as follows:

$$V_s(j, a, \theta, \eta) = \max_{a', c, l}\{u(c, 1-l) + \beta \int_{\eta'|\eta} V_s(j+1, a', \theta, \eta')d\eta\} \tag{1.14}$$

s.t.

$$(1+\tau_c)c + a' = (1 + (1-\tau_k)r_t)a + (1-\tau_p)w_{t,s}h_{s,1}l - y\tau_l(y) + Tr,$$

$$a' \geq -\underline{\mathrm{A}}_j. \tag{1.15}$$

<u>Decisions at age $j > j_r$:</u>

After retirement, individuals' labor productivity drops to zero, and, therefore, they live on capital income and pension benefits. The associated Bellman equation is given by:

$$V(j, a, \theta, 0) = \max_{a', c}\left\{u(c, 1) + \beta\varphi_{j+1}V(j+1, a', \theta, 0)\right\} \tag{1.16}$$

s. t.

$$(1+\tau_c)c + a' = (1 + (1-\tau_k)r_t)a + pen_t(s, \theta) + Tr.$$

Individuals after retirement face mortality risk φ_{j+1} in each period. They die with probability 1 if they reach maximum age, $j = J$.

1.3.9 Competitive Equilibrium

To define a general equilibrium of the model economy, it is useful to introduce some additional notation. In particular, I define the distribution of individuals on the state space. Let $\mathcal{J} = \{1, 2, ..., J\}$, $\mathcal{E} = [0, 1]$, $s = \{h,\, d,\, c\}$, $\mathcal{A} = \mathbb{R}$, $\Theta = \mathbb{R}$ and $\mathcal{H} = \mathbb{R}$ denote the state space for age j, ability e, education level s, wealth a, fixed productivity effect θ and the stochastic productivity component η. And let Σ denote the Borel σ-algebra defined on the product space $\mathbb{X} = \mathcal{E} \times \mathcal{J} \times \mathcal{S} \times \mathcal{A} \times \mathcal{F} \times \mathcal{H}$. Then for any $X \in \mathbb{X}$, a measure $\phi(X)$ can be properly defined. For ease of notation, let $X(j, s) \in \mathbb{X}$ be the state space of an individual of age j and with education status s, defined by the recursive representation of the individual's problems above.
With this preparation, I now define the stationary recursive competitive equilibrium as follows.

Definition 1. A stationary recursive competitive equilibrium is a collection of: (i) decision rules of individuals $\left\{\mathbb{1}(1, a_s, \mu_{e_0}, \eta), \mathbb{1}\big(2, a, z, \mu_{e_1}, \eta\big), c(X(j,s)), l(X(j,s)), a'(X(j,s))\right\}$; (ii) aggregate capital and labor inputs, $\{K, L_h, L_d, L_c\}$, on the part of firms; (iii) value functions $\{V\big(X(j,s)\big)\}$; (iv) government policies $\{\tau_c, \tau_k, \tau_p, \tau_l(y), pen(s,\theta_s), \kappa_s, z_1, z_2, Tr\}$; (v) prices $\{r, w_h, w_c\}$; (vi) education system characterized by $\{\iota, \xi(\mu_{e_0}), \xi(\mu_{e_1})\}$; and (vii) a vector of measures ϕ, such that:

1 The decision rules of individuals solve their respective life-cycle problems, and $V\big(X(j,s)\big\}$ are the associated value functions.

2 Aggregate capital and labor inputs, $\{K, L_h, L_d, L_c\}$, solve the representative firm's profits maximization problem, which is fully characterized by the following first order conditions:

$$r = \alpha A k^{\alpha-1} - \delta, \tag{1.17}$$

$$w_c = (1-\alpha)k^{\alpha}\left(\frac{L}{L_c}\right)^{1-\zeta} = w\left(\frac{L}{L_c}\right)^{1-\zeta}, \tag{1.18}$$

and

$$w_h = (1-\alpha)k^{\alpha}\left(\frac{L}{L_h+L_d}\right)^{1-\zeta} = w\left(\frac{L}{L_h+L_d}\right)^{1-\zeta}, \tag{1.19}$$

where $k = \frac{K}{L}$, $w = (1-\alpha)k^{\alpha}$, and the college wage premium is therefore given by:

$$\frac{w_c}{w_h} = \left(\frac{L_h+L_d}{L_c}\right)^{1-\zeta}. \tag{1.20}$$

3 The labor market for each skill type clears:

$$L_s = \sum_{s=\{h,d,c\}} \sum_{j=1}^{j_r-1} \int_{X(j,s)} h_{s,j}(\theta,\eta) l\big(X(j,s)\big) d\phi\big(X(j,s)\big), \tag{1.21}$$

4 The capital market clears:

$$K = \sum_{s=\{h,d,c\}} \sum_{j=1}^{J} \int_{X(j,s)} a'(X(j,s)) d\phi\big(X(j,s)\big) + A_{init},$$

where A_{init} is the aggregate wealth transfer to the newly arrived generation:

$$A_{init} = \sum_{s=\{h,d,c\}} \int_{X(1,s)} af(s,a)\, d\phi(X(1,s)) + \sum_{s=\{h,d,c\}} \int_{X(2,s)} af(s,a)\, d\phi(X(2,s)), \tag{1.22}$$

where $\phi(j,s)$ is the measure of individuals at age $j = \{1,2\}$ with college decision s and $f(s,a)$ is the distribution from which initial wealth is drawn.

5 The good market clears:

$$Y = C + G + E + I, \tag{1.23}$$

where

$$C = \sum_{s=\{h,d,c\}} \sum_{j=1}^{J} \int_{X(j,s)} c\big(X(j,s)\big) d\phi\big(X(j,s)\big),$$

$$E_t = \int_{X(1,c)} \iota w_c d\phi(X(1,c)) + \int_{X(2,c)} \iota w_c d\phi(X(2,c)),$$

where G is government spending, and I is gross investment.

6 The government budget constraint, equation (2.18) holds.

$$\tau_c C + \tau_k r A + T_l + (1+r)A_b = G + A_{init} + Z + Tr, \tag{1.24}$$

where T_l denotes labor income tax revenues, as given by:

$$T_l = \sum_{s=\{h,d,c\}} \sum_{j=1}^{j_r-1} \int_{X(j,s)} \tau_l(y_s) y_s d\phi(X(j,s)), \tag{1.25}$$

with $y_s = (1-\tau_s) w_{t,s} h_{s,j}(\theta,\eta) l(j,a,\theta,\eta)$.[15]

A_b denotes accidental bequest:

$$A_b = \sum_{s\in\{h,d,c\}} \sum_{j=j_r}^{J} \int_{X(j,s)} a'(X(j,s))(1-\varphi_{j+1}) d\phi(X(j,s)). \tag{1.26}$$

Z is the aggregate education subsidies:

$$Z_t = \int_{X(1,c)} z_1(\cdot)\iota w_c d\phi(X(1,c)) + \int_{X(2,c)} z_2(\cdot)\iota w_c d\phi(X(2,c)). \tag{1.27}$$

7 The pension budget (2.2) holds.

8 Individual behaviors are consistent with aggregate behavior: measure ϕ is a fixed point of $\phi(X) = \Pi(X,\phi)$, for any $X \in \mathbb{X}$, where $\Pi(X,\cdot)$ is the transition function generated by the decision rules of individuals, the process of exogenous states, and the survival probabilities.

9 All aggregate per capita variables increase by the population growth rate, n_p.

[15] Note that I slightly abused notation in that for college-bound individuals the state space also incorporates prior, posterior of ability and a shock to the grants.

1.4 Calibration

This section discusses the model calibration. A majority of the parameters are either estimated directly from the data or calibrated internally by matching certain aggregate moments in the US data. The remaining parameters are taken from the literature.

1.4.1 Demographics

A period in the model always corresponds to two years. New generations enter the economy at the age of 18 and it takes two model periods (four years) to complete college. Individuals retire at the age of 66, and the maximum age is 96. In addition, the population grows at a constant rate of $n = 1\%$ annually, which is consistent with the long-term population growth rate in the US Likewise, survival probabilities $\{\varphi_j\}$ are computed from the actuarial life Tables for the US.

1.4.2 Preferences

I consider a fairly standard utility function:

$$u(c, 1-l) = \frac{\left[c^{\nu}(1-l)^{1-\nu}\right]^{1-\frac{1}{\gamma}}}{1-\frac{1}{\gamma}}, \tag{1.28}$$

where ν is a taste parameter for consumption and $\frac{1}{\gamma}$ is a risk aversion parameter. The two parameters ν and γ determine together (i) the average labor supply, (ii) the intertemporal elasticity of substitution of consumption, and (iii) the Frisch elasticity of labor supply. ν is chosen such that individuals on average work one-third of their lifetime endowment. Parameter γ is set to 0.25 so that the intertemporal elasticity of substitution, $\dfrac{1}{\nu(1-\gamma)}$, yields 2.

1.4.3 Technology

The aggregate production function is a Cobb-Douglas form. The capital share α is set to 0.33. Total factor productivity A is normalized to 1. The elasticity of substitution between skilled and unskilled labor is borrowed from Card (2009) and set to 3.33. The depreciation rate and discount factor is chosen jointly to target at a capital-output ratio of around 3, and a yearly interest rate of approximately 4.8%. Finally, υ is calibrated internally to match the college skill premium of about 90%, reported in Table 4. The college wage premium is defined as the ratio of the (age-composition-adjusted) average wage between those with a college degree and those with only a high school degree.

1.4.4 Labor Productivity

Recall that the labor productivity of workers with education s and of age j is given by

$$h_{s,j} = \begin{cases} \epsilon_j \cdot \exp\left(\theta_s + \eta_{s,j}\right), & \text{if } j < j_r \\ 0, & \text{otherwise.} \end{cases}$$

To estimate the processes that govern labor productivity, I first run cross-sectional regressions of log earnings on education s and age j:

$$\ln(w_j) = f\left(X_j; x\right) + \tilde{w}_j, \tag{1.29}$$

where $f\left(X_j; x\right)$, a function of age and education, captures the life-cycle productivity profile, X_j is a vector of observables including education dummies and a cubic polynomial in age, and $\tilde{w}_j$ is a residual term. Estimates for $\epsilon_{s,j}$ are then obtained by normalizing $f\left(X_j; x\right)$ such that the mean labor productivity of skilled workers at age two $-$ when college education is completed $-$ is normalized to one. The residual term $\tilde{w}_{t,s}$ captures the fixed effect and stochastic component of the labor productivity process. More precisely, I consider the following process:

$$\begin{aligned} \tilde{w}_j &= \theta + \eta_j, \\ \eta_j &= \rho\eta_{j-1} + \epsilon_{\eta,j}. \end{aligned}$$

I estimate this process using the Panel Study of Income Dynamics data under the assumption that θ and $\epsilon_{\eta,j}$ are normally distributed with zero means and variances σ^2_θ and σ^2_η, respectively.[16] Our estimation strategy is similar to Guvenen et al. (2014), Karahan and Ozkan (2013) and Krueger and Ludwig (2016). The estimates are reported in Table 2.2. Next, I approximate the AR(1) process that governs the evolution of η using a two-state Markov chain with transition matrix:

$$\pi_{\eta,s} = \begin{bmatrix} p_s & 1-p_s \\ 1-p_s & p_s \end{bmatrix}.$$

The estimated Markov process is reported in Table 2.2.[17]

The last remaining parameter of labor productivity is the fixed effect component. I assume that the skill-specific fixed effect Θ_s takes on only two values $\{\theta_l, \theta_h\}$ and that the probability of drawing high θ_h depends on one's true ability, e. More precisely,

[16] I restrict the sample to male heads of individuals, aged 18-66, over the period 1978-2015. As of 1997, variables are available biennially. To minimize the impact of changes in hours worked, I consider only full-time full-year workers.

[17] I use the Rouwenhorst method. See Kopecky and Suen (2010) for a discussion of the Rouwenhorst method.

Table 1.5 – Estimates for the labor productivity process

	AR(1)		Fixed effects
	ρ	σ^2_η	σ^2_θ
College	0.95	0.025	0.064
Dropouts	0.96	0.021	0.054
Non-college	0.94	0.017	0.047

I assume that:

$$\pi(\theta_c = \theta_c^{\text{high}}|e) = e,$$

$$\pi(\theta_d = \theta_d^{\text{high}}|e) = \omega_d e,$$

$$\pi(\theta_h = \theta_n^{\text{high}}|e) = \omega_h e.$$

where ω_h and ω_d are parameters to be calibrated. I calibrate the ratio $\frac{\omega_d}{\omega_h}$ to match the dropout wage premium, and I calibrate ω_d to match the earnings premium of marginal students see, e.g., Findeisen and Sachs (2015) and Krueger and Ludwig (2016).

1.4.5 Education Costs and Subsidies

To pin down the resource cost of college, ιw_c, I rely on the data from the Digest of Education Statistics. It reports that the average annual education cost per student for a four-year college degree was \$24,000[18] in the 2011-2012 academic year. The amount approximates well the average cost of college attendance in non-profit universities (both public and private), which is what 95% of undergraduate students attend.[19]

The average GDP per capita was \$47,400 during the same years.[20] Therefore, I calibrate the cost parameter ι in the benchmark such that, the ratio of the college resource cost, $\iota w_{t,c}$, to GDP per capita, $\hat{Y}$, is as follows:

$$\frac{\iota w_{t,c}}{\hat{Y}} = \frac{24,000}{47,400} = 0.506.$$

Grants in the first period are calibrated as a fixed fraction of the total costs irrespective of the initial (wealth) transfers, a, and priors on ability, μ_{e_0}. This is motivated by the observation that grants do not differ strongly by family wealth,

[18]In 2016 dollars. Source: https://nces.ed.gov/fastfacts/display.asp?id=76

[19]The share of the students in public, private for nonprofit, and private for profit is respectively 0.7825, 0.1672, and 0.0503. Since private universities yield only very small share of undergraduate studentsfor calibration of the college cost, I drop the high cost of attendance of this group from the analysis.

[20]`Source:https://tradingeconomics.com/united-states/gdp-per-capita.`

as the wealthier students receive approximately the same amount in grants as their more disadvantaged counterparts. As shown in the empirical analysis, in Table 1.3, the difference between the bottom and top wealth quintiles is \$770 (around 15% of the average grant). Therefore, in the benchmark calibration, I assume that the status-quo subsidy rates for the first period are the same across the wealth. As for the concern that I might overestimate the subsidies for the rich, such modeling of the grants is still not a restrictive assumption as it does not affect the qualitative results of the paper. As it will be shown, the dropout decisions of wealthy students are independent of the grants in any case.

To pin down the rate, $z_1(\cdot)$, I rely on the data from the Education at a Glance report (OECD 2014, 2015) and the US Department of Education and I use the reference year of 2011. It reports that the public cost for a person attaining tertiary education is around 50% of the total cost. Consequently, in the benchmark calibration, I set the first-period grants at the rate $z_1(\cdot) = 0.5$.

To calibrate the second period grant, $z_2(\cdot)$, in equation (1.12), I need to pin down (1) the GPA threshold, $\overline{GPA}$, below which students lose their grants, and (2) the stochastic process, ζ. $\overline{GPA}$ is chosen carefully by considering the Satisfactory Academic Progress (SAP) requirements embedded in the current Pell grants system.[21] While the Pell grants requirement is to maintain a GPA above 2, only 17.5% do not meet the requirements after two years (BPS data, 2003-2004 cohort). In the model, I set the corresponding threshold $\overline{GPA} = 0.175$ i.e. approxamitely 17.5% of students lose grants due to the requirement.

Finally, the stochastic part of the second period grants, ζ, is calibrated internally to match the remaining dropout rates not explained by the other channels: labor productivity, and beliefs about ability. The stochastic process is thus calibrated so that the grants standard deviation is equal to 1. The associated values of the process are presented in Table 1.8.

1.4.6 Borrowing Constraints

In the model, the borrowing constraints are tied to the cost of college:

$$\underline{\mathrm{A}}_j = \Phi_j \iota w_{t,c}, \qquad j = 1, 2.$$

i.e., college-bound individuals can finance up to a fraction $-\ \Phi_j$ of their college tuition and fees, ιw_c, with student loans.

[21] The SAP requirements include GPA as well as credit accumulation thresholds. As shown in appendix C, the two requirements can be captured solely by GPA for full-time students.

To calibrate the parameter, I rely on the Office of Federal Student Aid, US Department of Education, which reports the federal loan limits for each year of college attendance: a full-time student can borrow up to $\$12,000$ during the first two years, up to $\$15,000$ for each additional year (see appendix B for details).

In the model, I allow for more relaxed borrowing constraints, so that students can finance 40% of the tuition cost in period one ($\Phi_1 = \frac{\$19{,}000}{\$48{,}000}$) and 80% in period 2 ($\Phi_2 = \frac{\$19{,}000+\$19{,}000}{\$48{,}000}$). The assumption is driven by the fact that students can finance their education in ways other than federal loans.

Borrowing constraints for $j \geq 3$ are set such that borrowers repay at least a minimum amount, P, in each period, and that the loan is fully paid back in 10 years after their graduation. More precisely, for $j = 3, 4, \cdots, 7$:

$$\underline{\mathrm{A}}_j = (1 + r_t)\underline{\mathrm{A}}_{j-1} - P,$$

and $\underline{\mathrm{A}}_{j_7} = 0$.

1.4.7 Initial Wealth Endowment

In this paper, heterogeneity in initial wealth is intended to capture family wealth effects on college attendance. An appropriate calibration requires micro-level data on college expenses. Fortunately, such data exists. I use the Consumer Expenditure Survey's public-use microdata (PUMD) to calibrate the initial wealth distribution collected by the US Bureau of Labor Statistics. It contains detailed data on college expenses, such as tuition and fees.[22] After consolidating the data, I estimate the distribution of college expenses. This distribution is then used in the model for college-bound individuals to draw their initial wealth.[23] Since my focus is on initial transfers for educational purposes only, those who do not go to college receive zero initial wealth.

Concerning initial transfers, I make a simplifying assumption. I assume that parents' income, and therefore their contributions do not change across the college years. Considering that parents' income is quite persistent in the data, this assumption is not restrictive.

[22]Student loan payments are not included as educational expenses.

[23]Initial endowment is expressed in terms of per capita GDP. When implementing this in the code, I start with an initial guess for GDP per capita and update it in each iteration.

1.4.8 Learning Ability and Beliefs

Each student has some innate yet unobserved learning ability. Without loss of generality, I normalize it between 0 and 1, and I assume that it is distributed uniformly across the population. As this true ability is not known, each individual forms beliefs about their ability based on some signals.

Newborns have a prior about their true ability via their high school grades. These grades are exogenous to the model, with mean μ_{e_0} and variance σ_{e_0}. Generally, high school grades are higher than college grades, and this leads students to be overly optimistic about their ability. This has shown by Stinebrickner and Stinebrickner (2009), who use a longitudinal survey of students' beliefs at Berea College. They show students on average expect their college grades to match their school grades. The optimism parameter, α_e, is therefore defined as the difference between the mean belief about future college GPA (which equals to the mean of high school-grades before enrollment), 3.21, and the mean of realized college GPA after the first half of college, 2.97. That leads to: $\alpha_e = \frac{(3.21-2.97)}{4} = 0.06$. Here, the denominator rescales the optimism into the support of the model GPA, which is normalized between 0 and 1.

As for the standard deviation of the prior, I impose a restriction that $\sigma_{e_0} = \sigma_{\mu_{e_0}}$.[24] The latter is the approximate standard deviation of the distribution describing beliefs about grades averaged over the college enrollees at the enrollment step. The parameter is measured in Stinebrickner and Stinebrickner (2009). Following them, $\sigma_{e_0} = \sigma_{\mu_{e_0}} = \frac{0.52}{4} = 0.13$.

After parameterizing the prior distribution, the only parameter left to be pinned down in the belief system is the standard deviation of the signal noise in the second period, σ_ψ. Stinebrickner and Stinebrickner (2009) estimate weights students give to their prior relative to the observed signals after each academic year. Using their weights and equation 1.4, I can back out σ_ψ. Specifically, I choose the estimated weights for the first year, where the highest belief revision occurs. By doing so, I obtain a conservative calibration for the model with respect to alternative channels of dropping out.

Finally, Table 1.6 summarizes the calibrated parameters for the prior and posterior distributions.

[24] This assumption is necessary since there is no usable or informative survey data about the dispersion of an individual's prior.

Table 1.6 – Parameters of Prior and Posterior Distributions

parameters	Definition	Value
$\sigma^2_{e_0} = \sigma_{\mu_{e_0}}$	var. of the prior	0.52
α_e	"optimism"	0.24
$1+\sigma^2_{\mu_{e_0}}/\sigma^2_{\psi_i}$	signal-noise ratio	1.34

1.4.9 GPA function

The deterministic part of the GPA function, as represented in equation (1.2), is pinned down by the results of Stinebrickner and Stinebrickner (2008), who identify the causal impact of studying on one's GPA. They estimate that studying one hour per day increases GPA by 0.36 points on average. That implies working 8 hours a day, reduces semester GPA by 2.52 (8×0.36). In the model, a full-time worker is defined as the average hours of work in the economy, 0.35. Given this, I can back out λ_l in equation (1.2) as follows: $0.35 \times \lambda_l = -\frac{2.52}{4}$.[25] At the same time, I set $\underline{l}$ to 0.1 i.e., working 15 hours a week in real life does not harm your GPA, as shown by the literature (Bozick (2007)).

1.4.10 Utility Cost of College

I parameterize the utility cost of attending college as follows: $\xi_1(\mu_{e0,i}) = -b_1\mu_{e0,i} + b_0$ and $\xi(\hat{S}_i) = -b_1\hat{S}_i + b_0$. I calibrate the constant to match the overall enrollment rate in the data, while calibrating the slope parameter to match the enrollment rates by ability. The results are reported in Table 1.8.

1.4.11 Government Policy

I set the ratio of government spending to GDP at 17%. Consumption tax rate is estimated from the US National Income and Product Accounts data set, which gives an estimate of $\tau_c = 7.3\%$. The capital income tax rate is taken from Chari and Kehoe (2006). Consistent with the current social security configuration, pension benefits are set to be 35% of the average income within each skill group, i.e., $\kappa_s = 35\%$. Payroll tax rate τ_p is then set to balance the pension budget.

$$\frac{d\tilde{y}/\tilde{y}}{dy/y} = 1 - \lambda_m. \tag{1.30}$$

[25] The denominator converts the data GPA into the scale of the model GPA.

Table 1.7 – Externally Calibrated Parameters

Parameter	Description	Value
Demographics		
n	Population growth rate (annually)	1%
φ Survival probabilities	Actuarial Life Tables	
j_r	Retirement age (age 66)	25
J	Maximum age (94)	40
Preferences		
γ	Risk aversion parameter	0.25
ν	Parameter for leisure (hours worked)	0.374
Technology		
α	Capital share of output	0.33
A	Total factor productivity	1
δ	Depreciation rate (annually)	7.55%
ϑ	Elasticity of substitution (Card (2009))	0.69
Labor productivity		
$\epsilon_{s,j}$	Life-cycle productivity profile	Supplementary data
θ_s	Fixed productivity effect	Table 2.2
η_s	Idiosyncratic productivity shocks	Table 2.2
Edu. costs and subsidies		
z_1	Subsidy rate in period 1	section 1.4.5
z_2	Subsidy rate	section 1.4.5
Φ_1	Student loan parameter (the Office of the Federal Student Aid)	0.396
Φ_2	Student loan paramete (the Office of the Federal Student Aid)	0.791
$\overline{GPA}$	GPA threshold (NLSY97)	0.175
λ_l	GPA function (Stinebrickner and Stinebrickner (2008))	-1.27
Government policy		
g_y	Government spending to GDP ratio	17%
τ_c	Consumption tax	7.3%
τ_k	Capital income tax	28.3%
κ_s	Pension benefits	35%
m	Progressivity	0.1

I rely on OECD estimates for the measure of progressivity λ_m (see, Taxing Wages (2013), Table I.8.).[26] The flat part of the labor income tax function, λ, is then set to balance the government budget.

[26] `https://www.oecd-ilibrary.org/taxation/taxing-wages-2013_tax_wages-2013-en`

Table 1.8 – Internally Calibrated Parameters

Parameter	Description	Value	Target
β	Discount factor	0.906	K/Y
Production function			
υ	MP of skill levels	0.850	College wage premium
Labor productivity			
ω_d	Scale parameter	0.950	(see Section 4.4)
ω_h	Scale parameter	0.750	(see Section 4.4)
Edu. costs			
ι	Cost parameter ($\frac{\iota w_{t,c}}{Y}$)	0.196	College tuition as a share of GDP
Utility cost of attending college			
a	const. in $\xi(\cdot)$	0.45	Enrollment rates
b	slope par. in $\xi(\cdot)$	-0.16	Enrollment rates by ability quintiles
Grants			
σ_ζ	variance of grants stochastic term	1	Dropout rates
Government policies			
τ_p	Payroll tax	0.07	Pension-budget clearing
$1-\lambda$	flat part of the earnings tax	0.19	G budget clearing

1.5 Model Fit

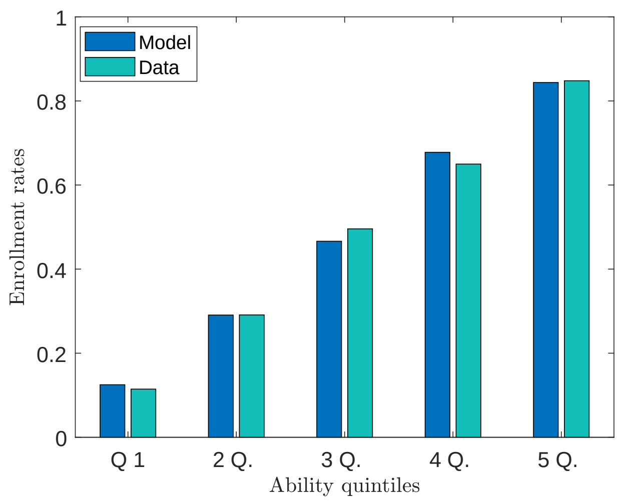
1.5.1 Targeted moments

I next discuss how the model matches the data moments. The targeted moments and their model counterparts are presented in Table 1.9 and in Figure 1.4. The model matches the overall enrollment (48.07 in the model vs. 48.01 in the data) and graduation rates (29.00 in the model vs. 30.00 in the data) well, which are found in the NLSY97. Figure 1.4 exhibits the enrollment rates by ability quintiles in the model and data. Clearly, the model successfully matches the observed enrollment patterns along the ability quintiles in the data. Furthermore, the model matches the distribution of skill prices well. The average college wage premium is 90% both in the model and in the data. The average wage premium of dropouts is around 20%, which is similar to its empirical counterpart. Additionally, the model effectively matches the capital-output ratio as well as the average percent of total time endowment devoted to the labor market.

Table 1.9 – Model vs. Data

Description	Model	Data	Source
Capital-Output Ratio	3	3	Fernandez-Villaverde and Krueger (2011)
College wage premium	90%	90%	Heathcote et al. (2010a), Lee et al. (2015)
Dropout wage premium	20%	20%	Lee et al. (2015)
Enrollment rates	48.07	48.01	NLSY97
Graduation rates	29.00	30.00	NLSY97
Average working time	0.36	0.35	PSID

Figure 1.4 – Enrollment Rates by Ability Quintiles. Model vs. Data (NLSY97).



1.5.2 Untargeted Moments

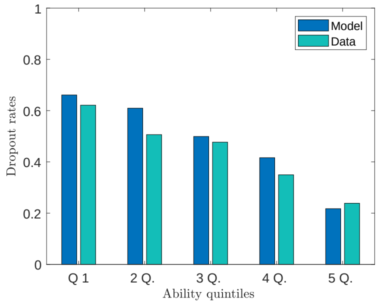
Next, I evaluate the model's performance in several dimensions. First, I examine how well the model captures the following non-targeted moments: dropout and graduation margins by ability quintiles as well as enrollment, dropout, and graduation rates by wealth quintiles. Afterwards, I use the micro-empirical literature estimates to validate the model's elasticities to a change in subsidy rates. Finally, I examine to what extent the model captures the earnings distribution of the economy.

College participation margins by ability and wealth quintiles

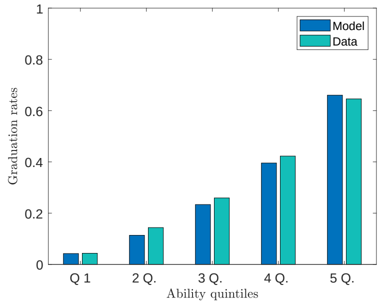
Figure 1.5 plots the dropout rates and graduation rates by ability quintiles for both the model and the data ($NLSY97$). The figure shows that the model fits both non-targeted college participation margins quite well. We observe that the dropout rates are decreasing in ability, while the graduation rates are increasing. The economic mechanism behind these observations is as follows. The riskiness of college is decreasing, and returns to college are increasing in ability. Specifically, high-ability students (1) are less likely to receive bad signals that are pivotal to a loss of grants; (2) are less likely to have such posterior beliefs that make a college degree suboptimal; (3) have lower time cost and therefore more time to work and finance college through labor earnings when experiencing adverse financial shocks; and (4) expect higher returns to a college degree than low-ability students, due to the complementarity assumption between ability and education level. These channels result in decreasing dropout rates and increasing graduation rates with respect to ability.

Figure 1.6 exhibits another set of non-targeted moments in the model: the enrollment (panel a), dropping out (panel b), and graduation rates (panel c) by initial wealth. The figure shows that the model does a good job matching these college participation patterns. It is observed that enrollment and graduation rates are increasing in initial wealth. These patterns are driven by the following factors. First, the wealthier the individuals are, the more affordable education becomes. Second, initial wealth compensates for the instantaneous loss of utility from attending college through consumption. Third, the assets help them to self-insure against adverse financial shocks at college. As a result, the wealthier the students are, the less risky college becomes, and the higher the probability of attaining the college wage premium. This results in increasing enrollment and graduation profiles and in decreasing dropout patterns with respect to wealth.

Figure 1.5 – Untargeted Moments: The Fraction of Dropouts and Graduates in Each Ability Quintile. Model vs. Data (NLSY97).

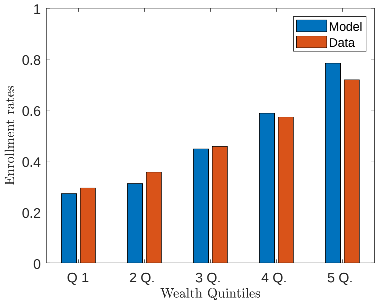


(a) Dropout rates

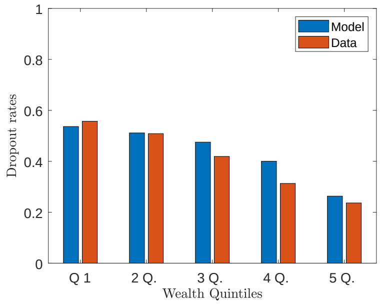


(b) Graduation rates

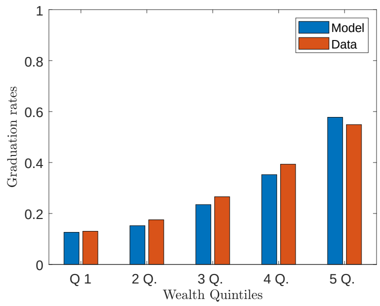
Figure 1.6 – Untargeted Moments. The Fraction of College Entrants, Dropouts and Graduates in Each Wealth Quintile. Model vs. Data (NLSY97).



(a) Enrollment Rates



(b) Dropout Rates



(c) Graduation Rates

1.5.3 Enrollment and graduation elasticities to an increase in subsidies

In this section, I examine the responsiveness of college enrollment and graduation rates in the model regarding subsidies. A few micro-empirical studies quantify the college participation elasticities to changes in the price of education using small-scale natural experiments. However, while many papers quantify effects on the enrollment margin, fewer quantify the change on the completion margin. Therefore, I discuss both margins separately.

Table 1.10 – Responsiveness to an Increase in Subsidies. Model vs. Empirical Estimates

Increase in subsidies by \$2900		
	Scott-Clayton (2011)	model PE
Δ in enrollment	–	5.51pp
Δ in graduation	7.51pp	5.42pp
Increase in subsidies by \$1000		
	Deming and Dynarski (2009)	model PE
Δ in enrollment	3 – 6pp	6.50pp
Δ in graduation	–	3.54pp

Using administrative data, Scott-Clayton (2011) quantifies the impact of the introduction of the PROMISE scholarship in West Virginia in 2002 on college completion margin by exploiting discontinuities in (1) the eligibility formula and (2) the timing of the implementation. The scholarship is worth on average \$2,900 annually. It is granted to college entrants with a high school GPA higher than 3.00, a requirement that was met by 40% of college enrollees. To maintain the reward, students needed to earn a GPA above 3.00. The requirement was met by 50% of the students at the end of the fourth year. Scott-Clayton (2011) finds that such increase in subsidies enhanced graduation rates by 7pp.

To implement the same exercise in the model, I implement a merit-based award of \$2,900, on top of the benchmark subsidies, to those students whose ability prior belongs to the top 40% of the distribution. I allow students to keep the grants in the second half of college if their realized GPA belongs to the top 50% of the grade distribution among those who got the merit-based grant in the first year. I check the model's responsiveness in the partial equilibrium framework, keeping skill prices and the tax system as in the benchmark economy. The results are summarized in Table 1.10. I find that this increases college completion by 5.52 percentage points, which is comparable to 7 percentage points found in Scott-Clayton (2011).

At the same time, the enrollment margin in the model increases by 5.51*pp*. Scott-Clayton (2011) does not examine this margin. However, I can compare the responsiveness of this margin with the large empirical literature summarized by Deming and Dynarski (2009). Their findings propose that a \$1,000 reduction in the cost of attending college leads to 3 to 6 percentage points increase in enrollment. Therefore, in the next experiment, I increase subsidies by \$1,000 and quantify the impact on college enrollment rates. I find that the model's enrollment rates as a response to this change in subsidies increases by 6.5pp, completion rates by 3.5pp. The results are summarized in Table 1.10.

Earnings Inequality: Model vs. Data

In this section, I quantify how far the model goes to generate realistic wage dispersion. This is particularly important as the general equilibrium wages are one of the main drivers of the elasticities of college participation margins in the model. I report different measures of earnings inequality, including wage ratios, Gini coefficients for wage income, log variance of hours, and wages. I then compare them to pre-tax earnings inequality observed in the data. Table 2.5 summarizes the results.

The benchmark model generates a Gini coefficient slightly lower than that observed in the data. On the other hand, the model slightly overshoots overall earnings inequality when measured by the wage ratio between the 90th percentile and 10th percentile of the wage income distribution. Overall, however, the model matches earnings inequality in the data reasonably well. I

Table 1.11 – Earnings Inequality: Model vs. Data

	Data	Model
Gini	0.40	0.32
P90/P10	5.16	4.70
P90/P50	2.36	2.05
P50/P10	2.18	2.29
$V(log(w))$	0.46	0.33
$V(log(h))$	0.09	0.08

1.6 Model Mechanism

1.6.1 Initial Wealth, Ability, and the Decision to Drop Out

In this section, I explore how family wealth and initial ability interact with the decisions to drop out of college. As discussed in section 1.3, dropping out can be driven by (1) ability signals, (2) shocks to grants, and (3) shocks to labor productivity. The policy functions of dropping out decisions are summarized in Figures 1.7a, 1.7b and 1.7c, respectively.[27] The figures are plotted for the decisions of an individual at the 10th (top), 50th (middle), and 90th (bottom) percentiles of the initial wealth distribution. The horizontal axis refers to an ability prior, while the vertical axis refers to the college dropout decisions. The red and blue lines plot the policy functions of dropping out under high and low shocks, respectively. The blue shaded area characterizes the region in the ability prior where individuals find it optimal to enroll in college in the first place. The black shaded area, on the other hand, is the region where students college dropout decisions depend on the type of the shock they receive, i.e., if they receive a favorable shock, they will remain in college, otherwise they drop out. Note that the black shaded area is conditional on the college enrollment decision. Outside of the black area, individuals decisions to stay in college or to drop out do not depend on the shocks. To the left, the individuals either never enrolled or they are determined to drop out after the first period irrespective of the type of the shock. To the right, the individuals are determined to complete college under any circumstance. Consider figure 1.7a, for instance. A median wealth individual with an ability prior of 0.6 (second panel) is in the black region. This implies she will stay in college if and only if she experiences a high shock (a high ability signal) and leave college if she gets a low shock (a bad ability signal). On the other hand, an individual with an ability prior of 0.2 within the same wealth group (middle panel, Figure 1.7a) is not inside the black region. Her education decision is shock-independent simply because she was never a student.[28]

Figure 5a illustrates how ability signals affect the dropout decisions. As discussed above, low ability signals influence the value of college in three ways. It leads to (1) lower GPA, and therefore, increases the utility cost from staying in college, (2) lower expected return on college graduation by lowering the (subjective) probability of drawing a high fixed effect after college graduation and (3) a higher probability

[27]Note, when I study each shock, I am keeping the other shocks at their highest realization level. For example, when I examine signals (panel (a)), I assume that the realizations of the grants and labor productivity shocks were at their highest levels. Doing so isolates the dropping out decisions driven solely due to the shock under study.

[28]If she were enrolled, she would also be part of the black region: she would stay in college if she received a high shock (red line), and leave college if she got a low shock (blue line).

of losing the grant.[29] The following observations can be made. First, students from poor backgrounds enroll in college only if their ability prior is high, more than 0.6 in my normalization. This is shown by the light blue shaded area on panel (a), Figure 1.7a. Second, their decisions to stay in college are not altered by bad ability signals. Their posterior remains high, and therefore, their college value also remains high.

Next, I discuss the drop out decisions of median wealth students in the presence of ability signals. The middle panel of 1.7a illustrates that they attend college with a wider ability prior, priors being higher than the bottom 35% percent. Therefore, the ability signals matter more for them than for the students from the poor backgrounds. Those students who have an ability prior between 0.5 and 0.7 will decide to drop out when they get a bad grade. Their reevaluation of college stems from, first, the high realized instantaneous utility cost from staying in college (which is a decreasing function in grades), second, the lower expected return to a college degree (due to lower beliefs about ability), and, third, the fact that they might not be eligible for grants going forward. In the next section, I quantify the fractions of students dropping out of college due to each of these factors..

Furthermore, I examine the behavior of wealthy individuals in response to low and high ability signals, presented in the bottom panel of Figure 1.7a. First, they enroll in college at ability priors above the bottom 10% (the light blue shaded area lies above prior 0.05, masked by the gray area). This indicates that the wealthy are quite comfortable using the college option regardless of the high monetary and utility costs. However, they remain sensitive to ability signals. Wealthy students who have a low ability prior and then earn low grades do not find staying in college optimal. They have a high instant-utility cost from remaining in college, lower expected returns to a college degree, and, to top it off, they can also lose grants due to GPA requirements. These factors mean that the benefits from dropping out outweigh the return to a college degree.

Next, I turn to investigate the impact of grant shocks on college continuation decisions. As shown in equation 1.6, uncertainty about grants in the current system changes from year to year due to (i) poor academic performance, and (ii) stochastic shocks. Figure 1.7b shows solely how the stochastic component of subsidies, ζ, interacts with the college retention decisions. As expected, poor students are particularly sensitive to adverse financial shocks. These students will leave college if they get a negative shock to the grants but stay in college otherwise. The gray shaded, i.e., the support of the ability prior at which students leave college if they get a low realization of the shock, extends almost until the very end of the ability support. This implies that poor students cannot afford to continue in college without

[29]Note, if GPA falls below the threshold – $\overline{GPA}$, individuals lose their grants.

the subsidies, unless they belong to the top 10% of the ability distribution. High ability mitigates the negative impact of the shock in three ways: first, they have a low utility cost from staying in college and therefore more time to work, second, they collect higher in-college earnings due to the ability-dependent labor market productivity, and, third, they get higher financial rewards after graduation through the ability-dependent college premium.

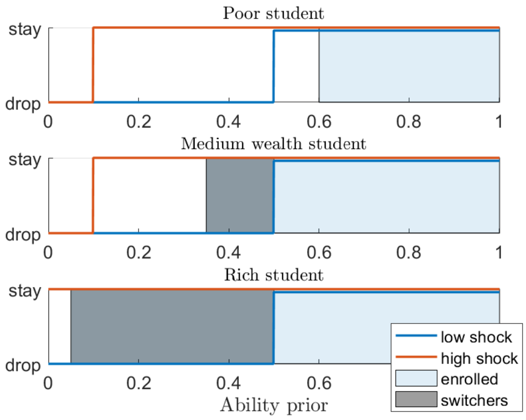
The middle panel of Figure 1.7b shows the dropout decisions of the median wealth students. One observes how pivotal it is for this group that the grants evolve across the two college periods. If they lose the grants and their prior is not high enough (higher than 0.83), they optimally leave college and engage in full-time work. Here, the gray area extends over the median ability levels. This implies that students of median wealth and high ability are able to insure themselves against the adverse shocks for the same reasons as the poor–high ability students. Therefore, high ability individuals survive in college regardless of financial shocks, while median ability individuals cannot afford to graduate without grants. Lastly, the bottom panel of Figure 1.7b shows that the wealthy students are unaffected by the adverse financial shocks as long as their ability prior lies above 0.3.

Finally, Figure 1.7c examines the impact of idiosyncratic productivity shocks, η, on the decisions to stay in college. These productivity shocks have an ambiguous effect on education decisions. They can motivate some students to stay in college by making education more affordable. At the same time, they can force others to leave college by increasing its outside value. Poor and median wealth individuals are not affected by the productivity shocks under this particular state space for which the figure is drawn. They remain in college in either case, as asset poor individuals wish to earn the college wage premium.

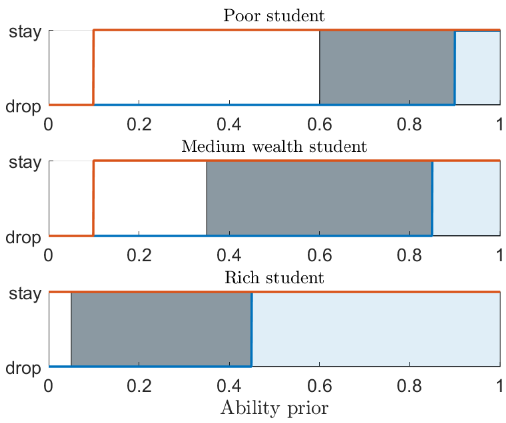
To conclude, this section highlights that having a high initial wealth level or a high ability prior mitigates the pivotal power of a low ability signal in college that encourages dropping out in general. Having a high ability prior can also partially mitigate students' sensitivity to bad financial shocks. However, after examining the dropping out policy functions, poorer students with higher ability remain sensitive to the negative financial shocks. This is a potential source of inefficiency, particularly when considering ability and education are complements in fostering labor productivity. In the next section, I explore distributional implications and quantify what fraction of students drop out due to each of those channels.

Figure 1.7 – Dropout Decisions by Ability Prior

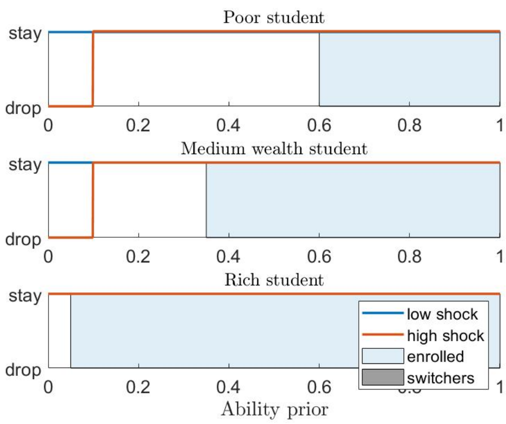
(a) Signals



(b) Shocks to grants



(c) Idiosyncratic prod. shocks



Notes: the y-axis plots the college dropout decision, and the x-axis plots the ability prior support, normalized between 0 and 1. The blue shaded area marks the ability priors in which the individuals find it optimal to enroll in college in the first period. The red (blue) line denotes the dropout decision under the high (low) realizations of the shock (ability signals in panel (a), grants in panel (b), and idiosyncratic productivity in panel (c)) at the beginning of the second college period. The gray shaded area marks the support of the ability prior in which students are sensitive to the shocks, i.e., where they drop out if they get a low shock and stay if they get a high shock. A comparison of the panels highlights that a poor student is more sensitive to the negative shocks of ability signals and grants) than a rich student.

1.6.2 Decomposing the Channels of Dropping Out

From policy point of view, it is worth analyzing what fraction of dropouts are driven by each dropout factor. If, for example, productivity and learning about ability drive a significant amount of dropout decisions, then there is little scope for policy intervention. On the other hand, if grants volatility has a strong impact on dropout decisions, then policy makers can use grants as an instrument to target dropout rates. Keeping such policy implication in mind, in this section, I explore how the benchmark dropout rates change when I eliminate one dropping out channel at a time. Throughout these experiments, I consider partial equilibrium outcomes (i.e., keeping prices and the tax system as in the benchmark economy). This is useful in isolating the effects of each particular dropping out channel from its interactions with the general equilibrium forces.[30]

The first experiment assumes that the students have complete information about their ability, leaving everything else as in the benchmark economy. Allowing students to know their true ability reduces uncertainty significantly over their grades and their post-graduation labor market outcomes. The three experiments that follow delve into the grant system. In the second and third experiments, I study what happens when grants face no stochasticity, $\zeta = 1$, and, what happens when grants are not GPA-contingent. In the fourth experiment, I study the two in combination, i.e., when the grants stay constant over the two college periods. In the fifth experiment, I isolate the impact of labor productivity shocks on dropout decisions. To achieve this, I recompute the model, eliminating all other types of uncertainties. In practice, this implies combining all the previous experiments: students have complete information on their innate ability, there are no shocks to grants during college education, and grants are unconditional on GPA. In this setting, all remaining dropout decisions are prompted by favorable idiosyncratic productivity shocks, η, or the dropout wage premium.

Table 1.12 summarizes the results. The first four rows report the college participation frequencies in the benchmark and the counterfactual experiments, and the last two rows report the average working hours and labor productivity. Labor productivity is defined as the average product of wages and the efficiency units of labor. Note here that the change in labor productivity is solely steered by the change in the efficiency units since wages are set to the benchmark value.

In the first experiment, under the complete information scenario, the enrollment rate barely changes. There is a set of low ability individuals who do not enroll into

[30] For example, if we allow for GE effects, that implies we allow skill prices to change, and the change in the skill prices would affect dropout rates. Then, it is not obvious what fraction of the dropout rates are driven by the particular channel and by the change in skill prices.

college since they are aware of their low academic ability, the high utility cost of attending college, and the low pay-off of a college degree. On the other hand, the high ability individuals want to enroll in college as they know they are academically talented. These countervailing factors result in the number of college entrants to remain virtually the same. As for the dropout margin, the reduced uncertainty leads the number of college dropouts to decrease by as much as 20.19% (about 8pp). The increased amount of skilled workers in the economy drives up aggregate productivity by 1.4%. Notably, this increase in aggregate productivity comes through the efficiency units per hour and not through the increase of hours (the average hours decrease by 0.32%).

Columns 3 and 4 in Table 1.12 depict the results from experiments 2 and 3, respectively. It is observed that eliminating the stochastic part of the grants and the GPA requirement reduces the dropout rates by 27.68% and 24.97%, respectively. While both channels affect dropout rates with almost the same magnitude, their impact on productivity differs significantly. Productivity increases significantly more in the stochastic shock experiment than the GPA requirement experiment. The difference in productivity growth is wholly driven by different patterns of ability sorting. While eliminating the stochastic part of the grants increases graduation rates of high ability individuals, relaxing the GPA requirements, as expected, drives up the graduation rates mostly for the low and mid-range ability individuals. I provide a discussion on the ability sorting in section 1.7, where policy experiments are analyzed.

In the fourth experiment, I find that keeping grants constant across the college periods has the largest effect on college dropout rates. The fifth column of Table 1.12 shows that the aggregate dropout rates fall by 53.14% (about 21.20pp) and now constitute only 18.68% of total enrollees. I observe that experiment 4 has more impact on the enrollment rates than the combination of experiments 2 and 3. This is because there are a set of individuals at risk of losing their grants either by a stochastic shcok to their grants, and/or the GPA requirement. Therefore, eliminating only one reason (like in experiments 2 and 3) puts them at risk of losing their grants because of the other. Only when one eliminates both simultaneously do the individuals find it significantly less risky to enroll. Consequently, under this experiment, about 9pp more people enroll in college than in the benchmark economy. Once enrolled, they maintain their grants, and, therefore, find it optimal to stay in college, and graduate. As a result, the graduation rates increase by 18.16pp. This has a positive impact on the overall economy. With the increase in the graduation rates, aggregate labor productivity increases by 6.73%. This result highlights the strong relationship between skilled workers and aggregate productivity in the economy. Note that this exercise defines a clear scope for policy intervention. Given the skill premium, if the uncertainty embedded in the current grant system

Table 1.12 – College Participation Rates: Experiments vs. Benchmark

	Benchmark	Exp1 Precise Ability	Exp2 No stochastic shock	Exp3 No GPA requirem.	Exp4 Constant grants	Exp5 Productivity
%Δ in dropout rates	–	-20.19	-27.68	-24.97	-53.14	-72.83
Dropout rates	39.87	31.82	28.83	29.91	18.68	10.83
Enrollment rates	48.07	48.45	49.08	48.43	57.88	55.94
Graduation rates	28.91	33.03	34.93	33.94	47.07	49.88
%Δ, Average Efficient Labor	–	1.4	2.53	1.99	6.73	5.29
%Δ, Average Hours	–	-0.32	0.02	-0.21	-0.28	-0.44

Notes: Counterfactual experiments are implemented in the partial equilibrium, i.e., keeping skill prices and tax system as in the benchmark economy.

was eliminated, 53.14% of students who drop out now would remain in college.

The last experiment, where students do not face any uncertainty in college but labor productivity shocks, reduces dropout rates by 72.83% (29.04%) and sets it to 10.83%. The students who still drop out find their outside options more attractive even in the absence of ability signal and grant volatility. Why do those students drop out? They get a favorable idiosyncratic wage shock, eta, that drives the value of the outside option of college higher than that for staying in college. Note that this experiment leads to slightly lower enrollment rates than experiment 4 (by 1.94pp), which can be explained by the elimination of optimism. Additionally, with complete information about ability, more students graduate than in experiment 4. Consequently, graduation rates increase by 2.81pp compared with experiment 4 and by 20.97pp compared with the benchmark.

Before concluding it is worth discussing why ability learning does not explain the largest share of dropouts. Looking at the data, there are considerable differences in enrollment rates by ability (see Table 1.20). Only 11% enroll from the lowest ability quintile, while from the highest quintile the same fraction is 86%. This marked difference in enrollment rates by ability implies that students have a decent prior on their ability when they consider enrollment. Furthermore, low ability students (measured by AFQT test scores) account for only a small fraction of total undergraduates in the NLSY97. Individuals from the lowest two quintiles of ability make up only 16% of enrolled students and thus cannot be solely responsible for the high dropout rates observed in the data. If the students were to face more uncertainty, then the model would be unable to capture the sharp difference in the enrollment rates by ability quintiles as observed in the data (see Figure 1.4).

To sum up, this section shows that the financial situation of college students plays a significant role in the decisions to drop out. Therefore, there is scope for an intervention if a government aims to reduce dropout rates caused by financial difficulties. I use this finding in the next section to study potential policies and evaluate their impact on skill allocation, sorting, macroeconomic equilibrium aggregates, and, finally, welfare gains.

1.7 Policy

In this section, I consider governmental policies that target dropout rates. I consider a general equilibrium framework. The general equilibrium's importance comes from the fact that any large-scale educational policy would affect the reallocation of skills and, therefore, equilibrium skill prices. Allowing the general equilibrium framework lets me quantify the corresponding dynamics of skill prices, equilibrium aggregates, and welfare[31] in the long run. The government is closing its budget by the level of the labor income tax schedule, λ, defined in equation 1.7. I consider that each policy lasts forever.

Specifically, I implement three governmental policies. First, the government eliminates the stochastic element in the grant system, leaving the GPA requirements intact. That implies, under policy 1 students lose grants only if their GPA drops below the threshold. The policy - eliminating the stochastic part of the grants - would imply in the real world to eliminate the necessity of the reapplication for each academic year. Instead, they automatically maintain the grants as long as their GPA requirements are met (the latter automatically would be checked by the universities). That would translate that if you qualify for grants in the first year, you maintain it as long as your academic progress is satisfactory (GPA and credits).

In the second policy, the government eliminates the GPA requirement, leaving the stochastic part of the grants as in the benchmark economy. That implies, students maintain the grants regardless of their grades; however, they might lose them because of the exogenous shock. As a reminder, GPA dependence helps students to leave college who were too optimistic (the initial signal was too high). However, it might lead some high ability students to lose grants because of unlucky grades and, therefore, increase college riskiness. Relaxing this would help high-ability, unlucky-individuals to face less adverse shocks at college. As a side note, we should expect that it would also motivate some low ability individuals to graduate (discussed further).

Finally, in policy 3, the government makes grants constant between academic years in both ζ, and GPA. Eliminating both sources of uncertainty together would have amplified effects on the college participation margins. There are groups of individuals who would lose grants due to either channel in the benchmark economy. Therefore, they do not benefit under either policy 1 or policy 2, but they benefit under policy 3.

I structure the rest of the section as follows. In section 1.7.1, I examine how college

[31] For example, if the college wage premium decreases in equilibrium, this would increase welfare keeping everything else constant given preference for redistribution.

enrollment and dropout margins change relative to the benchmark economy. In section 1.7.2, I investigate how sorting by ability and wealth in college are affected. In section 1.7.3, I quantify the change in the macroeconomic aggregates. Finally, in section 1.7.4, I analyze the welfare implications of these policies.

1.7.1 College Participation Rates in the Long-run

Table 1.13 shows the college participation margins in the benchmark and under the policies. The first four rows of the table show the relative differences in college participation frequencies under the policies compared with the benchmark economy. We observe that the first and second policies reduce dropout rates by 8.73% and 10.84%, respectively. The policies reduce dropout rates somewhat modest in the long-run compared with the partial equilibrium discussed in Table 1.12.[32] This divergence is due to the dynamics of skill prices under the general equilibrium: in the short-run reduced uncertainty makes college investment more attractive. That induces more students to enroll, and fewer students to drop out. As a result, the share of college graduates increases gradually, and this leads to a gradual decrease in the equilibrium skill premium (by around 6-8%, discussed in details in section 1.7.3). A lower skill premium increases the option value of dropouts. As a consequence, more students are willing to drop out even without losing grants. The significant divergence between the short-run and long-run dynamics emphasizes the importance of explicitly accounting for general equilibrium effects while studying education policies.

Table 1.13 – College Participation Rates under the Benchmark and Policies.

	Benchmark	No stochastic shock Policy 1	No GPA requirement Policy 2	Constant grants Policy 3
%Δ in dropout rates	–	-8.73	-10.84	2.4
Dropout rates	39.87	36.39	35.54	40.82
Enrollment rates	48.07	48.89	48.46	56.87
Graduation rates	28.91	31.1	31.23	33.66

As for the enrollment margin, the first two policies leave enrollment rates virtually unchanged (it increases by 0.82pp and 0.39pp in policies 1 and 2, respectively. See the third row in Table 1.13). That implies, the decrease in the dropout rates happens by improving graduation rates among the enrolled students (by around 2.19pp and 2.32pp, respectively, under policies 1 and 2). The fact that policy 1 significantly helps foster graduation rates without an increase in enrollment rates has a policy implication because it is often a subject of discussion that more universal

[32] We saw that when eliminating the stochastic shock dropout rates decrease by 27.68% in the partial equilibrium vs. by 8.73% in the general equilibrium. When eliminating GPA requirement dropout rates decrease by 24.97% in the partial equilibrium vs. by 10.84% in the general equilibrium.

grants would attract more marginal, academically unprepared individuals to enroll in college. Through the lens of this model, that does not happen.

As for policy 3, which is a combination of policies 1 and 2, we observe that the college enrollment margin increases significantly by about 8.8pp. At the same time, it increases graduation rates by 4.75pp, slightly more than the sum of policy 1 and policy 2 together (4.51pp).

The observations highlight that policy 1 and policy 2 give us different magnitudes depending on whether they are implemented separately or together (policy 3). The interactions are twofold. At the enrollment margin, they reinforce each other strongly (together has a much bigger effect than the sum (8.8pp in policy 3 vs. 1.21pp in policies 1 and 2 combined). At the graduation margin, they interact negatively, i.e., the effect is smaller than the sum (7.25pp in policy 3 vs. 7.81pp in policies 1 and 2 combined). Next, I will describe the intuition behind this divergence.

Under policy 3, at the enrollment stage, the riskiness in college decreases significantly. There is a group of students in the benchmark economy who are at risk of losing grants by both channels: (1) stochastic shocks, (2) GPA requirements. Some of them do not enroll because of this risk, and some who enroll, drop out after the adverse shocks materialize. Under policy 3, the first group has no more risk regarding the grants. This makes college more attractive, and, therefore, more students enroll. Additionally, under this policy, there is another channel that decreases the riskiness of college: even if they get some other adverse shocks at college, and they need to drop out, now their earnings as a dropout are higher relative to the benchmark economy (also relative to policy 1 and policy 2) as a college wage rate decreases by 3% than the benchmark (and by around 1% than policies 1 and 2). These channels magnify enrollment rates under policy 3. College and dropout wages are discussed further below.

As for the dropout margin, the interaction of policies 1 and 2 is mitigated due to the increase in the attractiveness of the dropout option under policy 3. Due to more graduates in the equilibrium, the college wage rate decreases and, therefore, even under the less adverse shocks in college, more students walk away to enjoy dropout wage premium.

One model limitation regarding policies 2 and 3 is that if the grant system is unconditional on GPA, students might decrease college effort, a dimension not integrated into the model. However, students still care about their GPAs as it goes to their instantaneous utility. That partially compensates the absence of the effort in the model. At the same time, note that as we see in Table 1.13, policy 1, where solely the stochastic part of the grants is eliminated, still increases the graduation rates significantly by almost half compared with policy 3.

1.7.2 Sorting into College by Ability and Wealth

I then examine how the reforms affect ability and wealth sorting at college. For that purpose, Figure 1.8 plots the percentage change in the dropout rates between policies and the benchmark. Panels (a) and (b) capture the deviations in dropout rates by ability and wealth quintiles, respectively. Policy 1 is captured with blue bars and policy 2 with red bars. Figure 1.9 captures the deviations of policy 3 against the benchmark.

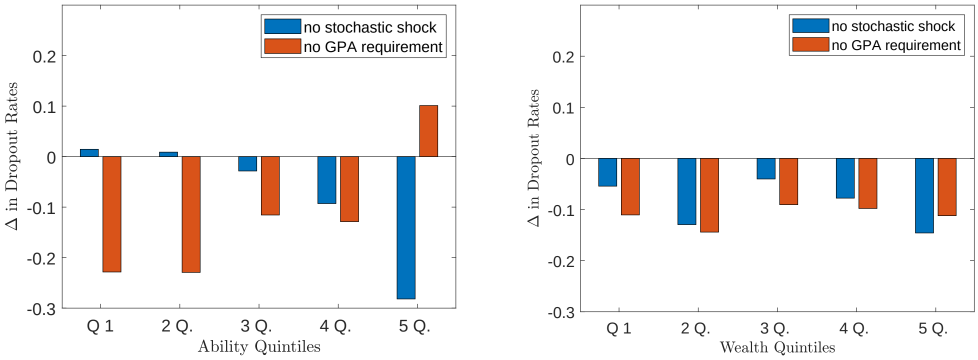
Figure 1.8 shows that policy 1 improves sorting significantly, implying that more people drop out at the lower ability quintiles and fewer people at the top ability quintiles than the benchmark economy. Specifically, panel (a) exhibits that dropout rates slightly increase in the bottom two ability quintiles compared with the benchmark. At the same time, now the highest two quintiles drop out respectively by about 10% and 30% less compared with the benchmark scenario. To summarize, with the enrollment rates remaining virtually unchanged, this policy improves not only overall graduation rates but also the ability composition of the graduates.

To better understand why the quality of graduates improves, it is useful to look at the economic mechanism behind these results. The people with high ability of poor and median wealth who were dropping out because of unlucky shocks to grants in the benchmark economy (as we saw in Figure 1.7b), now maintain the grants and can afford to remain in college. Interestingly, this policy does not affect much the dropout decisions of low ability students. The intuition is that, first, this group is at risk of other types of adverse shocks at college: low ability signals and tight GPA requirements. Therefore, the pivotal power of the stochastic shock is not high for this specific group. Second, the larger share of this ability group was wealthy students, as we discussed in section 1.6, for whom financial shocks mattered less for the first place.

Policy 2, in contrast to policy 1, worsens ability sorting. It decreases dropout rates at the bottom ability quintiles (by around 20%) and increases at the top (by about 10%). This is merely driven by the fact that students in the bottom ability levels face less risk of losing grants. Consequently, as their financial stability improves, they graduate more. Furthermore, somewhat surprisingly, fewer people graduate from the top ability quintile. That can be explained as follows: no people within this quintile lose grants due to a GPA-contingency in either scenario. However, now this group faces a higher outside option of college by a decreasing gap between college and dropout wages.

In addition to sorting with respect to ability, the model allows us to examine who wins/loses by family wealth under each reform. Panel (b) of Figure 1.8 exhibits the percent deviation in dropout rates by wealth quintiles. Blue denotes policy 1, and

Figure 1.8 – Relative Changes in Dropout Rates. Policies 1 and 2 vs. Benchmark



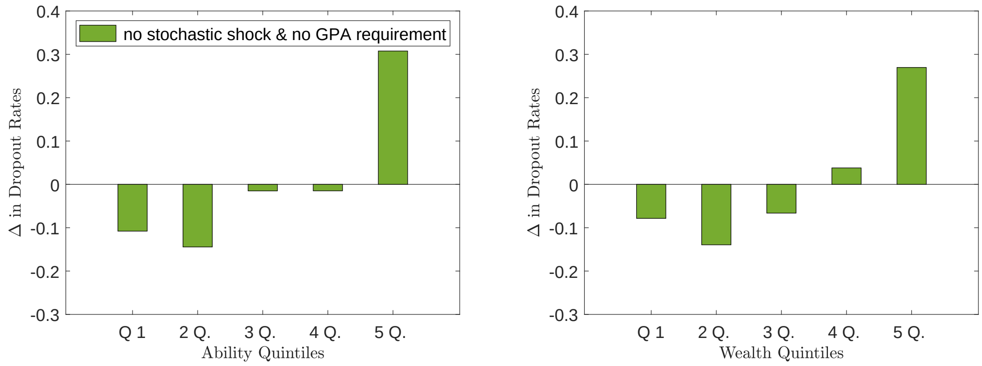
(a) Sorting by Ability **(b)** Sorting by Wealth

red denotes policy 2. We observe that all wealth group benefit under each of these policies, i.e., fewer people drop out in each wealth quintile. However, the fact that there are higher dropout rates at the bottom wealth quintiles implies the absolute change is the highest for these groups.

Finally, analyzing this figure highlights that although policies 1 and 2 have almost the same increase in graduates, policy 1 increases sorting by ability and hence improves the average quality of graduates. Solely the quality of graduates drives the fact that aggregate labor productivity is higher under policy 1 relative to policy 2. This is discussed further in section 1.7.3.

As for policy 3, summarized in Figure 1.9, it reduces dropout rates at lower ability levels and increases dropout rates at the top. At the same time, it pronouncedly decreases dropout rates from the bottom wealth quintiles (panel (b), Figure 1.9), but increases the dropout rates at the top wealth quintile. Once again, the reason lies in the fact that now college graduates get less payoff from graduating as the college wage premium decreases in this economy by around 8 percent relative to the benchmark.

Figure 1.9 – Relative Changes in Dropout Rates. Policy 3 vs. Benchmark



(a) Sorting by Ability **(b)** Sorting by Wealth

1.7.3 Macroeconomic Variables

Next, I examine the impact of each policy on the economy in terms of equilibrium aggregates. Table 1.14 reports the relative changes in the key macroeconomic variables under the experiments and the benchmark. We can make several observations. Under each policy, average labor productivity increases, while average hours worked falls or stays about the same. It is worth noting that under policy 1 productivity increases almost 1.4 times as much as under policy 2, even though graduation rates are slightly higher in the latter policy. This result is explained by the fact that policy 1 greatly improves sorting, while policy 2 weakens it. Better sorting in college improves productivity due to the complementarity assumption between ability and college earnings (through fixed effect).

Table 1.14 – Relative Changes in Macroaggregates under the Policies relative to the Benchmark Economy.

	No stochastic shock Policy 1	No GPA requirement Policy 2	Constant grants Policy 3
G edu	-4.99	13.64	13.34
G edu/GDP	-6.69	12.24	6.99
Interest rate, r	-0.14	0.04	-0.8
Wage,w	0.03	-0.01	0.19
Output, $\hat{Y}$	1.81	1.25	5.93
Capital, $\hat{K}$	0.06	-0.02	0.36
Consumption, $\hat{C}$	1.76	1.21	5.72
Productivity, $\hat{L}$	1.78	1.26	5.74
Hours, $\hat{H}$	0.08	-0.22	-0.20
Flat tax rate, τ_w	-1.27	0.62	-1.90

Hand in hand with the increase in labor productivity, we observe that aggregate output and consumption significantly increase under all policies. The relative magnitudes of these changes across the policies closely follow the relative magnitudes of the change in labor productivity. The increase in average consumption is 1.81%, 1.25%, and 5.93% under policies 1, 2, and 3, respectively. Policy 2 remains behind here as well because of poor ability sorting. Additionally, it is worth noting that the sum of the increase in output across the first two policies is less than the increase under policy 3 (which is a combination of policies 1 and 2). The effects on output is magnified under the latter policy as it particularly promotes the enrollment rates and, as a consequence, the graduation rates relative to the other policies.[33]

The relative changes in labor productivity, output and consumption have strong policy implications in that they highlight the macroeconomic importance of, first, fostering skilled labor and, second, fostering ability sorting. The first shows that the graduation rates define overall macroeconomic efficiency. The second shows that, given the same graduation rates, the equilibrium aggregates, including productivity, consumption and output are higher where there is a better ability composition of graduates.

Next, I examine what is the monetary cost for the government to implement each policy relative to the benchmark. To have some intuition, the output increased under all economies and, this directly affects the cost per student in all economies through the assumption that tuition is a fraction of average output. As a result, the government in absolute terms need to pay more (1) per student, (2) for more students, (3) for longer periods.

The first two rows of Table 1.14 show the percentage change of the absolute cost of education subsidies and education subsidies to GDP ratio, respectively. We observe that the government spending in education decreases under policy 1 (by 4.99%), and increases under policies 2 and 3 (by 13.64% and 13.34%, respectively) relative to the benchmark economy. The fact that it increases in the latter 2 policies is intuitive: (1) more students enroll, (2) they stay longer in college. As for policy 1, the education expenditure decreases relative to the benchmark as the grants do not have favorable draws any more as it is implied by the stochastic shock. Now the grants remain the same across periods. However, some people still lose it due to the GPA requirement. On the whole, under policy 1, in absolute terms, the government needs to pay less.

Next, I discuss how the ratio of government spending in education to GDP changes. Neglecting the increase in output while accounting for the increased government spending would overestimate the true cost of the policies. We observe that the

[33]This effect comes from the fact that eliminating both policies together reduces college riskiness for large share of individuals, and therefore they want to exercise a college option.

changing cost for the government is compensated by an increase in output. The ratio decreases by 6.69% under policy 1 relative to the benchmark. For the other two policies, the ratio increased less than the absolute cost of education for the government (12.24% vs. 13.63% under policy 2 and 6.99% vs. 13.34% under policy 3). The results have an important policy implication as they suggest that eliminating the uncertainty embedded in the current grant system (policy 1) is free lunch for the government, and eliminating the GPA requirement (policy 2) and both (policy 3) are partially self-financing for the government in the long run in the sense that the increased subsidies are translated into a higher output.[34]

Next, I turn to analyze whether the education policies constitute a burden on taxpayers. Table 1.14 shows that the equilibrium labor income tax rate τ_w decreases rather than increases under policies 1 and 3 – the policies that foster aggregate productivity the most. This is a result of the increased tax base in consumption, capital income, labor earnings, and pension contribution, which allows the equilibrium labor tax rate to decrease. In contrast, under policy 2, the equilibrium tax rate increases, as the increased aggregate tax base is not enough to compensate for the increased government spending.

Finally, it is important to discuss the wage premiums as the general equilibrium results are largely influenced by a change in the skill prices and is the major reason why partial equilibrium and general equilibrium results diverge (Table 1.12 vs. Table 1.13). The change in college and dropout wage premiums relative to the benchmark economy are summarized in Table 1.15. The college (dropout) wage premium is defined as the average earnings of a college graduate (dropout) with age 50 relative to the average earnings of the same age high school graduate. We can make several observations. First, we observe that the college wage premium decreases under each policy, and it becomes respectively 84%, 82%, and 82% under policies 1, 2, and 3. The decrease in the college premiums follows the fact that there is a larger share of skilled workers under the reforms relative to the benchmark. Somewhat surprisingly, the college wage premium is the same under policy 2 and policy 3, even though in the latter there is a higher share of college graduates. The intuition behind this result is as follows. Under policy 3, more able people manage to enroll in college relative to the benchmark and policy 2. That leaves the average ability of high school graduates to be lower relative under this policy and, as a result, their efficiency is lower because of the ability-dependent fixed effect.[35] This decrease in the efficiency

[34]Note that I made an assumption that the cost is tied to the aggregate output in the economy. If the absolute cost of education would remain the same as in the benchmark, then, in the long run, the price of education would become significantly lower share of aggregate output, and consequently, for the government the policies would be even cheaper.

[35]Note that, the average level of ability of high school graduates is comparatively low under policy 3.

units outweighs the increase in the wage rate of non-skilled workers and this leads the average earnings of high school graduates to decrease. As a result, the nominator decreases under policies 2 and 3, but the denominator decreases only under policy 3. This explains why we observe almost the same change of college wage premium under policies 2 and 3.

Table 1.15 – Wage Premiums, Efficiency Units and Wage Rates by Education Level and by Skill Type

	Benchmark	No stochastic shock Policy 1	No GPA requirement Policy 2	Constant grants Policy 3
College Premium	90%	84%	82%	82%
Dropout Premium	20%	21%	22%	32%
Average Efficiency Units, Skilled	0.81	0.81	0.81	0.81
Average Efficiency Units, Dropout	0.67	0.71	0.70	0.86
Average Efficiency Units, High-school	0.67	0.66	0.66	0.65
%Δ Skilled Wage Rate	–	-2.04	-2.04	-3.06
%Δ Non-skilled Wage Rate	–	1.59	1.59	3.17

The decrease in the college wage premium is closely accompanied by the increase in the dropout wage premium. It increases by 2%, 3%, and 10%, respectively, under policies 1, 2, and 3. The economic mechanism behind this is that the ability composition of college dropouts improves relative to the benchmark economy, and, as a result, the average labor productivity of this group improves due to ability-dependent labor market outcomes.[36] For example, in Figure 1.9, we observe that, under policy 3, 30% more of high able individuals are dropping out relative to the benchmark economy. Therefore, the dropout earnings are higher relative to the benchmark due to the complementarity between education level and fixed effect.

[36]Note that, non-skilled labor, i.e. college dropouts and high school graduates have the same wage rate.

1.7.4 Welfare

Next, I turn to analyze how the decreased dropout rates, increased productivity and decreased gap in the skill prices are materialized in welfare. I consider a welfare measure in terms of consumption equivalence, denoted by ω_{CEV}, showing what percent of consumption should be given to an individual in the benchmark economy to make her indifferent between being born in the pre-reform and the post-reform economy. The measure can be expressed as follows:

$$V^A(\{(1+\omega_{CEV})c_t^A, l_t^A\}_{t=1}^J) = V^B(\{c_t^B, l_t^B\}_{t=1}^J). \tag{1.31}$$

Given the utility form, defined in equation (1.28), it can be shown that:

$$\omega_{CEV} = \left(\frac{V^B}{V^A}\right)^{\dfrac{1}{\nu(1-\frac{1}{\gamma})}} - 1. \tag{1.32}$$

Decomposition of welfare gains The utilitarian welfare gains, ω_{CEV}, can be positive due to several reasons. The measure increases if consumption or leisure increases, if inequality is reduced (since the utility function is concave), or/and if uncertainty is reduced (since agents are risk-averse). To examine why welfare improves under each policy, I decompose the welfare gains into the following three components: gains through level effects, uncertainty effects, and inequality effects in the fashion of Floden (2001) and Domeij and Heathcote (2004). Level effects exhibit whether a reform generates additional resources in the economy, i.e., at least one individual can be made better off under the policy, while the others keep the same utility. Uncertainty effects capture the fraction of welfare gains that is driven by the decrease in the volatility of an individual's consumption path. Inequality effects are measured by comparing how equally consumption is distributed across different groups.

For the decomposition, it is useful to define certainty-equivalent bundles. The bundle characterizes the constant amount of consumption and work hours an individual can consume and work for throughout her lifetime to get the same lifetime utility, $V(\cdot)$, as she has in the uncertain world. Formally, the derivation of certainty equivalent bundles proceeds as follows.

$$\sum_{t=1}^{J} \beta^{t-1}\varphi_t U(\tilde{c}, 1-\tilde{l}) = V(\{c_t, l_t\}_{t=1}^J) \tag{1.33}$$

Note, for notational simplicity, I suppressed the state space. For each point of a state space of newborns, $(1, a, \eta, \theta, \mu_{e_0})$, there is an associated bundle $(\tilde{c}, \tilde{l})$ that solves equation (1.33). Since there are two unknowns and one equation, there is a continuous set of $(\tilde{c}, \tilde{l})$ that solves the equation. To tackle this, in practice, I set the certainty equivalent working hours, $\tilde{l}$, to average hours in the economy. Then, the remaining unknown, $\tilde{c}$, can be easily solved as follows:

$$\tilde{c} = \left(\frac{V(\{c_t, l_t\}_{t=1}^J)(1 - \frac{1}{\gamma})}{\sum_{t=1}^J \beta^{t-1} \varphi_t} \right)^{\frac{1}{\nu(1-\frac{1}{\gamma})}} \frac{1}{(1 - \tilde{l})^{\frac{1-\nu}{\nu}}}. \tag{1.34}$$

Finally, it is useful to define average certainty equivalent hours, $\tilde{H}$ and consumption, $\tilde{C}$:

$$\tilde{H} = \int \tilde{l}(1, a, \theta, \eta, \mu_{e_0}) \; d\phi(1, a, \theta, \eta, \mu_{e_0}), \tag{1.35}$$

$$\tilde{C} = \int \tilde{c}(1, a, \theta, \eta, \mu_{e_0}) \; d\phi(1, a, \theta, \eta, \mu_{e_0}). \tag{1.36}$$

Given the following variable set in each economy $\left(\tilde{c}, \tilde{l}, \tilde{C}, \tilde{H}, V(\cdot), C, H\right)$, we are equipped to decompose the welfare gains in level, ω_{level}, uncertainty, $\omega_{\text{uncertainty}}$, and, inequality, $\omega_{\text{inequality}}$, effects.

Level effect. To isolate the level effects, I compare the average consumptions between economies A and B, while controlling for the possible differences in leisure across those two economies. To compensate leisure differences, I calculate a 'leisure-compensated' consumption bundle, $\hat{C}^B$, for economy B:

$$V\left(\{\hat{C}^B, L^A\}_{t=1}^J\right) = V\left(\{C^B, L^B\}_{t=1}^J\right). \tag{1.37}$$

Given the utility form in equation (1.28), it can be shown:

$$\hat{C}^B = C^B \left(\frac{1 - L^B}{1 - L^A} \right)^{\dfrac{1-\nu}{\nu}}. \tag{1.38}$$

Then, the gains in welfare due to the level effect is calculated as:

$$\omega_{\text{level}} = \frac{\hat{C}^B}{C^A} - 1. \tag{1.39}$$

Uncertainty effect. The cost of uncertainty, $p_{uncertainty}$, in economy i is defined as a fraction of consumption an individual would be willing to give up in order to avoid all uncertainty facing in her consumption path. It solves the following equation:

$$V\big(\{(1 - p^i_{uncertainty})C^i, H^i\}_{t=1}^J\big) = V\big(\{\tilde{C}^i, \tilde{H}^i\}_{t=1}^J\big). \tag{1.40}$$

After calculating $p^i_{uncertainty}$ for $i \in \{A, B\}$, then, the welfare gain in reduced uncertainty in economy B relative to economy A is defined as follows:

$$\omega_{\text{uncertainty}} = \frac{1 - p^{B}_{\text{uncertainty}}}{1 - p^{A}_{\text{uncertainty}}} - 1. \tag{1.41}$$

Inequality effect. The cost of inequality, $p_{inequality}$, answers what fraction of consumption an individual should give up to be indifferent between being born into economy i and into economy where everyone consumes and works the same amount. For that purpose, the value of average certainty equivalent bundles and average values of certainty equivalent are compared. Formally, this is summarized as follows:

$$V\big(\{(1 - p_{\text{ineq}})\tilde{C}, \tilde{L}\}\big) = \int V\big(\tilde{c}(1, a, \theta, \eta, \mu_{e0}), \tilde{l}(1, a, \theta, \eta, \mu_{e0})\big) d\phi(1, a, \theta, \eta, \mu_{e0}) \tag{1.42}$$

Then, it follows that the welfare gains in reducing inequality in economy B relative to economy A for an individual with a state space $(\cdot)$ is given by:

$$\omega_{\text{inequality}} = \frac{1 - p^{B}_{\text{inequality}}}{1 - p^{A}_{\text{inequality}}} - 1. \tag{1.43}$$

Finally, following Floden (2001), it can be shown that $\omega_{CEV} \approx (1 + \omega_{level})(1 + \omega_{inequality})(1 + \omega_{uncertainty}) - 1$.

Results

Table 1.16 summarizes the results. We observe that the policies improve the utilitarian welfare over the benchmark policy. The welfare gains for newborns are 2.3%, 1.31%, and 6.94%, for policies 1, 2, and 3, respectively. The substantial welfare gains under policies are consequences of the positive co-movements in the macroaggregates we discussed above. An increase in skilled labor fosters labor productivity. That drives the equilibrium output to rise significantly and, therefore, to increase the average consumption. At the same time, the gap in skilled prices decreases pretax income inequality for ex-ante identical individuals. All of these elements result in large utilitarian welfare gains.

Table 1.16 – Welfare Gains under Policies Relative to the Benchmark

	No stochastic shock Policy 1	No GPA requirement Policy 2	Constant grants Policy 3
Welfare CEV	2.3	1.31	6.94
Decomposition of welfare gains			
Welfare Levels, ω_{level}	1.7	1.23	5.6
Welfare Uncertainty, $\omega_{uncertainty}$	1.2	-0.23	3.42
Welfare Inequality, $\omega_{inequality}$	-0.52	0.27	-1.89

The separation of welfare effects shows that the level effect contributes significantly to these large welfare gains, as we observe in the second row of Table 1.16. The level gains are 1.7%, 1.23%, and 5.6% for policies 1, 2, and 3, respectively. These results are quite intuitive. As we discussed, all policies yield a substantial increase in aggregate output. This directly translates into a higher level of consumption path in the new economies relative to the benchmark.

As for the uncertainty effect, policies 1 and 3 result in 1.2% and 3.42% contribution to the overall welfare, while under policy 2 there is negative effect. Under policy 1 and policy 3, uncertainty improves because capital stock increases, and therefore individuals can risk share better across periods. This does not happen under policy 2, as capital stock is slightly lower and it moderates self-insurance across periods (only rich individuals might risk share better). However, note that the negative contribution of the uncertainty effect to the overall welfare is comparatively small under this policy.

As for the inequality gains, we observe that policies 1 and 3 slightly worsen inequality as now more able individuals have better access to college, and, therefore, keeping everything else constant, they have higher earnings than low ability individuals, who stay out of college. In contrast, lower ability agents maintain the same education status as in the benchmark. Furthermore, under policy 1, there are fewer dropouts. Therefore, fewer people get the dropout wage premium, which plays a channel of lowering inequality. Under policy 3, the inequality effect is negative due to a different reason. Here more people drop out, in absolute terms, as more people enroll, resulting in lower high school graduates' earnings, as discussed above.[37] On the other hand, relaxing the GPA requirement under policy 2 improves inequality as now low ability agents are motivated to graduate more, and, therefore, have higher earnings. However, the positive inequality effect is small and constitutes 0.27.

Conditional Welfare Gains

Next, to have a look who wins and loses by initial wealth and ability, I provide conditional welfare gains for newborns given their ability prior and wealth percentiles. Specifically, I consider students at the 10th, 50th, and 99th percentiles of wealth and ability distributions, nine types in total. Table 1.17 reports the conditional welfare gains for policies 1 (panel (a)), 2 (panel (b)), and 3 (panel (c)).

First, examining panel (a) in Table 1.17 indicates that eliminating the stochastic part of the grant system actually leads all groups to win unconditional on whether they go to college or not. For example, poor and median wealth individuals with low ability and poor individuals with median ability do not go to college in either

[37]The group has, on average lower ability than in the benchmark. This drives their earnings to be lower through ability-dependent high school fixed effects.

case. However, they face welfare gains of about 1.77% in terms of consumption equivalence. The gains are entirely driven by the increase in their relative wages in the long-run and the decrease in average labor taxes. We also observe that rich low ability individuals lose as they are missing out the high college premium in this scenario. They could go and graduate in the benchmark scenario. Now, some of them still lose grants due to a GPA requirement, and on top of that, the college premium decreases. In the equilibrium some of this group does not want to graduate. Therefore, on average, their welfare is lower than in the benchmark. Furthermore, high ability agents gain despite that college wages decline because they face less uncertainty by the elimination of the shock.

As for the case of the elimination of the GPA requirement (policy 2), panel (b) in Table 1.17 shows that only two groups, rich − high ability and rich - median ability individuals, lose (by 2.28pp and 0.72pp, respectively). That can be explained by the following observation. These groups would go to college and graduate in either case. The requirement does not affect them in the benchmark as they have a quite high prior, and even in the presence of lower grade, the chance of losing grants are minor. But now, they face decreased college wage premium (by around 8pp) compared with the benchmark case. That is the driving force of their welfare losses. All other types gain.

Finally, as for the last policy, panel (c) in Table 1.17 shows that all groups but top ability–top wealth group are better off relative to the benchmark economy. College-bound individuals win as the policy greatly reduces the adverse shocks at college. Non-college individuals win as their wage rate increases. We observe that low ability and rich individuals win particularly (by 27.44%). The reason why this group wins significantly is as follows. First, they enroll in college in either scenario. Second, they face a stochastic shock (like all college-bound individuals), but they are also particularly risk-group for a GPA requirement shock, as they are the only low ability group that can afford to go to college. Then, it is not surprising that eliminating both shocks benefits them the most.[38] All individuals also enjoy the fact that the budget-balancing tax rate is reduced. High ability and rich individuals lose. This group was privileged in the benchmark economy because they had no financial constraints to attain a college degree and earn a college wage premium. Now, just they face a lower wage premium, lowering their welfare by 0.03% in terms of consumption equivalence.

[38] Some of the groups either did not enroll or have a higher ability when they enroll and therefore they have a lower probability of being affected by the GPA requirement.

Table 1.17 – Conditional Welfare Gains under Policies by Ability and Wealth

	low ability	median ability	high ability
Policy 1 − No Stochastic Shock			
Poor	1.77	1.77	2.92
Median	1.77	1.79	2.85
Rich	-1.24	0.2	1.26
Policy 2 − No GPA Requirement			
Poor	1.40	1.40	1.39
Median	1.40	1.40	1.31
Rich	7.36	-0.72	-2.28
Policy 3 − Constant Grants			
Poor	2.71	2.70	7.29
Median	2.71	2.7	16.92
Rich	27.44	4.45	-0.03

1.8 Conclusions

This paper addresses the fact that 40% of college entrants drop out of a bachelor's degree in the US I provide empirical evidence that the probability of dropping out of college is strongly associated with both ability and finances, even after controlling for other ex-ante family characteristics. By modeling the time-varying nature of the grants, imperfect information about ability, and labor market outcomes, I decompose the relative roles of each factor in explaining college dropout rates. I find that making financial aid constant across academic years reduces dropout rates by 53 percent. Students from the lower half of the wealth distribution are particularly sensitive to the uncertain grant system. Negative shocks to grants force them to leave college, whereas the shocks barely affect rich students' college participation decisions. I also find that eliminating uncertainty in grants increases the welfare of the newborns as much as 2.3% of life-time consumption. Partially, this large gains come from the increased productivity of skilled labor, the decreasing gap in skill prices and therefore redistribution from high income to low income individuals. In addition, the elimination of the grants' volatility reduces uncertainty, which drives further increases in welfare for ex-ante identical, risk-averse individuals. Lastly, I show that eliminating uncertainty in the current grant system is cost effective for the government, as the overal governmental revenue increases through increased tax base in consumption, capital and earnings due to more productive (educated) labor force.

Appendix

A Data Description

The NLSY79 sample consists of individuals born between 1957 and 1964. At the time of the first interview, respondents' ages ranged from 14 to 22. The respondents were 49 to 58 at the time of their last interview, in 2014. There were originally 12686 respondents in the sample, out of whom 61111 belong to a representative, cross-sectional sample designed to represent the civilian segment of the people living in the US in 1979 and born between 1957 and 1964[39]

The NLSY97 surveys 8984 individuals who were born between 1981 and 1984. It started in 1997, and continued until 2017. From 1997 to 2011, the survey rounds were taking place annually, and biannually afterwards. Each round thoroughly questions respondents about information on their family characteristics, education process and labor market outcomes.

A.1 Data cleaning

The data cleaning process which I implemented on the NLSY97 sample is not straightforward, because of a large number of missing values. Therefore, below I carefully describe the methodology I used to construct the dataset.

College financement: Respondents are supposed to give the amounts they get from each sources for each first semester of each academic year, but there are several missing values. I construct an average measure of financement from each source by collecting the total amount that they report during their time spent in college, and dividing it by the number of years during which they are enrolled for a degree (excluding years enrolled in a masters or higher degrees). It allows me to get an average amount of financial assistance for each respondent during his college years including grants, family aid, out-of-pocket payments, governmental loans, family loans and work study.

Grants, Family Aid, Loans, Out of pocket & **Other finances:** They are provided as half-year measures, but I am interested in yearly measures. Hence, I multiply the average amount of all finances by 2. This method is subject to some (my) concerns: first, grants are merely offered in the first semester and possibly, in some cases, for the whole year, but in the questionairre it is clearly stated to report finances from each source for the specific term. Therefore, the respondent should

[39] 5295 respondents are oversampled minorities such as Black, Hispanic or Latino, and economically disadvantaged non-Black/non-Hispanic. The remaining 1280 respondents were drawn to represent the population serving in one of the four branches of the US military. In my analysis, I solely concentrate on a cross-sectional sample.

Table 1.18 – Education attainment in the NLSY97 data

	2-year[a]	4-year	Any degree
Enrollments	20.10 (1806)	42.87% (3852)	62.97% (5658)
Dropouts	78.02% (1409)	39.72% (1530)	46.06% (2606)
Graduates	21.98% (397)	60.28% (1530)	53.94% (3052)

[a]tried only 2 year degree

divide yearly transfers/ grants/ tuitions/ loans by 2 naturally. But we are not safe from measurement errors like in all other survey data.

Ability: Throughout the empirical analysis, I measure ability using two scores: the ASVAB math verbal percentile score and the PIAT (for the Mathematics Assesment subtest [40]) percentile score. I drop 918 individuals who did not take the ASWAB test, and 2940 individuals who did not take the PIAT test.

Weekly hours: As the measure of hours worked, I take the number of hours students work in the second week of October (week 41) and in the second week of April (week 14) during their tenure at college, when their enrollment status indicates that they are enrolled in a 2-year or in a 4-year degree (I excluded working hours during master or higher degrees). I choose those months as reference to capture the working burden during the study process and not during term breaks or in exam periods.

Enrollment & dropout rates: I calculate enrollment rates as follows. Taking enrollment status in October and in April (that is in the middle of the semester), if a respondent is coded as enrolled in a college (2-year or 4-year), then I assume that he attended college for at least one semester. Finally, I sum up all the semesters during which he attended college and divide by two to capture the number of years a respondent i spends in college. I define a dropout as someone who has spent at least a semester in college but did not earn any degree (neither 2-year, nor 4-year degree).[41]

Inconsistency in the Table 1.18: 22 individuals are not coded as enrolled in a 4-year degree institution, however, their degree is reported to be higher than a 2-year college degree. Therefore, when I sum up the dropouts in the lowest row, I find that 22 people are missing. I drop these 22 individuals when I restrict my analysis to bachelor degree owners only.

[40]One of the PIAT subtests, the Mathematics Assessment, was given in Round 1 to all respondents 9th grade or lower, regardless of age.

[41]`http://nlsinfo.org/content/cohorts/nlsy97/topical-guide/education/education-training-achievement-scores-introduction`

A.2 Sample selection in the NLSY79 and NLSY97

The questionnaires across those two surveys are not exactly identical. For the NLSY79, parental education is measured as the number of years they spend in schooling;[42] while the NLSY97 parental education is measured as a binary variable, high school graduate or higher.[43] As for the place of residence, in the NLSY79, I include two variables, urban/rural and south/nonsouth, in the NLSY97 only one variable, urban/rural, as there is no information about south/nonsouth. Furthermore, in the NLSY97, an intact family is measured whether a youth is living with both parents at age 14. For the NLSY79, the actual number of siblings are reported, while for the younger cohort, I use the number of youth under 18 for the younger cohort. Finally, for the NLSY97, as a measure of financial situation, I use family wealth rather than family income. This is motivated by the fact that family wealth captures more comprehensively the financial state of the household.[44] However, the qualitative findings are robust to the choice between those two measures.

B Federal Financial Aid

B.1 Getting Aid

After refiling the Free Application for Federal Student Aid (FAFSA), which estimates the difference the cost of attending college and expected family contribution. If the gap is positive, then a students get a package of financial aid, which includes:

1. Pell Grants: Pell grants are assigned as $\min(COA - EFC, 6905\$) = PELL$ However, if $COA - EFC < 700$ then $Pell$ is equal to 0. Therefore note, if one makes COA to the same for all students, that implies subsidies must vary according to EFC. So if one gets transfer $'x'$ then the subsidies should be $\min(COA - x, 6905\$) = PELL$ [45] COA based on NCES is 24300 . That means subsidies cannot be more than 25%

2. Federal Loans[46]: Loan limits by year of undegraduate studies and by type of loans are given in Table 1.19.

3. Work-study: a student might get as an award, but you might still do not find the job and consequently, lose the assigned amount of work-study income. You

[42] There is no information what degrees parents actually earned.

[43] I only control for mothers' education, since there are lots of missing information about fathers' education, particularly in NLSY97.

[44] There is no information about family wealth in NLSY79.

[45] https://ifap.ed.gov/dpcletters/attachments/GEN1804AttachRevised1819PellPaymntDisbSched.pdf

[46] https://studentaid.ed.gov/sa/types/loans/subsidized-unsubsidized

may not find a job (1) you maynot exert enough effort to find a job (personal reason) (2) there is no work-study job available in the campus.

Table 1.19 – Federal Loan Limits.

		Dependent student	Independent Student
	Subsidized loan limit	Total	Total
First year	3,500	5,500	9,500
Second year	4,500	6,500	10,500
Third year & beyond	5,500	7,500	12,500

Note: interest rate for the both types of loans are 5.05%.

B.2 Staying Eligible:

For staying eligible you need to satisfy the following from year to year (up to 6 years):

1. Fill Out the $FAFSA$ Form Each Year (17% of students who stay enrolled, and exhibit GPA higher than 3 does not reapply for the Grants. (Such students have higher probability to dropout afterwards.))

- Recalculating Expected Family Contribution. That is EFC will change every year based on latest FAFSA information, so changes to income or savings levels can impact students' financial aid throughout their college career.

  In our model framework, that means your work income should stay below 6450$.

2. Make Satisfactory Academic Progress
   - A GPA higher than 2.0
   - Take 12 credit hours i.e. approximately 12 hours per week classes, plus 24-36 hours work outside the class. To summarize, that implies students need officially to spend $36 - 48$ hours for studying purposes, i.e., $5 - 7$ hours a day. However, if one works as well around 20 hours a week, that implies, student needs to work around $8 - 10$ hours a day (including weekends)

C Measuring SAP in the Model

The Satisfactory Academic Progress (SAP) requirement involves qualitative and quantitative measures. The qualitative measure examines the quality of the student's academic performance as measured by grade point average. The quantitative measure examines the student's progress towards completion of the number of credit hours required to receive a degree. I integrate both SAP measures into GPA

In the model, I consider full-time students: they attempt full-time credits. The minimum pace requirement for them to maintain Pell-grants (and most other types of grants) is 67%, which is measured earned credits divided by attempted credits. Note, failing in 33% of chosen credits yields GPA lower than $\overline{GPA}$ threshold, which disqualifies students from grants. At the same time, it yields GPA lower than $\overline{GPA}$ threshold. Therefore, for full-time students, both the qualitative and quantitative measures of SAP coincide. This enables me to have in the model qualitative measure.

D Assumption about Working Hours into GPA Function

There are approximately 19 papers that study how the working hours affect postsecondary educational attainment outcomes measured by GPA, credit accumulation, and persistence in college (summarized in a review paper Neyt et al. (2019)). Understanding the relationship is hard due to high endogeneity between working and studying decisions. Giving a causal interpretation, one must adequately control for all possible confounds.

Series of empirical literature has tried to isolate the causal impact of working hours on education attainment using methods such as propensity score matching (Scott-Clayton and Minaya (2016), IV (Stinebrickner and Stinebrickner (2003)), FE Wenz and Yu (2010), Darolia (2014), and dynamic discrete choice modelling (Bozick (2007)). All of those papers found negative effects either on GPA or on persistence in college or on both of them together. Besides, working while studying is associated with psychological and psychosomatic stress Steinberg and Dornbusch (1991). The theory of the allocation of time by Becker (1965) suggests that time spent working crowds out time spent on activities that enhance academic performance (i.e., studying, doing homework, and attending classes;) There is an obvious trade-off in time allocation between working in the labor market or using this time for studying.

E Graduation & Enrollment Rates

E.1 Life-Cycle Profiles

Figure 2.1 plots the life-cycle profiles of average consumption, asset holdings, hours worked, and earnings for each education level: high school graduates, college dropouts,

Table 1.20 – Enrollment, Graduation and Dropout rates by ability and wealth (NLSY97)

College participation rates by ability quintiles						
	Quint 1	Quint 2	Quint 3	Quint 4	Quint 5	All
Bachelor degree						
Enrollment rates	0.1192	0.3014	0.5243	0.6643	0.8607	0.494
Graduation rates	0.0508	0.1454	0.2899	0.4421	0.6473	0.315
Dropout rates	0.5743	0.5176	0.4470	0.3345	0.2497	0.363
Any degree						
Enrollment rates	0.3294	0.6040	0.7325	0.8428	0.9351	0.6891
Graduation rates	0.1027	0.2411	0.3917	0.5496	0.7219	0.4013
Dropout rates	0.6882	0.6008	0.4653	0.3478	0.2298	0.4176
College participation rates by wealth quintiles						
Bachelor degree						
Enrollment rates	0.2943	0.3567	0.4575	0.5728	0.7189	
Graduation rates	0.1303	0.1753	0.2658	0.3935	0.5489	
Dropout rates	0.5574	0.5085	0.4191	0.3130	0.2366	
Any degree						
Enrollment rates	0.5115	0.5732	0.6663	0.7461	0.8697	
Graduation rates	0.2051	0.2576	0.3580	0.4910	0.6345	
Dropout rates	0.5991	0.5506	0.4627	0.3419	0.2705	

Note: I recover enrollment rates in the month of four and tenth. Then, given whether they were enrolled in those semesters at college at, specifically, the bachelor degree, I check their graduation probabilities and accordingly update.

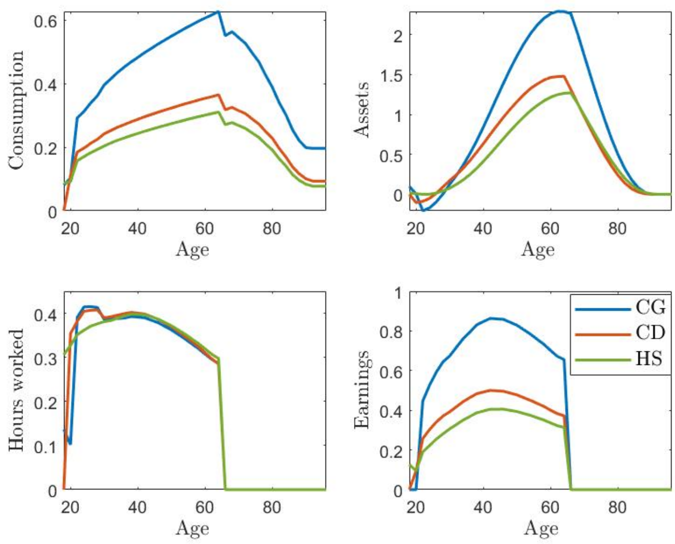
and college graduates. They exhibit shapes that are typical of any life-cycle model. Consumption rises steadily over the working life for both skilled and unskilled workers. Slightly it dips when workers retire because pension benefits are only a fraction of average earnings. Gradually consumption decreases as they age and face rising death hazards.

Wealth exhibits the typical hump-shaped profile. For young individuals who are not attending college, the initial wealth is slightly positive. College students, on the other hand, take out loans and, therefore, have negative wealth. On average, it takes about eight years to pay off student loans.

Labor supply does not differ much across skill types. At age one, when the young generation enters the economy, labor supply is low not only for college-bound individuals but also for non-college-bound individuals. For college students, the reason is obvious because attending college takes time. For those who are not attending college, the relatively low level of labor supply reflects their low productivity, which is in line with the data. In the second period, college students work less than in the first period. This can be explained by considering that the selection into college already shows up in the second period: richer and more able students remain in college. Consequently, they need to work less to self-finance college.

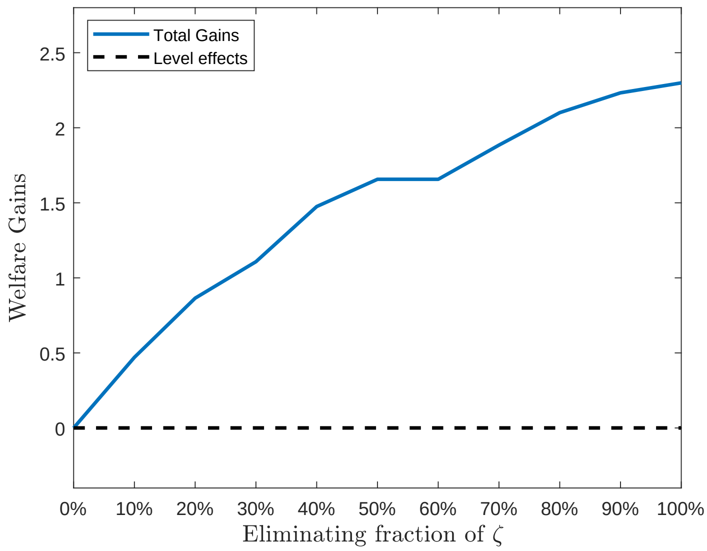
Finally, the life-cycle earnings profile also matches the data pretty well. Earnings are relatively low for young individuals as they enter the economy. College students do not have much time to work; those who are not attending college have low productivity. Earnings rise more rapidly for college-educated workers than unskilled workers (both high school graduates and dropouts). Average earnings decline gradually before retirement and drop to zero at the time of retirement. Though the wage rate for dropouts is the same as high school graduates, they still earn more than their non-college counterparts. This is because dropouts have higher probabilities of drawing a high fixed effect of θ (see Section 4.4).

Figure 1.10 – Life-cycle profiles of average consumption, asset holdings, hours worked and earnings for college graduates (blue), college dropouts (red) and high school graduates (green), respectively.



F Robustness of Welfare Gains to the Elimination of Grants Uncertainty

Figure 1.11 – The Effects of Eliminating Fraction of the Stochastic Shock in the Grant System



Before concluding this section, I would like to discuss the robustness of the results on the welfare gains of policy 1. I am mainly interested in how robust the welfare gains are when only the fraction of the stochastic shock, ζ, is eliminated. This clarifies whether a policy that is successful in decreasing at least a partial amount of the uncertainty would still yield welfare gains. Figure 1.11 summarizes the results. It exhibits the welfare gains as a function of the standard deviation of ζ. Specifically, the X-axis refers to the fraction of the uncertainty eliminated, and Y-axes presents the welfare gains in terms of consumption equivalence. The figure plots the total gains in terms of consumption equivalence. We observe that the total and level gains increase as the variance of the stochastic shock decreases.

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Chapter 2

Education Affordability and Earnings Inequality

joint with Fuzhen Wang [1]

1 Introduction

This paper studies the role of education affordability in shaping earnings inequality. We begin by documenting an empirical fact about the correlation between education affordability and earnings inequality across countries. Table 2.1 reports the Gini index of before-tax gross earnings for full-time male workers, the private and public direct cost of a person attaining tertiary education as well as the fraction of tertiary education costs borne by the government for the United States, the United Kingdom and five continental European countries.[2] It shows a strong correlation between education affordability and earnings inequality: the Pearson correlation coefficient between the Gini index and the private cost of a person attaining tertiary education is 0.939.[3]

This empirical fact motivates us to consider education affordability as a potentially important determinant of earnings inequality. To evaluate the role of education affordability in driving earnings inequality, we build an overlapping generations model where agents, heterogeneous with respect to learning ability and initial wealth en-

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[2]The table is compiled using data from OECD.stat online database.

[3]The correlation coefficient between the Gini index and the private cost of education as a fraction of per capita GDP is 0.932.

Table 2.1 – Education affordability and earnings inequality

	Gini index	**Private costs**	**Public costs**	**Subsidy rate**
		c_1	c_2	$z = \dfrac{c_2}{c_1 + c_2}$
Denmark	0.285	4300	98400	0.958
Finland	0.268	3400	91300	0.964
Germany	0.314	5200	87500	0.944
Netherlands	0.286	16900	73000	0.812
Sweden	0.272	200	97200	0.998
U.K.	0.341	25900	27700	0.517
U.S.	0.410	55000	55900	0.503

1. The Gini index is compiled using before-tax gross earnings for full-time male workers for the period from 2005 to 2014.
2. Private and public direct costs of a person attaining tertiary education are in 2011 PPP international dollars.

dowment, decide whether to attend college, subject to borrowing constraints and idiosyncratic income risks. To capture the various aspects of government policy, our model features progressive labor income taxation, consumption tax, capital income tax as well as subsidies for college. After calibrating the model to the U.S. economy, we conduct a number of counterfactual experiments. In particular, we replace the status quo US education policy, the fraction of higher education costs borne by the government, with its German counterpart and study the change in earnings inequality. Besides, we also examine the roles of other policy dimensions such as progressive labor taxation. Though this paper is motivated by observations from cross-country comparisons, it focuses squarely on the US.

We find that earnings inequality, as measured by the Gini coefficient for before-tax gross earnings, would decrease by as much of 6.79% percent if the current education policy, the share of higher education costs borne by the government, were replaced with its German counterpart. Two groups of households would benefit from the hypothetical policy reform. First, poor households with medium and medium-high ability would benefit the most from increased government subsidies for college: this group would enjoy an increase in life-time utility equivalent to an increase in consumption by as much as 7.14%. Those are the households that cannot afford to go to college in the benchmark, although they would benefit greatly from a college education. Second, low ability households would also benefit from the hypothetical education policy reform, albeit for different reasons. They don't go to college anyway. But when more households attend college, the college wage premium decreases. Unskilled workers become relatively scarcer and thus enjoy a higher wage rate. On the other hand, our results suggest that a small fraction of rich and high-ability households would lose out from the hypothetical education policy reform due to compressed college wage premium. However, the utility loss they would suffer is relatively small. For example, a household with an initial wealth at the 90th percentile of the initial wealth distribution and a learning ability at the 99th percentile of the ability distribution would suffer a utility loss equivalent to a 2.3% decrease in consumption. Finally, in contrast with the existing literature, we find that labor tax progressivity plays a less significant role in explaining earnings inequality.

The evaluation of the transitional dynamics shows that if the education policy was implemented permanently, every new generation would be better off and over half of the long run welfare gains would be achieved after only one generation. Older generations alive at the time the policy is introduced, depending on their education status have divergent welfare effects: those who are non-college educated have welfare gains, while college-educated cohorts generally lose. While several factors play a role, the main channel of those dissimilar effects are decreasing college wage premium over time.

The rest of the paper is organized as follows. Section 2 relates this paper to the literature. Section 3 sets up the model and defines the equilibrium. Section 4 describes our calibration strategy. We present the results in section 6. We discuss the transitional dynamics in section 7. We briefly conclude the paper in section 4.

2 Relation to The Literature

Our paper is mostly related to the strand of literature that explores the determinants of cross-countries differences in wage inequality (see, for example, Guvenen et al. (2014)) and intergenerational earnings persistence (see, for example, Holter (2015)). Guvenen et al. (2014) attributes the wage inequality gap to differences in labor income tax progressivity: More progressive labor income taxes, as seen in continental European countries, distort the incentives for individuals to accumulate human capital, which compresses the wage income distribution. However, Guvenen et al. (2014) abstracts from the general equilibrium effects of government policy on relative factor prices and it assumes that markets are complete so that individuals that wish to invest in human capital accumulation are always able to do so by borrowing. We instead consider an environment where markets are incomplete and those who wish to attend college may find themselves financially constrained. In addition, we allow for endogenous evolution of college premium. Importantly, while taking inspiration from cross-country comparisons, our paper focuses squarely on the US. The reason is that factors affecting cross-countries differences in earnings inequality may go well beyond government policies. Importantly, we study the general equilibrium framework, as well as taking into account the transitional dynamics.

A major goal of this paper is to evaluate the role of education affordability in shaping earnings inequality. In terms of modelling choices, our paper is built on the public economics literature on tax and education policy, for example, **?**, Benabou (2002), Bovenberg and Jacobs (2005), Findeisen and Sachs (2015, 2016a,b), Heathcote et al. (2017), and Krueger and Ludwig (2013, 2016). This tradition, pioneered by Benabou (2002), emphasizes the distortionary effects of progressive taxation on human capital accumulation; it also recognizes that education subsidies can partially mitigate the tax distortions and therefore serve as a complement to progressive labor income taxation. Most of this literature allows for general equilibrium effects of government policies on relative factor prices. In line with this literature, this paper considers the distortionary effects of taxation, the complementary role of education subsidies as well as the general equilibrium effects of government policy on relative factor prices. In particular, our paper is closely related to **?**, which studies, in a similar but more complex framework, the general equilibrium effects of various financial aid policies intended to foster college participation and Krueger and Ludwig (2016), which characterizes the optimal mix of progressive taxation and education subsidies. Our paper overlaps with **?** in that college participation, the main variable of interest in their paper, is an intermediate variable of interest for us. Our paper, however, is not solely concerned with college attainment, but also evaluates the importance of various policy dimensions in driving earnings inequality. Moreover, our paper also differs from **?** in that we calibrate the model to the latest data (2011) which exhibits higher college wage premium and earnings inequality than those used in their paper. This may partially explain why we come to different conclusions about the impact of increased government spending on higher education on college attainment. Our paper differs from Krueger and Ludwig (2013, 2016) in terms of research questions: while we study the roles of various government policies in shaping earnings inequality, they quantitatively characterize the optimal tax and education policy and are largely silent on earnings inequality.

Finally, our paper is related to the strand of empirical literature on returns to skills, for example, David (2014), Goldin and Katz (2009), Hanushek et al. (2015) and Lemieux (2006). A central message of this literature is that the rising wage premium associated with higher education is a key driver in the evolution of earnings inequality. Therefore, our paper captures the pivotal role of the interplay of supply and demand for skills.

3 The Model Economy

We consider an overlapping generations model. The model economy consists of households that are heterogenous with respect to age, wealth, learning ability, education and labor productivity, firms that produce a final good by hiring labor and capital on competitive spot markets, and a government that operates the tax system and the pension system. Decisions of households differ depending on the phase in which they find themselves. First, in the first period of its life, having drawn its learning ability, an idiosyncratic labor productivity shock and education-contingent initial wealth endowment, each household decides whether to attend college. Second, after making their college decisions, households make their consumption and labor supply decisions in each period of their working life. Finally, households retire and live on capital income and pension benefits. We will describe the model environment and household life cycle decisions in detail in the following.

3.1 Demographics

Time is discrete, indexed by t, and it goes forever. At each point in time, the economy is populated by J overlapping generations indexed by $j = 1, 2, \cdots, J$, where J denotes the maximum age. Individuals survive from age j to $j+1$ with probability ψ_{j+1}. For simplicity, we assume that the survival rate before retirement is equal to one; agents face death hazard once they retire, i.e., $\psi_j \in [0, 1)$ for $j \geq j_r$, where j_r denotes the retirement age. Let N_t denote the initial size of the cohort that enters the economy in period t; N_t grows at a constant rate n, i.e., $N_t = (1+n)N_{t-1}$. Since the growth rate of population is constant and the age-specific survival rates are time-invariant, the relative share of population of each age cohort is constant over time. To ease aggregation later on, we define m_j as the size of population of age cohort j relative to the youngest cohort alive in the current period:

$$m_j := \frac{N_{t-j+1} \left(\prod_{i=0}^{j-1} \psi_i \right)}{N_t}.$$

3.2 Firms and Production

Firms hire labor and capital on competitive spot markets to produce a final good. Workers come in two skill types, indexed by $s = \{c, n\}$, where we refer to college-educated workers as skilled workers ($s = c$), and those without college education unskilled workers ($s = n$). Within each skill type, labor is perfectly substitutable across ages; but across skill types, labor is imperfectly substitutable in the tradition of Katz and Murphy (1992) and Borjas (2003). Let $L_{t,c}$ and $L_{t,n}$ denote aggregate labor–in terms of efficiency units– of skilled workers and unskilled workers, respectively. Then aggregate labor across skill types is given by

$$L_t := \left(L_{t,c}^{\zeta} + L_{t,n}^{\zeta}\right)^{1/\zeta}, \tag{2.1}$$

where $\frac{1}{1-\zeta}$ is the elasticity of substitution between skilled and unskilled labor. Final output is produced according to the Cobb-Douglas production function,

$$Y_t = AK_t^{\alpha} L_t^{1-\alpha},$$

where A denotes total factor productivity and α is a parameter that governs the elasticity of output with respect to capital. With perfect competition and a constant return to scale production function, the size distribution of firms is indeterminate; without loss of generality, we assume the existence of a representative firm. The representative firm takes the wage rates of skilled and unskilled labor, $w_{t,c}$ and $w_{t,n}$, and the interest rate r_t as given.

3.3 Endowments, Labor Productivity and Preferences

When a new generation enters the economy, individuals are heterogeneous in their learning ability e and initial wealth a.[4] We assume that college-bound households draw their initial wealth from a different distribution than non-college-bound households; the reason is that inter vivos transfers from parents to their college age children are mainly motivated by parents' preference for their children to attend college. In addition, each household is endowed with one unit of labor in each period of its life. There are three elements to labor productivity $h_{s,j}$ for each skill type: a deterministic life-cycle productivity profile $\epsilon_{s,j}$, a fixed productivity effect θ_s, and a stochastic component η_s that evolves according to a Markov process π_{η_s} Labor productivity is given by

$$h_{s,j} = \begin{cases} \epsilon_{s,j} \cdot \exp\left(\theta_s + \eta_{s,j}\right), & \text{if } j < j_r \\ 0, & \text{otherwise,} \end{cases}$$

where we assume that labor productivity drops to zero in retirement.

Individuals have preferences over streams of consumption c_j and leisure $\tilde{l}_j$. Except for college students, $\tilde{l}_j = 1 - l_j$, where l_j denotes labor supply. In the case of college students, $\tilde{l}_j = 1 - \xi(e) - l_j$, where $\xi(e)$ is the time cost of college. More precisely, households' preferences are given by

$$u\left(c_1, 1 - \mathbb{1}_s \cdot \xi(e) - l_1\right) + \beta \mathbb{E}_1 \sum_{j=2}^{J} \beta^{j-2} \left(\prod_{i=0}^{j} \psi_i\right) u\left(c_j, 1 - l_j\right),$$

[4] We use heterogeneity in initial wealth to capture the family income effect on college attendance. For example, Belley and Lochner (2007) show that the effects of family income on educational achievement increased substantially from the early 1980s to the early 2000s.

where $\mathbb{1}_s$ is an indicator variable, equal to one for college-bound households, and zero otherwise.

3.4 College Education

At age one, after having drawn her learning ability e and education-contingent initial wealth a, an individual decides whether to attend college. Attending college takes one period. Moreover, going to college entails a resource cost that is a fraction or multiple, ι, of the wage rate of skilled labor $w_{t,c}$, and a time cost $\xi(e) \in (0, 1)$ that depends on learning ability.[5]To accommodate the case where college education is, at least partially, funded by government subsidies, let z denote the fraction of resource cost borne by the government. Upon deciding to go to college, financially constrained individuals can work part-time and/or take out student loans subject to a borrowing constraint.

3.5 Market Structure

Financial markets are incomplete in that there is no insurance against idiosyncratic labor productivity shocks and mortality risks. Individuals can self-insure against those risks by accumulating risk-free assets in the form of capital and government bonds.

Borrowing is allowed only for financing college education. We further assume that student loans are fully paid back before retirement when early death hazard sets in so that we rule out student loan defaults.

3.6 Government

The government runs the tax system and the pension system. First, the government collects taxes on household consumption, capital income, labor income and issues one-period government bonds so as to finance public expenditure G_t, debt service payment on outstanding government bonds B_t and education subsidies. Taxes on consumption and interest income are flat with a tax rate of τ_c for consumption expenditures and τ_k for interest income. Following Heathcote et al. (2010b), we consider a potentially progressive labor income tax function,

$$\tau_l(y) = 1 - \lambda y^{-m},$$

[5]Ability-based time cost is intended to capture the notion that students of higher ability take less time to reach the same academic achievement. Granted, this involves a high degree of simplification since high-ability students may aspire to achieve more than their peers. Thus we homogenize college education in this sense.

where $\tau_l(y)$ is the tax rate at income level y, $m > 0$ is a measure of progressivity of the tax schedule and λ is a parameter that governs the average tax rate (for a given m).
In addition, the government collects accidental bequests and redistribute them to the generation that has just entered the economy. To come up with a plausible calibration of the initial wealth distribution, we assume that the government fills the gap between accidental bequests and actual transfers in each period.
The pension system operates on a pay-as-you-go basis: it collects contributions from current workers and distributes the revenues directly to current pensioners. In period t, current workers of skill type $s \in \{c, n\}$ contribute a fraction, τ_p, of their labor income to the pension fund, and current retirees receive a pension benefit that is proportional to their average life-time income: $pen_t(s, \theta_s) = \kappa_s w_{t,s} \bar{L}_t(s, \theta_s)$, where $\bar{L}_t(s, \theta_s)$ is the average labor supply, in efficiency unit terms, of working age cohort with characteristics (s, θ_s). The budget constraint of the pension system then reads

$$\sum_{s \in \{c,n\}} \tau_p w_{t,s} L_{t,s} = \sum_{s \in \{c,n\}} \sum_{\theta_s} \sum_{j=j_r}^{J} pen_t(s, \theta_s) m_j(s, \theta_s), \tag{2.2}$$

where $m_j(s, \theta_s)$ is the relative size of age cohort j that falls into the skill category s and has a fixed productivity component θ_s.

3.7 Life Cycle

In this subsection, we set out the households' life-cycle decisions more precisely.
Decisions at age 1: Before the college decision is made, each household draws its learning ability e from a truncated normal distribution on the unit interval $(0, 1)$, education-contingent initial wealth $\{a_c, a_n\}$, and an idiosyncratic labor productivity shock from the non-college idiosyncratic productivity distribution, $\pi_{\eta_n}(\eta)$. Then households decide whether to attend college. The college decision is formally defined as

$$\mathbb{1}_s(e, a, \eta) = \begin{cases} 1, & \text{if } W(e, a_c, \eta, c) > W(e, a_n, \eta, n) \\ 0, & \text{otherwise,} \end{cases}$$

where $W(e, a_s, \eta, s)$ is the expected present value of life-time utility of a household with college decision s, learning ability e, an initial wealth endowment of a_s, and an idiosyncratic labor productivity shock, η. It is formally defined as

$$W(e, a_s, \eta, s) = \sum_{\theta} \pi_{\theta_n}(\theta) V(1, e, s, a_s, \theta, \eta)$$

where $\pi_{\theta_n}(\theta)$ is the distributions from which individuals draw their fixed productivity effect θ, and $V(1, e, s, a_s, \theta, \eta)$ is the expected present value of life-time utility of a

household with state vector $(1, e, s, a_s, \theta, \eta)$. While initial wealth is drawn from an education-dependent distribution, initial fixed productivity effect θ and idiosyncratic productivity shock η are drawn from distributions for unskilled workers, whether the household is college-bound or not.[6] Upon finishing college education, skilled workers, those with a college degree, will redraw the fixed productivity effect θ and idiosyncratic shock η from distributions for skilled workers. Thereafter, the stochastic productivity component evolves over time according to $\pi_{\eta_s}(\eta' \mid \eta)$.
Given its initial wealth a, college decision s, fixed labor productivity effect θ and its initial draw of stochastic productivity η, each household then chooses consumption and labor supply so as to maximize its expected present value of life-time utility. Formulated recursively, each household solves the following Bellman equation

$$V(1, e, s, a, \theta, \eta) = \max_{c,\, l} \left\{ u(c, 1 - \mathbb{1}_s(e, a)\xi(e) - l) + \beta\psi_2 \sum_{\eta'} \pi_{\eta_s}(\eta' \mid \eta) V(2, e, s, a', \theta, \eta') \right\} \tag{2.3}$$

subject to the budget constraint

$$(1+\tau_c)c+a'+\mathbb{1}_s(1-z)\iota w_{t,c} = (1+(1-\tau_k)r_t)a+(1-\tau_p)w_{t,s}h_{s,1}l-y\tau_l(y)+Tr, \tag{2.4}$$

where $y = (1 - \tau_p)w_{t,s}h_{s,1}l$, and the borrowing constraint

$$a' \geq -\underline{\mathrm{A}}_1.^7 \tag{2.5}$$

<u>Decisions at age $j = 2, ..., j_r - 1$</u>: While decisions at age one may differ for college-bound and non-college bound households, decisions during the normal working life are pretty standard: given the current situation $(j, e, s, a, \theta, \eta)$, each household chooses consumption and labor supply so as to maximize its present value of utility.[8] The Bellman equation reads

$$V(j, e, s, a, \theta, \eta) = \max_{c,\, l} \left\{ u(c, 1 - l) + \beta\psi_{j+1} \sum_{\eta'} \pi_{\eta_s}(\eta' \mid \eta) V(j + 1, e, s, a', \theta, \eta') \right\} \tag{2.6}$$

[6]Initial idiosyncratic productivity shock, η, is drawn from the corresponding stationary distribution of $\pi_{\eta_n}(\eta' \mid \eta)$.

[7]For college-bound individuals, the Bellman equation is slightly different because they will redraw θ and η at the beginning of period two from $\pi_{\theta_c}(\theta)$ and $\pi_{\eta_c}(\eta)$, where $\pi_{\eta_c}(\eta)$ is the stationary distribution of $\pi_{\eta_c}(\eta' \mid \eta)$.

[8]From period 2 onward, learning ability e becomes a redundant state variable. We nonetheless keep it in the state vector for consistency. The same is true for θ and η for retirees.

subject to

$$(1+\tau_c)c + a' = (1+(1-\tau_k)r_t)a + (1-\tau_p)w_{t,s}h_{s,j}l - y\tau_l(y) + Tr, \tag{2.7}$$

and

$$a' \geq -\underline{\mathrm{A}}_j. \tag{2.8}$$

Decisions at age $j_r, ..., J$: After retirement, households' labor productivity drops to zero, and they live on capital income and pension benefits. The associated Bellman equation is given by

$$V(j,e,s,a,\theta,\eta) = \max_{c} \left\{u(c, 1-l) + \beta\psi_{j+1}V(j+1,e,s,a',\theta,\eta)\right\} \tag{2.9}$$

subject to

$$(1+\tau_c)c + a' = (1+(1-\tau_k)r_t)a + pen_t(s,\theta) + Tr. \tag{2.10}$$

3.8 Competitive Equilibrium

To define the general equilibrium of the model economy, it is useful to introduce some additional notation. In particular, we need to define the distribution of households on the state space. Let $\mathcal{E} = [0,1]$, $\mathcal{J} = \{1,2,...,J\}$, $\mathcal{S} = \{c,\, n\}$, $\mathcal{A} = \mathbb{R}$, $\mathcal{F} = \mathbb{R}$ and $\mathcal{H} = \mathbb{R}$ denote the state space for ability e, age j, education level s, wealth a, fixed productivity effect θ and the stochastic productivity component η. And let Σ denote the Borel σ-algebra defined on the product space $\mathbb{X} = \mathcal{E}\times\mathcal{J}\times\mathcal{S}\times\mathcal{A}\times\mathcal{F}\times\mathcal{H}$. Then for any $X \in \mathbb{X}$, a measure $\phi(X)$ can be properly defined.
With this preparation, we now define the stationary recursive competitive equilibrium as follows.

Definition 2. A stationary recursive competitive equilibrium is a collection of: (i) decision rules of households $\{\mathbb{1}_s(e,a), c(j,e,s,a,\theta,\eta), l(j,e,s,a,\theta,\eta)\}$; (ii) aggregate capital and labor inputs, $\{K_t, L_{t,c}, L_{t,n}\}$, on the part of firms; (iii) value functions $V(j,e,s,a,\theta,\eta)$ $V(j,e,s,a,\theta,\eta)$; (iv) government policies $\{\tau_c,\tau_k,\tau_p,\tau_l(y), pen(s,\theta_s),\kappa_s,z,Tr\}$; (v) prices $\{r_t, w_{t,c}, w_{t,n}\}$; (vi) education system characterized by $\{\iota, \xi(e)\}$; and (vii) a vector of measures ϕ, such that:

1 The decision rules of households solve their respective life-cycle problems, and $V(j,e,s,a,\theta,\eta)$ is the associated value function.

2 Aggregate capital and labor inputs, $\{K_t, L_{t,c}, L_{t,n}\}$, solve the representative firm's profits maximization problem, which is fully characterized by the following first order conditions:

$$r_t = \alpha A k_t^{\alpha-1} - \delta, \tag{2.11}$$

$$w_{t,c} = (1-\alpha)k_t^{\alpha}\left(\frac{L_t}{L_{t,c}}\right)^{1-\zeta} = w_t\left(\frac{L_t}{L_{t,c}}\right)^{1-\zeta}, \tag{2.12}$$

and

$$w_{t,n} = (1-\alpha)k_t^{\alpha}\left(\frac{L_t}{L_{t,n}}\right)^{1-\zeta} = w_t\left(\frac{L_t}{L_{t,n}}\right)^{1-\zeta}, \tag{2.13}$$

where $k_t = \frac{K_t}{L_t}$, $w_t = (1-\alpha)k_t^{\alpha}$, and the college wage premium is given by

$$\frac{w_{t,c}}{w_{t,n}} = \left(\frac{L_{t,n}}{L_{t,c}}\right)^{1-\zeta}. \tag{2.14}$$

3 The labor market for each skill type clears:

$$L_{t,s} = \sum_{j=1}^{J}\iiint_{\mathbb{X}(j,s)} h_{s,j}(\theta,\eta)l(j,s,a,\theta,\eta)\phi(j,s,a,\theta,\eta)\,da\,d\theta\,d\eta, \tag{2.15}$$

where $\mathbb{X}(j,s)$ is the subset of the state space $\mathbb{X}$ corresponding to age j and skill type s.

4 The capital market clears:

$$K_{t+1} + B_{t+1} = A_{t+1}, \tag{2.16}$$

where B_{t+1} is the supply of government bonds and

$$A_{t+1} = \sum_{s\in\{c,n\}}\sum_{j=1}^{J}\iiint_{\mathbb{X}(j,s)} a'(j,s,a,\theta,\eta)\phi(j,s,a,\theta,\eta)\,da\,d\theta\,d\eta.$$

5 The good market clears:

$$Y_t = C_t + G_t + E_t + I_t, \tag{2.17}$$

where

$$C_t = \sum_{s\in\{c,n\}}\sum_{j=1}^{J}\iiint_{\mathbb{X}(j,s)} c(j,s,a,\theta,\eta)\phi(j,s,a,\theta,\eta)\,da\,d\theta\,d\eta,$$

$$E_t = \iiint_{\mathbb{X}(1,c)} \iota w_{t,c}\phi(1,c,a,\theta,\eta)\,da\,d\theta\,d\eta,$$

G_t is government spending, and $I_t = (n+\delta)K_t$ is gross investment.

6 The government budget constraint holds:

$$\tau_c C_t + \tau_k r_t A_t + T_{l,t} + (1+r_t)A_{b,t} + (1+n)B_{t+1} = G_t + (1+r_t)B_t + (1+r_t)A_{init,t} + Z_t + Tr_t, \tag{2.18}$$

where $T_{l,t}$ denotes labor income tax revenues, as given by

$$T_{l,t} = \sum_{s\in\{c,n\}} \sum_{j=1}^{j_r-1} \iiint_{\mathbb{X}(j,s)} \tau_l(y)y\phi(j,s,a,\theta,\eta)\, da\, d\theta\, d\eta, \tag{2.19}$$

with $y = (1-\tau_{t,s})w_{t,s}h_{s,j}(\theta,\eta)l(j,s,a,\theta,\eta)$, $A_{b,t}$ denotes accidental bequest:

$$A_{b,t} = \sum_{s\in\{c,n\}} \sum_{j=1}^{J} \iiint_{\mathbb{X}(j,s)} a'(j,s,a,\theta,\eta)(1-\psi_{j+1})\phi(j,s,a,\theta,\eta)\, da\, d\theta\, d\eta, \tag{2.20}$$

$A_{init,t}$ is the aggregate wealth transfer to the newly arrived generation:

$$A_{init,t} = \sum_{s\in\{c,n\}} \phi(1,s) \int_{\mathcal{A}} af(s,a)\, da, \tag{2.21}$$

where $\phi(1,s)$ is the measure of households at age one with college decision s and $f(s,a)$ is the distribution from which initial wealth is drawn, and Z_t is the aggregate education subsidies:

$$Z_t = \iint_{\mathcal{E}\times\mathcal{A}} \mathbb{1}_s(e,a)z\iota w_{t,c}\phi_0(e,a)\, da\, de. \tag{2.22}$$

7 The pension budget (2.2) holds.

8 Individual behaviors are consistent with aggregate behavior: measure ϕ is a fixed point of $\phi(X) = \Pi(X,\phi)$, for any $X \in \mathbb{X}$, where $\Pi(X,\cdot)$ is the transition function generated by the decision rules of households, the process of exogenous states, and the survival probabilities.

9 All aggregate variables are constant over time.

4 Calibration

This section discusses our parameter choices. We calibrate the model to the US economy. The majority of parameters are either estimated directly from the data or calibrated internally by matching certain aggregate moments in the US data. The rest of the parameters are taken from the literature. In addition, parameters that pertain to the education system and government policy are also estimated for Germany–these counterfactual values are then used in the policy experiments to assess the roles of various policy dimensions in shaping wage inequality. All parameter values are reported in Table 2.3 (parameter values for Germany are reported in parentheses).

4.1 Demographics

A period in the model corresponds to four years. New generations enter the economy at the age of 18. It takes four years to complete college. Households retire at the age of 66 and the maximum age is 94. In addition, the size of the population grows at a constant rate $n = 1\%$ annually, which is consistent with the long run population growth rate of the US. Survival probabilities $\{\psi_j\}$ are computed from the actuarial life tables for the US. Consistent with our focus on full time male workers, we consider survival probabilities for male workers. The reference year is 2011.

4.2 Preferences

We consider a fairly standard utility function

$$u(c, 1 - \mathbb{1}_s \xi(e) - l) = \frac{\left[c^{\nu}(1 - \mathbb{1}_s \xi(e) - l)^{1-\nu}\right]^{1-\frac{1}{\gamma}}}{1 - \frac{1}{\gamma}},$$

where ν is a taste parameter for consumption, $\frac{1}{\gamma}$ is risk aversion parameter. The two parameters ν and γ jointly determine (i) the average labor supply, (ii) the intertemporal elasticity of substitution of consumption, and (iii) the Frisch labor supply elasticity. γ is set to 0.5 (see, for example, Krueger and Ludwig (2016)). ν is chosen such that households on average work one-third of their time endowment. The subjective discount factor β is set so as to target a capital-output ratio of around 2.4, which falls in the range commonly used in the literature.

4.3 Technology

The aggregate production function is of Cobb-Douglas form. The capital share α is set to 0.33. Total factor productivity A is set to one. We set the elasticity of substitution between skilled labor and unskilled labor such that in equilibrium college wage premium is in line with the data. This leads to an elasticity of substitution of 1.5 – in accordance with the estimate in Katz and Murphy (1992) and Ciccone and Peri (2005). In addition, we set the annual depreciation rate to 7.55%, as in Krueger and Ludwig (2016).

4.4 Labor Productivity

Recall that the labor productivity of workers with education s and of age j is given by

$$h_{s,j} = \begin{cases} \epsilon_{s,j} \cdot \exp\left(\theta_s + \eta_{s,j}\right), & \text{if } j < j_r \\ 0, & \text{otherwise.} \end{cases}$$

To estimate the processes that govern labor productivity, we first run cross-sectional regressions of log earnings on education s and age j:

$$\ln(w_j) = f\left(X_j; x\right) + \tilde{w}_j, \tag{2.23}$$

where $f\left(X_j; x\right)$, a function of age and education, captures the life-cycle productivity profile, X_j is a vector of observables including education dummies and a cubic polynomial in age, and $\tilde{w}_j$ is a residual term. Estimates for $\epsilon_{s,j}$ are then obtained by normalizing $f\left(X_j; x\right)$ such that the mean labor productivity of skilled workers at age two–when college education is completed–is normalized to one. The residual term $\tilde{w}_{t,s}$ captures the fixed effect and stochastic component of the labor productivity process. More precisely, we consider the following process:

$$\begin{aligned} \tilde{w}_j &= \theta + \eta_j, \\ \eta_j &= \rho\eta_{j-1} + \epsilon_{\eta,j}. \end{aligned}$$

We estimate this process using the Panel Study of Income Dynamics data under the assumption that θ and $\epsilon_{\eta,j}$ are normaly distributed with mean zero and variance σ_θ and σ_η, respectively.[9] Our estimation strategy is similar to Guvenen et al. (2014), Karahan and Ozkan (2013) and Krueger and Ludwig (2016). The estimates are reported in Table 2.2. Then we approximate the AR(1) process that governs the evolution of η using a two-state Markov chain with transition matrix

$$\pi_{\eta,s} = \begin{bmatrix} p_s & 1 - p_s \\ 1 - p_s & p_s \end{bmatrix}.$$

The estimated Markov process is reported in Table 2.2.[10]

This leaves us with the fixed effect component of labor productivity. We assume that the skill-specific fixed effect θ_s takes on two values $\{\theta_{s,l}, \theta_{s,h}\}$ and that the probability of drawing a high fixed effect $\theta_{s,h}$ depends on one's ability. More precisely,

[9] We restrict the sample to male heads of households, aged 18-66, over the period 1978-2015. As of 1997, variables are available biennially. To minimize the impact of changes in hours worked, we consider only full-time full-year workers.

[10] We use the Rouwenhorst method. See Kopecky and Suen (2010) for a discussion of the Rouwenhorst method.

Table 2.2 – Estimates for the labor productivity process

	AR(1)		Markov Chain		
	ρ	σ^2_η	p_s	η_s	σ^2_θ
College	0.963	0.011	0.982	{-0.041, 0.041}	0.048
Non-college	0.926	0.019	0.963	{-0.050, 0.050}	0.065

we assume that

$$\pi(\theta_c = \theta_{c,h}|e) = e$$

and

$$\pi(\theta_n = \theta_{n,h}|e) = \omega e,$$

where ω is a parameter to be calibrated. Finally, we choose the free parameter ω such that the steady state of the model economy matches the college earnings premium of marginal students, which is primarily determined by ω, see, e.g., Findeisen and Sachs (2015) and Krueger and Ludwig (2016).

4.5 Education Costs and Subsidies

For the benchmark calibration, we assume that the fraction of educational costs borne by the government is the same for all individuals, regardless of their learning ability and financial situation.[11] To pin down the two parameters concerning the resource costs of college and government subsidies, ι and z, we rely on the data in Education at a Glance (OECD 2014, 2015). The year of reference is 2011. Table A7.3a(b) and Table A7.4a(b) (Education at a Glance, 2015) report, respectively, the private and public costs for a person attaining tertiary education. The private costs for a person attaining tertiary education are $55,000$ US dollars, while public costs stand at 55900 US dollars (in 2011 dollars).[12] From this, we can infer the fraction of resource costs borne by the US government: $z = \frac{55900}{55000+55900} = 0.504$. Since we concentrate only those who got a bachelor degree, we assume average college time is 4 years. Furthermore, GDP per capita in 2011 is 49791 dollars. Combining all information, we have:

$$\frac{\iota w_{t,c}}{\hat{Y}} = \frac{(55000 + 55900)/4}{49791} = 0.5568,$$

where $\hat{Y}$ denotes GDP per capita. We calibrate the cost parameter ι such that in the benchmark model the ratio of the resource costs of college to GDP per capita is

[11] Need-based grants and merit-based scholarships are considered later on as extensions.

[12] The cost of higher education is slightly lower in Germany– the private and public costs for a person attaining tertiary education are 5200 US dollars and 87500 US dollars, respectively.

0.5568.[13]

4.6 Initial Wealth Endowment

Heterogeneity in initial wealth in this paper is intended to capture the family income effects on college attendance. An appropriate calibration requires micro-level data on college expenses. Fortunately such data exist. To calibrate the initial wealth distribution, we use the Consumer Expenditure Survey (2015) public-use microdata (PUMD) collected by the US Bureau of Labor Statistics. The public-use microdata contains detailed data on college expenses such as tuition and fees.[14] After consolidating the data, we estimate the distribution of college expenses. This distribution is then used in the model for college-bound individuals to draw their initial wealth.[15] Since our focus is on initial transfers for educational purposes, those who do not go to college receive zero initial wealth.

4.7 Learning Ability and Time Costs of College

We assume that learning ability follows a truncated normal distribution over the unit interval. The probability density function is given by

$$\pi_e(e) = \frac{\psi_{sn}\left(\frac{e-\mu_e}{\sigma_e}\right)}{\sigma_e\left(\Psi\left(\frac{1-\mu_e}{\sigma_e}\right) - \Psi\left(-\frac{\mu_e}{\sigma_e}\right)\right)}, \tag{2.24}$$

where ψ_{sn} and Ψ denote, respectively, the probability density function and the cumulative distribution function of standard normal distribution, μ_e and σ_e denote the mean and the standard deviation of the un-truncated distribution. Without loss of generality, we set μ_e to 0.5. The standard deviation, σ_e, is chosen such that 95% of the probability mass falls in the unit interval.

In addition, we model the time cost of attending college as a parametric function of learning ability:

$$\xi(e) = \exp(-\lambda_e e), \tag{2.25}$$

where λ_e is a parameter. Given the specification for the distribution of learning ability, λ_e is chosen in an attempt to match tertiary education attainment in the data (see OECD (2018)).

[13] Our estimate of $\frac{\iota w_{t,c}}{\hat{Y}} = 0.5568$ is slightly lower than the estimate (0.694) in Krueger and Ludwig (2016).

[14] Student loan payments are not included as educational expenses.

[15] Initial endowment is expressed in terms of per capita GDP. When implementing this in the code, we start with an initial guess for GDP per capita and update it in each iteration.

4.8 Government Policy

We choose the government debt level and government spending to target a debt-to-GDP ratio of 60% and a government spending to GDP ratio of 19%, as observed in the data. The consumption tax rate is estimated from the U.S. National Income and Product Accounts data set, which gives rise to an estimate of $\tau_c = 7.3\%$. The capital income tax rate is taken from Chari and Kehoe (2006). Consistent with the current social security configuration, pension benefits are set to be 35% of the average income of each skill group, i.e., $\kappa_s = 35\%$. Payroll tax rate τ_p is then set to balance the budget. To estimate the two parameters associated with the labor income tax function m and λ, note that m is a natural measure of progressivity and λ governs the average tax rate (for a given m). More precisely, let $\tilde{y}$ denote the post-tax wage earnings, then $\tilde{y} = \lambda y^{1-m}$, where y is the pretax wage earnings. The elasticity of post-tax earnings to pre-tax earnings is then given by

$$\frac{d\tilde{y}/\tilde{y}}{dy/y} = 1 - m. \tag{2.26}$$

We rely on the estimates for m of OECD (see, Taxing Wages (2013), Table I.8.). λ is then chosen such that the average tax rate in the model is in line with the data.[16]

4.9 Borrowing Constraints

The borrowing constraint for age one is set such that college-bound individuals can finance up to a fraction, Φ, of their college tuition and fees with student loans:

$$\underline{\mathrm{A}}_j = \Phi(1 - z(e))\iota w_{t,c}.$$

Borrowing constraints for $j \geq 2$ are set such that borrowers repay at least a minimum amount, P, in each period, and that the loan is fully paid back by the age of retirement. More precisely, for $j = 2, 3, \cdots, j_r$:

$$\underline{\mathrm{A}}_j = (1 + r_t)\underline{\mathrm{A}}_{j-1} - P,$$

and $\underline{\mathrm{A}}_{j_r} = 0$.

To calibrate Φ, we rely on the National Postsecondary Student Aid Survey (2011-2012) from which we estimate an average loan size of $\$21,300$. We then choose Φ such that in equilibrium an average loan covers $\frac{21300}{55000}$ of the college costs borne by individuals.

[16] The average tax rate is 17.1% for the US.

Table 2.3 – Baseline Parameterization

Parameter	Description	Value
Calibrated externally		
Demographics		
n	Population growth rate (annually)	1%
ψ	Survival probabilities	Actuarial Lif
j_r	Retirement age (age 66)	13
J	Maximum age (94)	20
Preferences		
γ	Risk aversion parameter	0.5
Technology		
α	Capital share of output	0.33
A	Total factor productivity	1
δ	Depreciation rate (annually)	7.55%
Labor productivity		
$\epsilon_{s,j}$	Life-cycle productivity profile	Supplementary
θ_s	Fixed productivity effect	Table 2.2
η_s	Idiosyncratic productivity shocks	Table 2.2
ρ_s	Persistence parameter	Table 2.2
p_s	Transition probability	Table 2.2
Edu. costs and subsidies		
z	Subsidy rate	0.504 (0.944)
Ability and time cost of college		
μ_e	Mean of learning ability	0.5
σ_e	Standard deviation of learning ability	0.255
Government policy		
τ_c	Consumption tax	7.3% (19%)
τ_k	Capital income tax	28.3% (25%)
τ_p	Payroll tax	14% (33.7%)
κ_s	Pension benefits	45% (50%)
m	Progressivity	0.1 (0.27)
λ	Labor tax parameter	0.857
Calibrated Internally(**target**)		
Preferences		
ν	Parameter for leisure (hours worked)	0.374
β	Discount factor (K/Y)	0.985
ζ	Elasticity of substitution (college premium)	0.285
Labor productivity		
ω	Scale parameter (see Section 4.4)	0.850
Ability and time cost of college		
λ_e	Time cost parameter (college attainment)	0.5
Edu. costs and subsidies		
ι	Cost Parameter ($\frac{\iota w_c}{\hat{Y}}$)	0.316
Borrowing constraints		
Φ	Student loan parameter	0.38
ϑ	MP of skill levels ($\frac{w_c}{w_n}$)	0.417

Notes: Parameter values in parentheses are estimated from German data.

Table 2.4 – Model Fit

Description	Model	Data	Source
Targeted Moments			
College attainment	0.3	0.3	NCES
College wage premium	1.8	1.8	Heathcote et al. (2010a), Lee et al. (2015)
Capital-Output Ratio	2.7	2.7	Fernandez-Villaverde and Krueger (2011)
Average working time	0.4	0.4	PSID
Loans To College Cost	40%	40%	NCES
Non-targeted Moments			
G Expednditure to GDP ratio	0.7	0.7	World Bank

4.10 Model Fit

Finally, to examine how well the model fits the targeted moments I provide table 2.4. We observe that the model does a reasonably good job to match the data moments are well. The associated parameters are presented in table 2.3, lower panel.

5 Model Dynamics

Before conducting policy experiments and drawing policy conclusions, it is useful to first examine the model dynamics. In this section, we examine the life-cycle profiles of average earnings, consumption and labor supply by education, investigate the role of initial wealth in college attendance and look at the ability-composition of college students. In addition, this section shows that our model matches the earnings distribution remarkably well.

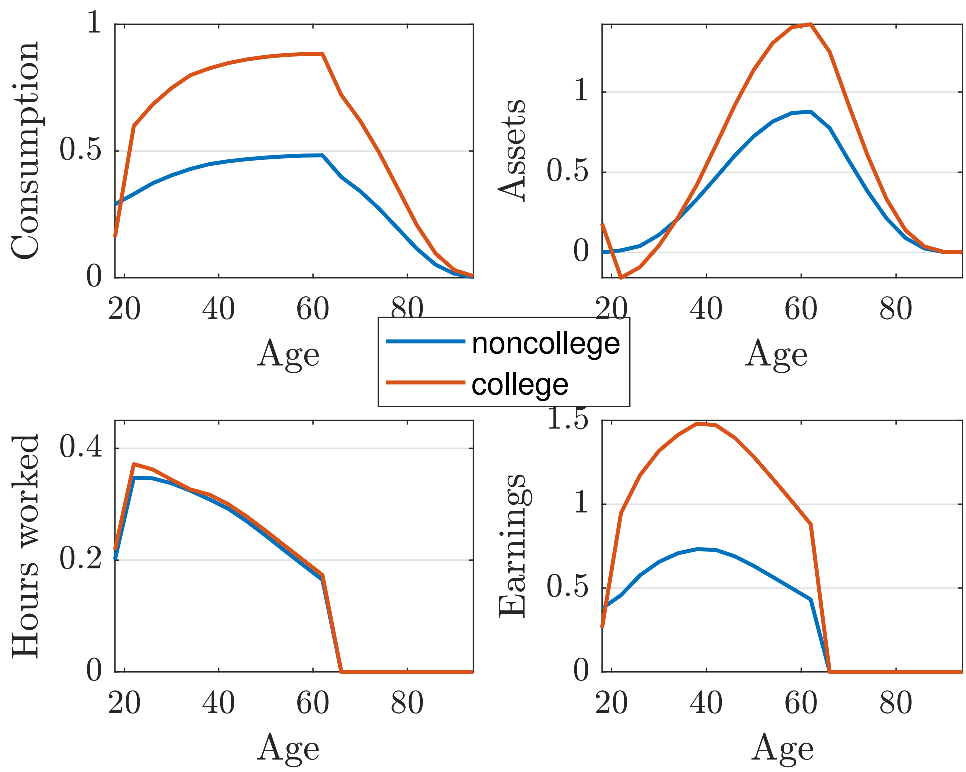
5.1 Life-Cycle Profiles

Figure 2.1 plots the life cycle profile of average consumption, asset holdings, hours worked and earnings for skilled workers and unskilled workers, respectively.
Consumption rises steadily over the working life for both skilled and unskilled workers. It dips slightly when workers retire because pension benefits are only a fraction of average earnings. Then consumption decreases gradually as they age and face rising death hazards.
Wealth exhibits the typical hump-shaped profile. For young households who are not attending college, initial wealth is slightly positive. College students, on the other hand, take out loans and therefore have negative wealth. On average, it takes about eight years to pay off student loans.
Labor supply does not differ much across skill types. At age one, when the young generation enters the economy, labor supply is low not only for college-bound households but also for non-college-bound households. For college students, the reason

is obvious because attending college takes time. For those who are not attending college, the relatively low level of labor supply reflects their low productivity, which is in line with the data.

Finally, the life cycle earnings profile also matches the data pretty well. Earnings are relatively low for young households as they enter the economy. College students don't have much time to work; those who are not attending college have low productivity. Earnings rise more rapidly for college-educated workers than unskilled workers. Average earnings decline gradually before retirement and drop to zero at the time of retirement. Tough the wage rate for college students is the same as unskilled workers, college students earn more than their non-college attending peers. This is because college students have higher probabilities of drawing a high fixed productivity effect θ (see Section 4.4) .

Figure 2.1 – Life cycle profile of average consumption, asset holdings, hours worked and earnings for skilled workers (blue) and unskilled workers (red), respectively.



5.2 Initial Wealth, Ability and College Attendance

Heterogeneity in initial wealth endowment is a shortcut to capture the family income effect on higher education attendance. It is calibrated to reflect heterogeneity in family contribution to higher education expenditures. From a policy maker's point of view, it is particularly important to know whether there are still high ability individuals left behind merely because they were born into low income families. For this reason, we plot the college decisions of households by learning ability and initial wealth endowment and the fraction of households in college by ability.

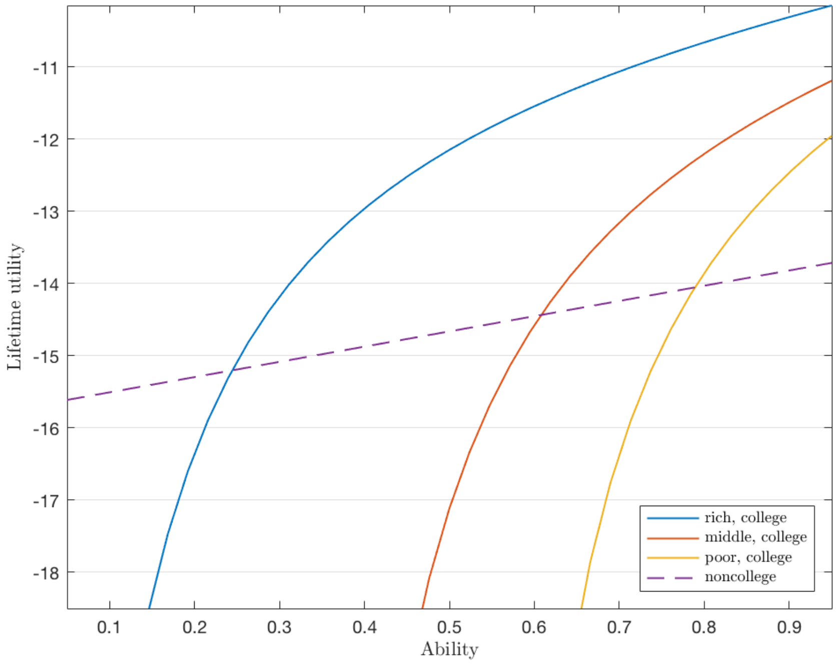
Figure 2.2 plots the expected lifetime utility of a household if it decides to attend college and receives an initial endowment at the 10th (yellow), 50th (red) and 90th (blue) percentile of the initial wealth distribution and the expected lifetime utility of the household if it decides not to attend college (dashed line). Since initial wealth endowment for non-college bound households is zero, they differ only in terms of learning ability. Household will attend college if and only if attending college delivers a higher expected lifetime utility. Figure 2.2 shows that even relatively low ability individuals can benefit from a college education if they can afford to do so.[17] On the other hand, some medium-high ability individuals with low initial wealth are unable to reap the benefits of college education. Figure 2.3 plots the fraction of college-age households in college by ability. It shows that a substantial fraction of medium- to high-ability households cannot afford to attend college although they would benefit from a college education.

Finally, to get a sense of the ability composition of college students, we also plot (see Figure 2.4) the cumulative fraction of college age individuals in college. It shows that, in the benchmark model, college students consist of mainly high and medium ability agents (consistent with the data), and that low ability individuals constitute only a small fraction of college students. The reason is twofold. First, assuming that ability follows a truncated normal distribution, low ability households constitute only a small fraction of the population. Second, for those low ability households, only a small fraction is rich enough to attend college. While high ability households can pay their way through college by working part time, this option is not viable for low ability households because they face higher time cost of college and earn less when working part time.

Later we will show that changes in government policy in general and education policy in particular would affect earnings inequality primarily through their effects on the ability composition of college students. We will also show that a well designed education policy can reduce earnings inequality without compromising efficiency.

[17] It is important to note that this is because college wage premium is high in the benchmark model. If medium and high ability households who cannot afford to go to college were enrolled into college through increased government financial aid, college wage premium would drop and low ability households would find it not optimal to go to college.

Figure 2.2 – Expected lifetime utility of a household if it decides to attend college and receives an initial endowment at the 10th (yellow), 50th (red) and 90th (blue) percentile of the initial wealth distribution and the expected lifetime utility of the household if its decides not to attend college (dashed line)



5.3 Validation Exercises

Earnings Inequality: Model vs Data

Since earnings inequality is a major variable of interest of this paper. It is therefore important to know how far the model can go in generating realistic earnings distribution. For this reason, we report two different measures of earnings inequality, wage ratios and Gini coefficients for wage income, and compare them with before tax earnings inequality observed in the data (Table 2.5).[18]

The benchmark model generates a Gini coefficient is in line with the one in the data. On the other hand, the model slightly overshoots overall earnings inequality when it is measured by the wage ratio between the 90th percentile and 10th percentile of the wage income distribution. But overall, the model does a reasonably good job in matching earnings inequality in the data.

[18]Both the Gini index and wage ratios are used in the literature to measure earnings inequality. The Gini index is typically a more robust measure since wage differentials are based on only two data points across the wage income distribution. Moreover, survey data on earnings are typically top-coded. Nonetheless we report both measures. See Burkhauser et al. (2009) for more discussions on different measures of inequality.

Figure 2.3 – Fraction in college by learning ability

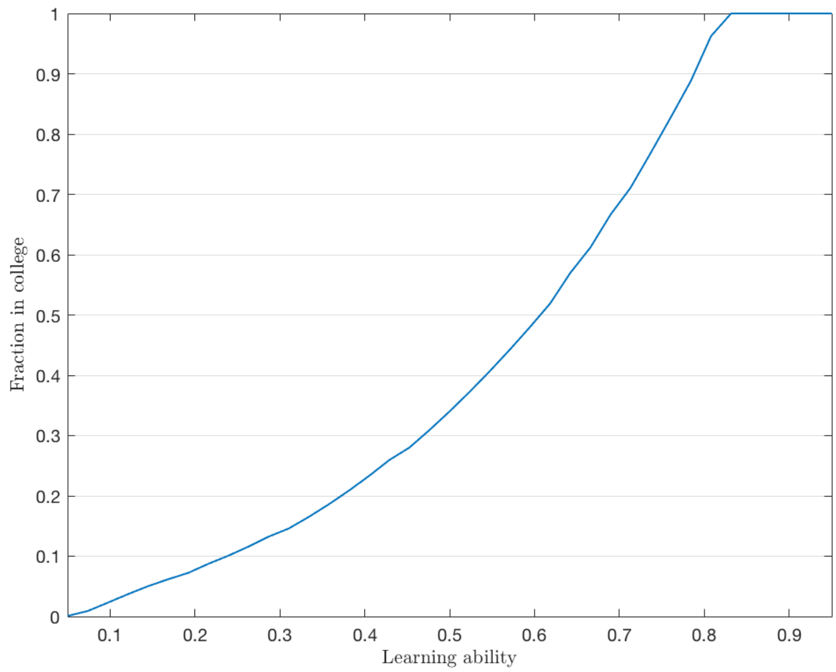
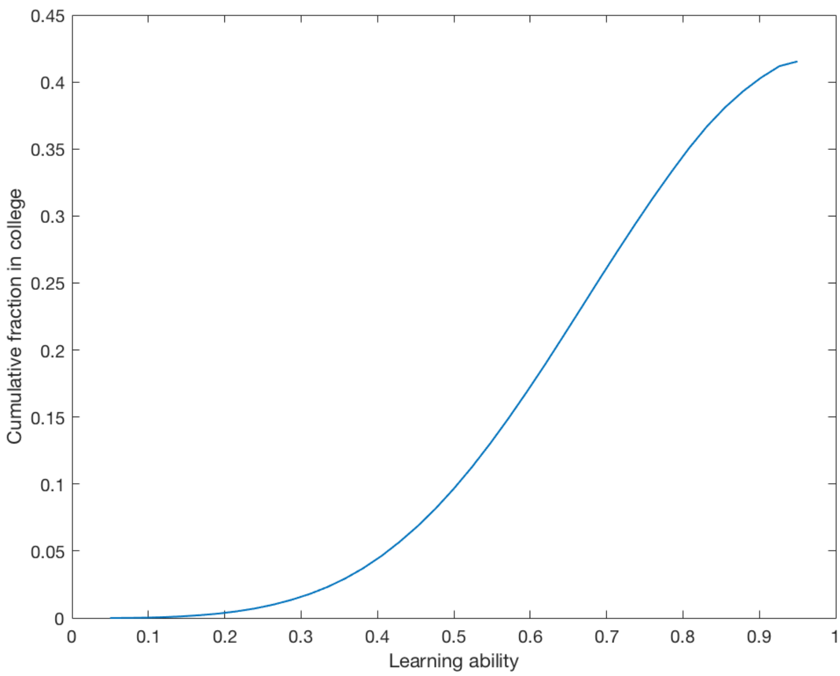


Figure 2.4 – Cumulative fraction of college age individuals in college



College Completion Elasticities to an Increase in Subsidies

Before we conduct counterfactual experiments, it is important to check whether the model generates reasonable college participation elasticities to change in col-

Table 2.5 – Earnings Inequality: Model vs Data

title	Model	Data	
Gini	0.36	0.36	PSID
P90-P10	5.57	5.33	PSID
P90-P50	2.24	2.32	PSID
P50-P10	2.49	2.3	PSID
$V(log(y))$	0.47	0.7	PSID
$V(log(w))$	0.37	0.46	PSID
$V(log(h))$	0.06	0.09	PSID

lege costs. There is large micro-empirical literature that quantifies response rates to changes in the price of education using natural experiments in different states. Dynarski (2003) summarizes this literature as follows: A $1,000 reduction in the cost of attending college (in the year 2000 prices) leads to a 3 to 5 percentage points increase in college completion.

We carry out the same experiment in the model as follows. We increase tuition subsidies by $1,000 in the partial equilibrium framework and quantify its impact on the enrollment margin. We find that the model generates values largely consistent with their empirical counterpart: in the short run college completion increases by 5.2%. A fraction that closely falls within the estimates.

Besides, we examine the long-run responsiveness to the increase in grants by the same amount. We quantify that the enrollment rates increase in the long run by 2.15%, a value 2.05 percentage points less compared with its partial equilibrium counterpart. This is driven by the fact that in the general equilibrium, college premium decreases with the share of college graduates increases. The less is the college premium, the less the incentive to enroll in college. As a result, there is less responsiveness to an increase in the subsidy rates in the long run. This indicates the importance of studying educational policies in the short-run (by means of transitional dynamics) as well as in the long run (steady-state analysis), which is implemented below.

6 Policy Experiments

To evaluate the roles of the various aspects of government policy in shaping earnings inequality, we conduct several policy experiments. First, we replace the benchmark education subsidy rate with the one estimated from German data. To allow for the crowding-out effect of increased government subsidies for higher education, we implement couple of robustness checks, for example, we consider the extreme case that initial wealth transfers completely vanish. Relaxing this assumption can only strengthen the role of education policy.[19] Second, keeping everything else unchanged, we replace the benchmark labor income tax progressivity parameter with the one estimated for Germany. This experiment allows us to evaluate the role of tax progressivity in shaping income inequality. Finally, we also consider deviations from the benchmark along policy dimensions other than education policy and tax progressivity. In each of these experiments, the government budget is balanced through the flat part of income tax schedule, λ. We report the results of these policy experiments in this section.

6.1 Crowding out parental transfers

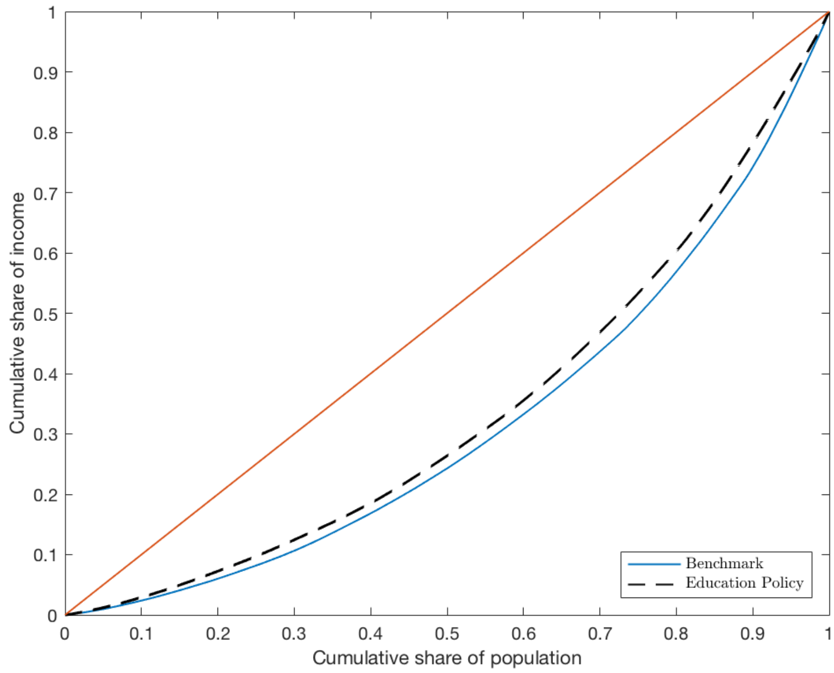
Literature indicates that parents' transfers are elastic to the subsidy policies. Therefore, in our robustness analysis, we follow **?** to pin down the average size of parental transfers that would crowd out under the hypothetical education policy. **?** find that, on average, increase subsidies by 1 dollar crowds out 35 cents of transfers. Therefore, during the education reform, we assume that as a response to the increased government subsidies, parental transfers will be crowded out by $(0.35(z^{new} - z))\iota w_c$. In the appendix, we also suggest a case when the initial wealth for students completely vanish. It worth noting that the qualitative results of the paper remains the same across these counterfactuals.

6.2 Education Inequality and Earnings Inequality

In this subsection, we examine the roles of various policy dimensions in driving college attendance and consequently in shaping earnings inequality. In Table 2.6, we report college attendance and various measures of earnings inequality for the benchmark model as well as for model variants under the policy experiments. We first report the results for the benchmark model (2nd column). Then we report the results for the education policy experiment (3rd column), where we replace the status quo subsidy rate (z) with its counterpart estimated from German data. In the fourth column, we report results for the model variant where we only change the labor income tax progressivity parameter (m) and keep other policy dimensions the same as in the benchmark. In the fifth column, we report results for the experiment in which we change both the college subsidy rate and labor tax progressivity. Finally, we report results for the experiment where we change other policy dimensions other than education policy and labor income tax, including capital income tax and consumption tax. The numbers below each measure are percentage reductions in the respective measure of earnings inequality from the benchmark model. A negative number therefore indicates an increase in that measure.

[19] see discussion in appendix H.

Figure 2.5 – Lorenz curve under the benchmark model (solid blue line) and the education policy experiment (dashed line).



The results suggest that raising the college subsidy rate from the US status quo to the German level would reduce earnings inequality, as measured by the Gini index, by as much as 7% (see also Figure 2.5). It would greatly boost college attendance– from 32% to 47%. Besides, such a move would shift the ability composition of college students. Figure 2.6 shows the fraction of college-age households in college in the benchmark model (solid line) and that in the counterfactual experiment (dashed line) where education subsidy is raised to the German level. We observe free education ultimately leads to a better skill allocation into college: while under the current policy low ability individuals with sufficient initial wealth choose to go to college, under the policy reform, only individuals with medium and high ability would go to college. Improving ability sorting at college is driven by two factors: first, education is affordable for individuals at any family wealth background, thus, high ability and poor individuals now can afford college (improving sorting at the upper half of ability distribution). Second, the marginal return of college decreases in the general equilibrium, and youth from rich families with lower ability would not find it optimal to go to college (improving sorting at the lower half of ability distribution).

Interestingly, such a reform would not only have distributional gains, in the next section, we will show that it would also lead to more efficient aggregate outcomes in

Table 2.6 – Policy Experiment Results

	Benchmark	Education	Progressivity	Edu. & Prog.	Other Taxes
Gini	35.6	33.2	35.7	33.7	36.1
%Δ	0	-6.8	0.2	-5.5	1.3
P90-P10	5.8	5.7	5.7	5.8	5.8
%Δ	0	-2.1	-1.9	-0.3	-0.4
P90-P50	2.3	2.3	2.3	2.3	2.3
%Δ	0	0.6	0.3	1	0.3
P50-P10	2.6	2.5	2.5	2.5	2.5
%Δ	0	-2.6	-2.2	-1.3	-0.7
log var. of wages	4.6	4.6	4	4.1	3.8
%Δ	0	1.2	-12.1	-10	-15.6
log var. of hours	36.9	32.4	37.4	33.8	37.5
%Δ	0	-12.3	1.4	-8.6	1.6
log var. of earnings	45.3	40.4	44.9	40.9	46
%Δ	0	-10.9	-1	-9.7	1.5
College Attainments	32%	47%	30%	43%	30%

the long run.

On the other hand, increasing labor tax progressivity has a negligible impact on inequality. For example, replacing the US status quo progressivity with its German counterpart can increase earnings inequality by 0.17%, the result which is solely driven by the fact that with a higher progressivity the flat tax rate is increasing, and therefore less poor people can afford college. This slightly increase college wage premium, and therefore slightly increases inequality (though the increase is negligible).

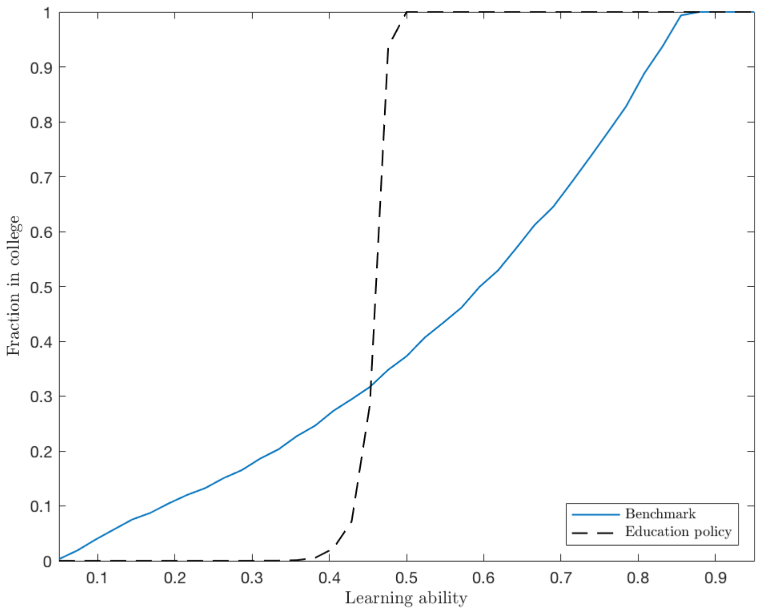
This finding is in stark contrast to Guvenen et al. (2014), who single out labor tax progressivity as the most important determinant of earnings inequality. Guvenen et al. (2014) consider a model with complete markets. The price of human capital in their modeling is the same across countries and is normalized to be 1. Thus they are silent on the role of education affordability. Moreover, they consider a partial equilibrium, and in this framework, increasing progressivity does not allow a channel that allows our general equilibrium model. Keeping everything else constant, more progressivity implies less investment in human capital, which on the other hand, increases the equilibrium college wage premium. As a result, increasing tax progressivity does not lead to lower income inequality.

Moreover, increased labor tax progressivity necessarily leads to lower economic efficiency, a topic we will address in the next subsection.[20]

[20] In the robustness check, our results suggest more progressive labor income tax may increase college attendance, if we keep the status-quo flat tax rate, τ_w, as in the benchmark, and close the government budget by transfers. The reason is that the additional government

The model findings suggest that price of education can be the major determinant of income inequality across countries. In contrast with the existing literature, we find that labor tax progressivity plays a less significant role in explaining earnings inequality compared with the price of education. In the next subsection, we show that education policy can partially offset the distortion of increased labor tax progressivity.

Figure 2.6 – Fraction of college-age households in college: education reform (dashed line) vs the benchmark (solid line).



6.3 Equality, Efficiency and Welfare

In the previous subsection, we focus on the importance of various policies in shaping earnings inequality. In this subsection, we bring the other component of social welfare, efficiency, into the picture, and examine the welfare gains of each policy reform.

Table 2.7 reports a few key macroeconomic variables under the benchmark and deviations from it along the education policy dimension and the labor income tax dimension. Three observations can be made. First, raising government spending on education not only reduces earnings inequality, it also increases macroeconomic efficiency: output, aggregate labor (in efficiency units), capital and aggregate consumption are higher than those in the benchmark. Second, not surprisingly, more

revenues are transferred to households in a lump-sum manner, which can be used by credit-constrained young households to finance college education. However, even so, the change in earnings inequality is less than 2%.

progressive labor income taxes not only increase earnings inequality but also lead to greater distortions: workers work fewer hours, and output, capital stock and aggregate labor (in efficiency units) are lower compared with the benchmark. Third, higher subsidies for higher education partially offset the distortions induced by progressive labor taxation. This is not because higher subsidies provide workers better incentives to work, but rather because higher subsidies for education boost labor productivity through increased college attendance.
Table 2.8 reports the welfare gains of each hypothetical policy reform relative to the benchmark. It shows that, in line with Krueger and Ludwig (2016), a combination of more generous subsidies for college and more progressive labor income taxation is most desirable in terms of social welfare. Specifically, replacing the college subsidy rate and labor tax progressivity with their German counterparts would increase social welfare by an amount equivalent to a 9% increase in consumption.

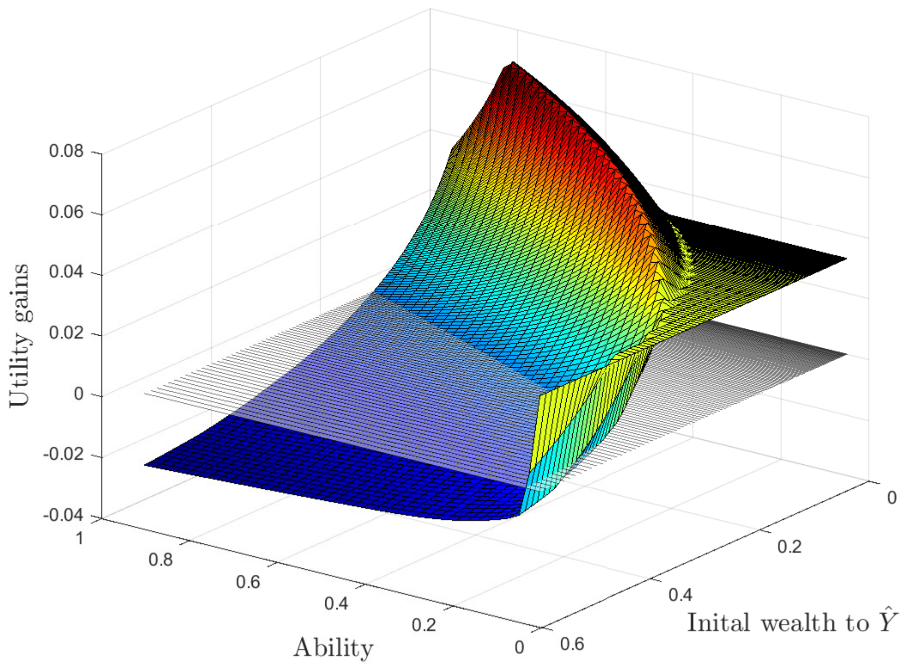
Table 2.7 – Macroeconomic variables under the benchmark and deviations from it along the education policy dimension and the labor income tax dimension. The number below each variable is the percentage increase of that variable relative to the benchmark.

	Benchmark	Education	Progressivity	Edu. & Prog.	Other Taxes
Enrollment rates	0.32	0.47	0.30	0.43	0.30
Wage Premium	1.7	1.4	1.8	1.5	1.8
Δ in Enrollment rates	0	45.4	-5.5	33.4	-7.6
Δ Wage premium	0	-17.1	2.5	-13.2	3.5
Output, $\hat{Y}$	0	7.3	-8.9	-2.8	3
Capital, $\hat{K}$	0	6.8	-8.1	-2.4	8.8
Consumption, $\hat{C}$	0	6.5	-8.9	-3.4	0.7
Efficiency units, $\hat{L}$	0	7.6	-9.3	-3	-0.1
Hours, $\hat{H}$	0	-1.5	-7.9	-9.1	1.3
interest rate, r	0	1.1	-2	-1	-12.2
G edu	0	192.1	-13.9	143	-4.9
G edu/GDP	0	172.3	-5.5	149.9	-7.6
Flat rate, τ_w	0	16.3	-3	12.2	-83.6

Table 2.8 – Social Welfare. The first row reports the welfare gains, in consumption equivalent terms, of each hypothetical policy reform compared with the benchmark. The second row reports the welfare gains, in Hicksian equivalent terms, of each hypothetical policy reform compared with the benchmark

	Benchmark	Education Policy	Progressivity	Edu. & Prog.
Consumption Equivalence	7.62%	2.68%	9.09%	1.06%
Hicksian Equivalence	2.78%	0.99%	3.31%	0.39%

Figure 2.7 – Welfare gains, in Consumption equivalent variation, from the hypothetical education policy reform.



6.4 Winners and Losers

In this subsection, we examine the winners and losers of increased government subsidies for college. For this purpose, we plot the welfare gains, in consumption-equivalent terms, from the hypothetical education policy reform (see Figure 2.7). It shows that poor households with medium and medium-high ability would benefit the most from increased government subsidies for college: this group would enjoy an increase in life-time utility equivalent to an increase in consumption by as much as 8%. Those are the households that cannot afford to go to college in the benchmark, although they would benefit greatly from a college education. Somewhat surprisingly, low ability households would also benefit from the hypothetical education policy reform, albeit for different reasons. They don't go to college anyway. But when more households attend college, the college wage premium decreases. Unskilled workers become relatively scarcer and thus enjoy a higher wage rate. Finally, our results suggest that a small fraction of rich and high-ability households would lose out from the hypothetical education policy reform due to compressed college wage premium. However, the utility loss they would suffer is relatively small. For example, a household with an initial wealth at the 90th percentile of the initial wealth distribution and a learning ability at the 99th percentile of the ability distribution would suffer a utility loss equivalent to a 2.3% decrease in consumption.

7 Transitional Dynamics

In this section, we examine the transitional dynamics of the education reform.[21] Our focus is to evaluate the time frame of the transition period and how the current and future generations are affected by the policy in terms of consumption equivalent variation of welfare. Afterward, we examine how the macroeconomic aggregates evolve along the transitional path.

We assume that the economy is in the benchmark steady-state when the education policy, raising college subsidies from 50.4% to 94.4%, is unexpectedly implemented. Along with the change, the government adjusts the labor income tax rate, λ, to balance the budget in each period. The policy is known to remain in place forever.[22]

We examine the dynamics of welfare in terms of consumption equivalent variation along the transitional path. Figure 2.8 shows the CEV welfare gains for both the current and future cohorts, with cohort 0 being the first cohort to be affected. For the current generations, we evaluate the average equivalent variation per cohort, while for the future generations, we report the ex-ante equivalent variation.

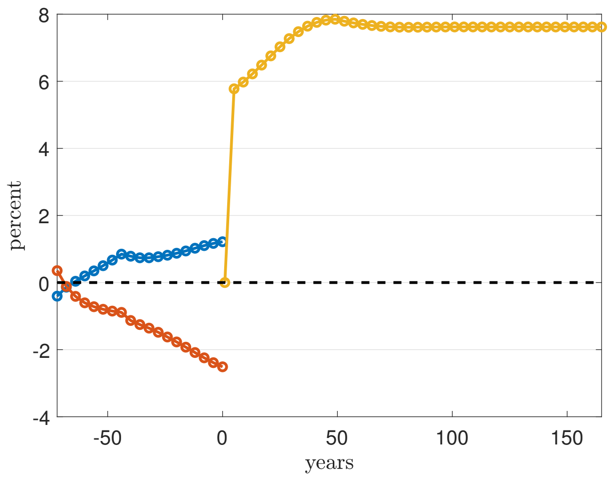
The first cohort that experiences free education, as shown in Figure 2.8, obtains welfare gains of 6%, about 80% of the gains obtained by the cohorts born in the new (free education) steady state. That implies that the policy can generate significant welfare improvement in the short run. Welfare gains grow slow cohort-by-cohort until it converges to its new steady-state value of 7.68%, which happens in about 55 years. The increasing profile of welfare along the transition is driven by the following: over time, the fraction of college-educated individuals in the whole population increases. That increases overall labor productivity and, consequently, the output. The larger output is to be shared more equally among ex-ante identical individuals through the decreasing gap in the relative wages between skilled and non-skilled workers.

The current generations, depending on their education status, experience dissimilar welfare effects. Particularly, the college-educated cohort loses out, whereas non-college educated benefits. The intuition is as follows: college-educated cohort paid high tuition fees in seek of high college returns. However, unexpectedly, the college wage premium starts to decrease. The average loss in their welfare is small, and it does not exceed 2.5%. On the other hand, those who belong to the unskilled labor at the point of the policy announcement enjoy the policy reform (up to 2% in terms

[21] Krueger and Ludwig (2016) finds that taking into account explicitly the transitional dynamics might overturn conclusions about the optimality of a particular governmental policy that is based only on the steady-state analysis.

[22] Furthermore, with the policy change, in the robustness check, we study the dynamics when the initial wealth of students is crowd out, as it was discussed in the steady-state analysis above. The qualitative results remain the same.

Figure 2.8 – Welfare Gains of Current and Future Cohorts



(a) Welfare gains for cohorts born after the policy is introduced (i.e., cohorts from 0 on) as well as for cohorts already alive at such time (i.e., cohorts less than 0). For the first group, welfare gains are computed for newborns. For the cohorts already alive at the time the reform is introduced, welfare gains are computed with (i) the same age and with (ii) the same education status. For example, -50 is the agents who are 50 years old in the reform period. Red line denotes welfare gains (losses) of college educated currently alive cohorts, while black dot-line denotes the welfare gains (losses) of non-college educated currently alive cohorts

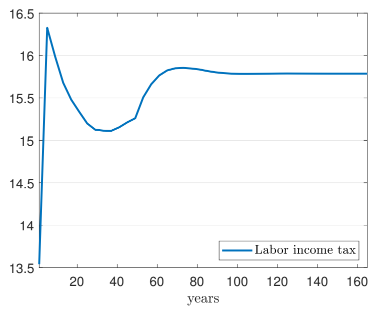
of CEV welfare) due to the same wage effects: they experience increasing relative non-college wage rates. Naturally, the younger is the college-educated (non-college educated) cohort at the point of the policy announcement, the bigger is the loss (gains) in their welfare, which is captured in figure 2.8.

Next, we examine how an aggregate efficiency along the transition path is affected by the education reform. For that purpose, first, we calculate the labor tax rate that is required to finance the reform. Second, we examine the evolution of macroeconomic aggregates.

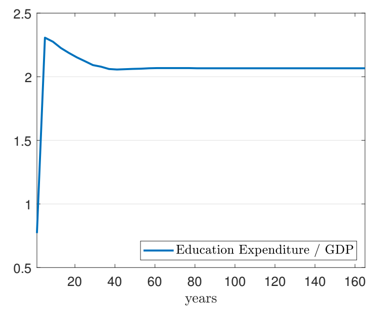
After the policy announcement, the labor tax rate increases from 13.6% to 16.4%, however, in about 2 periods (10 years) it reduces by 1.5 percentage points. The tax rate stabilizies in around 90 years at the rate of 15.79% (see panel (a) figure 2.9). Besides, the total government expenditures on education as a fraction of GDP increases up to 2.3% in the short run, and afterward, it decreases to 2.2%, as shown in panel (b), Figure 2.9.

The fact that government expenditure on education as a share of GDP exhibits hump-shaped behavior is a result of two effects: (1) after the policy announcement, there is a college boom, and the government needs to finance a way more students at

Figure 2.9 – Wage income tax and Governmental Expenditure in Education as a Fraction of GDP



(a)



(b)

college.[23] Over time the share of college entrants decreases slowly hand in hand with the decrease of college wage premium toward its new steady-state value; (2) At the same time, the average GDP increases over time as the share of college-educated in the labor force increases. The first effect decreases the nominator, the second effect increases the denominator, resulting in decreasing profile of government expenditure on education to GDP ratio.

Finally, we examine the macroeconomic aggregates in Figure 2.10. The effects of the increased taxes are reflected in lower consumption in the first few periods (about 6%). However, after already a few years, it starts to rise again. Overall, the consumption decline lasts about 13 years. Aggregate GDP drops by less than 1%. Moreover, it recovers faster, and in about 13 years, it becomes higher than in the initial steady state.

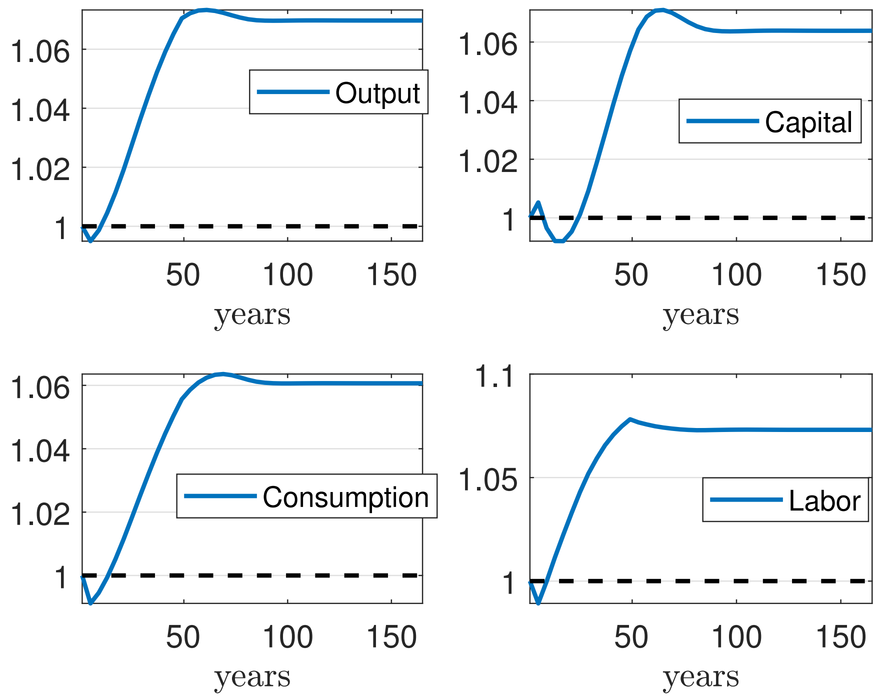
To summarize the analysis of the transitional dynamics, the economy would gain from the policy reform: a slight recession at the beginning is followed by the fast recovery of the macro aggregates, that starts 8 years after the reform, and eventually, outperforms the initial steady-state in less than 15 years.

8 Conclusion

We study the role of education affordability in shaping earnings inequality in the context of an overlapping generations model. We find that earnings inequality, as measured by the Gini coefficient for before-tax gross earnings, would decrease by as much of 6.7 percent if the current education policy, the share of higher education costs borne by the government, were replaced with its German counterpart. Two groups of households would benefit from the hypothetical policy reform. First, poor households with medium and medium-high ability would benefit the most from

[23]The evolution of college entrants are plot 2.11 in appendix G.

Figure 2.10 – Macroeconomic Aggregates along the Transition



increased government subsidies for college. Those are the households that cannot afford to go to college in the benchmark, although they would benefit greatly from a college education. Second, households of low ability would also benefit from the hypothetical education policy reform, albeit for different reasons. They do not go to college anyway. Nevertheless, when more households attend college, the college wage premium decreases. Unskilled workers become relatively scarcer and thus enjoy a higher wage rate. On the other hand, our results suggest that a small fraction of wealthy and high-ability households would lose out from the hypothetical education policy reform due to compressed college wage premium. In line with the literature, we find that a combination of more generous subsidies for college and more progressive labor income taxation is most desirable in terms of social welfare. Finally, in contrast with the existing literature, we find that labor tax progressivity plays a less significant role in explaining earnings inequality compared to the high price of education. Therefore, if the goal is to reduce income inequality while preserving efficiency, the more generous tertiary education subsidy is an effective tool to achieve that.

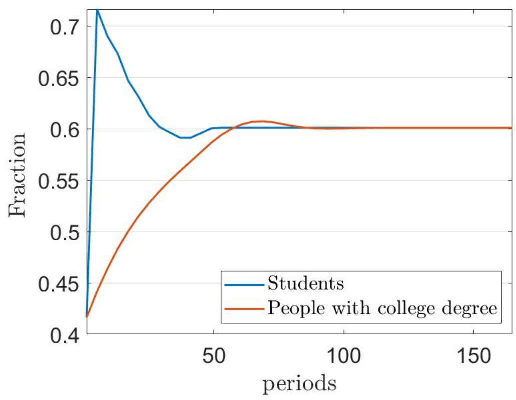
G Transitions

College demand, wage premium and earnings inequality

Figures 2.11 exhibits the evolution of college demand after the policy announcement. Not surprisingly, in the first period of the reform, the college demand spikes by as much as 30pp due to high college wage premium and reduced tuition. However, along with the transition, an adjustment in skill prices parallels the increased demand for college. The fraction of the educated population increases slowly, and correspondingly the college wage premium decreases. In about 48 years, three-fifths of individuals are college-educated, i.e., 18.46 percentage points higher than it was in a status-quo economy.

Figure 2.12 exhibits the deviation of the skill prices from its initial steady-state along with the transition: college wage decreases by 20.18%, noncollege wage increases by 37.78%.

Figure 2.11 – Fraction of (i) student age population going to college (blue), (ii) total population going to college (red)



Decreasing college wage premium translates into decreasing income inequality, which after 12 period decreases by 14.6%. Figure 2.13 presents Gini indexes of labor income, consumption, and wealth along with the transition.

H The importance of parental transfers in post-secondary education outcomes

This section determines the role of initial wealth in this model environment. For that purpose, we examine how education policy would allocate skills in the absence of crowding out effects of initial wealth.

Figure 2.14 depicts how students initial wealth affect ability selection into college.

Figure 2.12 – Changes in wages compared to the benchmark. College wage(red), noncollege wage (blue)

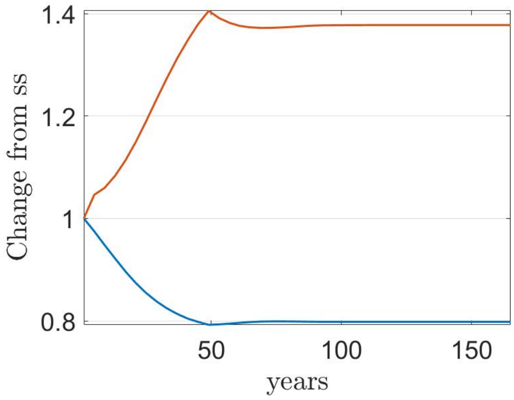
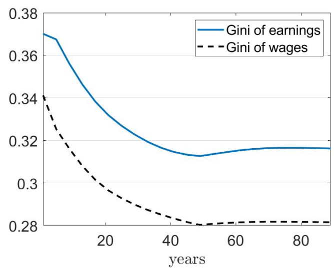
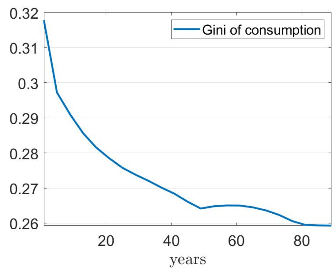


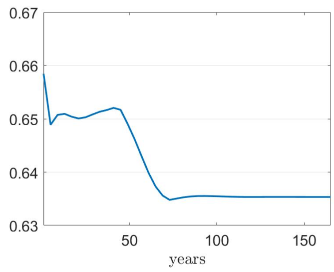
Figure 2.13 – Transitional dynamics of inequality determinants



(a) Wage income inequality, (blue), wage inequality (red)



(b) Consumption inequality, gini index

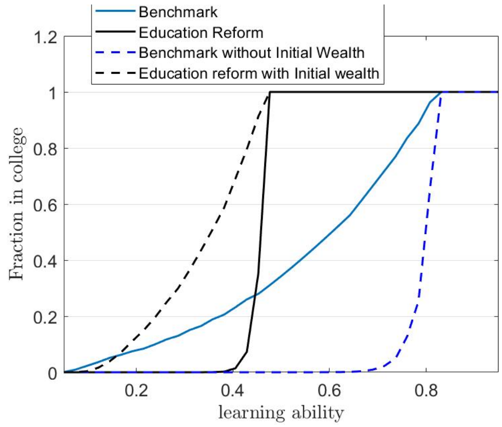


(c) Wealth Inequality, gini index

First, we examine the benchmark economy (solid blue line) and the economy when students do not get initial transfers, keeping everything else the same as in the benchmark scenario (dashed blue line). We observe in the absence of initial transfers only students from the highest quintile ability distribution can afford to go to college: i.e., without family wealth effects selection into college improves, however, at the expense of lower graduation rates.

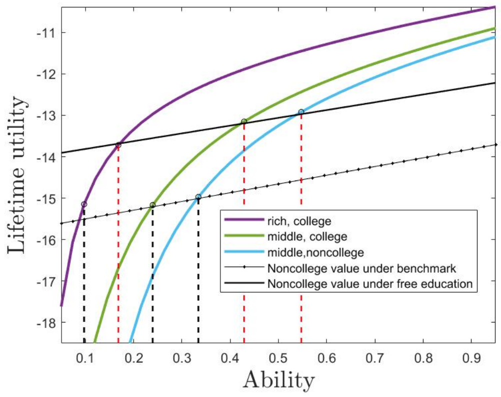
Under the educational policy, we saw that the selection improves, shifting the blue dashed line to the left (solid black line): individuals from the top three ability

Figure 2.14 – Fraction of college-age households in college: education reform (dashed line) vs the benchmark (solid line).



quintiles now find it optimal to go to college. However, here we assumed that initial wealth is crowd out. In the scenario, when we allow students to have the same initial wealth as in the benchmark economy sorting into college worsens: the top three quintiles still go to college, however, also some lower ability students find it optimal to enroll college (dashed black line), who are motivated to do so just because they are rich.

Figure 2.15 – Lifetime utilities with keeping parental transfers distribution as in benchmark.



(a) This figure plots the life-time utilities of going to college under education policy without allowing parents to crowd out the transfers (Purple line for rich, green line for medium, and blue line for poor youth). It also plots life-time values of non-college (1) benchmark economy (dotted straight line), (2), under education reform. everyone with ability above 35 percentiles would go to college if parental transfers as well as the noncollege value function would stay as in the benchmark. Just because under the education policy the value of noncollege increases, this mechanism makes ability threshold above which college is attractive shift upward from 35th percentile to 55th percentile.

(b) how free education shifts noncollege value function upward. Implying, if noncollege value function did not increase, and the parents did not crowd out the transfers, everyone above 0.35 ability would find it optimal to go to college. Given the increase in noncollege value function, everyone above 0.55 go to college.

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Chapter 3

Larger transfers financed with more progressive taxes? On the optimal design of taxes and transfers

joint with Axelle Ferriere, Philipp Grübener, Gaston Navarro [1]

1 Introduction

High economic inequality in the U.S. has put redistributive policies at the heart of the policy debate. The U.S. fiscal system redistributes through two main instruments: a progressive income tax and a rich set of means-tested transfers. Both components significantly alter the after-tax-and-transfer income distribution, as shown in Figure 3.1. Means-tested transfers account for about a fifth of households' income in the bottom income quintile. In contrast, income taxes paid by households in the top quintile reduce their income by more than a quarter.

In this paper, we study the optimal joint design of taxes and transfers. Both progressive income taxes and means-tested transfers are powerful tools to redistribute resources across households, but they also create efficiency costs. Large income tax progressivity implies high marginal tax rates at the top, which lower labor supply of the most productive households. Large transfers generate a heavy fiscal burden,

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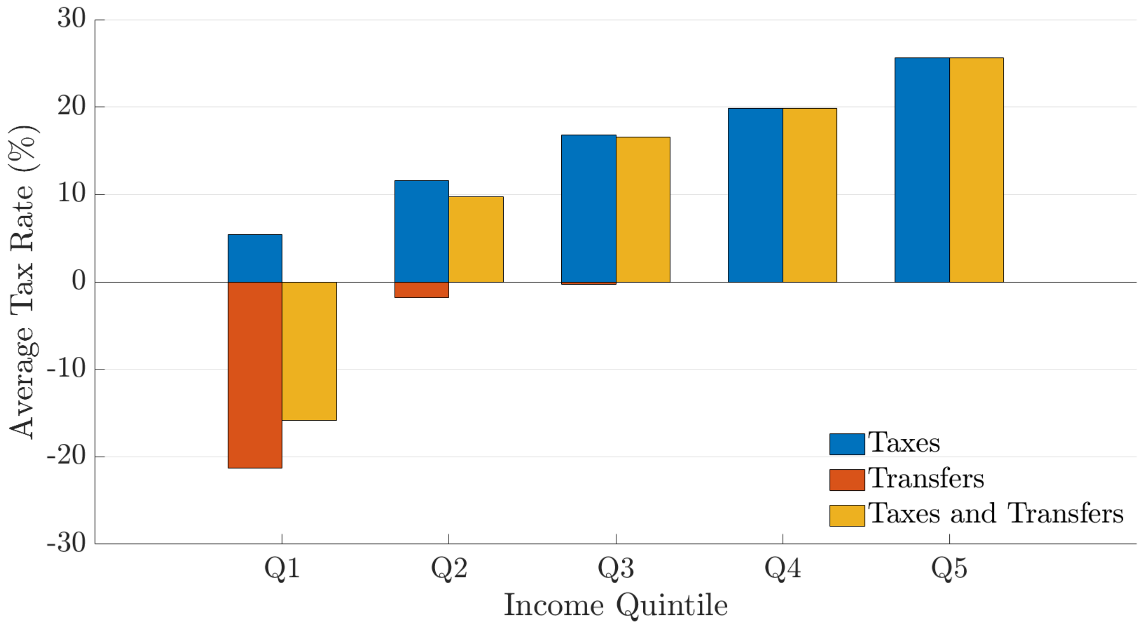
Figure 3.1 – Redistribution in the United States



Notes: This figure shows taxes and transfers by income quintile in the US. Taxes include individual income taxes, payroll taxes, excise taxes, and corporate taxes. Transfers include programs for the purpose of income security such as SNAP and TANF. Authors' calculations on basis of data from the Congressional Budget Office for the working age population.

to be financed with distortionary income taxes. Overall, what should be the joint optimal tax progressivity and generosity of transfers? Should transfers be more generous compared to the current U.S. system? If so, who should face higher tax rates to finance these larger transfers?

To answer these questions, we first build intuition in a simple, analytically tractable model, and then quantify the key trade-offs in a rich heterogeneous-agent model. A central insight throughout the analysis is that optimal income tax progressivity is decreasing in the size of transfers. This negative relationship between tax progressivity and transfers emerges for both redistribution and efficiency reasons. First, large transfers provide redistribution, reducing the value of a further reduction in inequality through more progressive taxes. Second, large transfers increase the fiscal burden; to increase tax revenues, it is efficient to incentivize high labor supply of the most productive households with lower marginal tax rates at the top. Quantitatively, given the large inequality in income and wealth in the U.S. we find that optimal transfers are large and phase-out slowly. The income tax schedule used to finance these large transfers is only moderately progressive, thereby preserving labor supply incentives and easing the financing of a large welfare state.

We start our analysis with an analytically tractable model, following Heathcote et al. (2017). A continuum of ex-ante homogeneous workers chooses consumption and labor supply subject to idiosyncratic income shocks, and a government has a loglinear tax schedule as its only policy instrument. In this case, a progressive tax schedule is desirable as the welfare gains of lower consumption inequality outweigh the efficiency costs of progressive taxation in the form of lower labor supply. We then extend this tractable framework by endowing the government with a lump-sum transfer as an additional instrument. We derive a closed-form formula for welfare based on local approximations around zero transfers and obtain two analytical results. First, for realistic levels of income inequality, transfers should be positive. Second, higher transfers reduce the optimal income tax progressivity. This optimal negative relationship between income tax progressivity and transfers exists for both redistribution and efficiency reasons, as the welfare formula transparently shows. Lump-sum transfers already provide redistribution to the poor, reducing the redistributive gains of more progressive income taxes. Furthermore, larger transfers increase the fiscal burden, which raises efficiency concerns. These efficiency concerns are amplified by the fact that generous transfers are a force for lower labor supply themselves. Consequently, larger levels of spending on transfers are optimally financed with lower income tax progressivity to incentivize labor supply. While the analytical results are based on approximations, we quantitatively confirm them by numerically solving for the optimal combination of lump-sum transfers and loglinear taxes in the simple model. We find that redistribution should be achieved with generous transfers while efficiency should be preserved via less progressive income taxes. As such, the optimal tax-and-transfer system implies very progressive average tax rates while marginal tax rates actually turn out regressive.

Having established the intuition for the optimal relation between transfers and the progressivity of the tax rates schedule, we turn to our second question: what should the optimal level of transfers and the tax progressivity be relative to the current U.S. system? We answer this question using a quantitative heterogeneous agent model. For the quantitative analysis we propose new functional forms to closely approximate the two main components of the U.S. fiscal system: progressive income taxes and targeted transfers. In contrast to the loglinear specification, our proposed income tax function is bounded below by zero, in line with the statutory income tax rates in the United States. For the transfer function, we use a logistic functional form, which captures both the level and the phasing-out patterns of the current U.S. transfer system when appropriately parameterized. While tractable, these parameterized functional forms are flexible enough to explore a wide variety of shapes of the tax-and-transfer system. The tax reforms we consider are once-and-for-all changes to the tax-and-transfer system. After a tax reform the economy slowly moves towards a new steady state and for the computation of welfare we take into account the entire transition.

For the quantitative analysis, we proceed with two versions of the quantitative model. First, we compute the optimal tax-and-transfer system in a standard incomplete-market model à la Aiyagari (1994) with endogenous labor supply. Restricting the transfers to be lump-sum, we find that the optimal transfer should be large, and financed with moderately regressive taxes. This result is in line with the intuition built in the analytical model: the optimal system is very progressive in average tax rates, but regressive in marginal tax rates. It leads to large welfare gains because the lowest income, asset poor households gain a lot, as do asset rich households who benefit from higher interest rates. Overall, a majority of households supports the reform. Taking into account transitions increases the size of the optimal transfer, but does not alter the negative optimal relationship between tax progressivity and transfers. We then allow the government to phase-out the transfers, which moderately improves welfare further, because it allows for non-monotonic marginal tax rates. In contrast, restricting the government to use a loglinear function only to approximate the entire tax-and-transfer system significantly deteriorates welfare, suggesting that the tight link between marginal and average tax rates imposed by this tax function is severely restrictive.

The standard incomplete-market model is consistent with our analytical model but does not replicate well the concentration of income and wealth at the top that we observe in U.S. data. Therefore, we extend the model in three dimensions to better quantify the redistributive and insurance needs in the U.S. economy. First, we add a Pareto tail to the productivity distribution to better match the concentration of income at the top. Second, we incorporate unemployment risk to appropriately capture the dynamics of the income risk. Third, we introduce heterogeneous discount factors in order to generate a stronger concentration of wealth at the top. Of these extensions, the Pareto tail to the productivity distribution turns out to be quantitatively most important for the size of the welfare state. The optimal tax-and-transfer system in the full model consists of a very large transfer that phases out slowly, financed with large average tax rates which are only moderately progressive.

Related Literature. This paper builds on a large literature documenting rising inequality in the United States since the 1980s. Seminal contributions to this literature are Piketty and Saez (2003) on the rise of income inequality, Saez and Zucman (2016) on wealth inequality, and Piketty et al. (2017) introducing the concept of distributional national accounts. Also on the empirical side, this paper is related to a number of contributions estimating parametric tax functions approximating the U.S. income tax system. Gouveia and Strauss (1994) propose a tax function and estimate it using U.S. data for the 1980s. Guner et al. (2014) estimate several parametric tax functions using data for the year 2000. Feenberg et al. (2020) provide estimates of the loglinear tax function over time. Splinter (2020) empirically analyzes the redistributive impacts of a variety of tax-and-transfer programs in the U.S.

On the theoretical side, we build on Heathcote et al. (2014) and Heathcote et al. (2017), who propose an analytical framework with partial insurance against idiosyncratic shocks to study risk sharing and optimal taxation. We extend this framework to allow for transfers. Our quantitative framework relates to several papers studying optimal tax progressivity in incomplete markets models. An early contribution to this literature is Conesa and Krueger (2006). More recently, several papers investigate optimal tax progressivity in frameworks with human capital accumulation (Badel et al., 2019; Peterman, 2016; Krueger and Ludwig, 2016), superstar earners (Kindermann and Krueger, 2017), transitional dynamics (Bakış et al., 2015), and with the goal of maximizing revenue (Guner et al., 2016). Our paper also relates to the recent contributions of Boar and Midrigan (2020), who explore the role of wealth taxes to finance the welfare state, and Daruich and Fernández (2020), who analyze the welfare effects of a universal basic income.

Finally, while our model firmly falls in the Ramsey (1927) approach to optimal taxation, it is also related to some literature in the Mirrleesian tradition (Mirrlees, 1971; Diamond, 1998; Saez, 2001). Most papers in the Mirrleesian tradition use static models; some recent papers, however, extend the approach to dynamic models (Farhi and Werning, 2013; Golosov et al., 2016). Our flexible functional forms allow for many shapes of marginal and average tax rates schedules, thereby helping to bridge the gap between the Mirrlees and the Ramsey approach. We share this aim with Findeisen and Sachs (2017) and Heathcote and Tsujiyama (2019).

Roadmap. The paper proceeds as follows. In Section 2, we introduce the simple model and characterize analytically the optimal interaction between lump-sum transfers and the progressivity of the income tax schedule. In Section 3, we build a rich quantitative model calibrated to the U.S. to quantitatively analyze the optimal joint design of the income tax schedule and means-tested transfers. Section 4 concludes.

2 An Analytical Model

As shown in Figure 3.1, transfers play an essential role in the redistribution of resources in the U.S. Motivated by that, we analyze the optimal progressivity of the tax schedule in the presence of transfers. We first present a simplified version of the partial-insurance framework of Heathcote et al. (2017), where a government has a loglinear tax schedule as its only policy instrument. We then extend this benchmark by endowing the government with a lump-sum transfer as an additional instrument. We derive analytical results based on local approximations around zero transfers. We confirm the analytical results by finding the global optimum using numerical methods.

2.1 HSV Revisited

The model in this subsection is a simplified version of the partial insurance framework of Heathcote et al. (2017).[2]

Environment. The economy is populated by a continuum of ex-ante homogeneous infinitely-lived households. Households value consumption c_{it} and leisure $1 - n_{it}$ using a utility function which is separable and log over consumption:

$$\log c_{it} - B\frac{n_{it}^{1+\varphi}}{1+\varphi}. \tag{3.1}$$

Households are subject to insurable and uninsurable idiosyncratic income shocks. Specifically, productivity z_{it} of an individual i follows

$$\log z_{it} = \alpha_{it} + \varepsilon_{it}. \tag{3.2}$$

The uninsurable component follows

$$\alpha_{i,t} = \rho_\alpha \alpha_{i,t-1} + \omega_{i,t}, \quad \omega_{i,t} \sim \mathcal{N}\left(-\frac{v_\omega}{2(1+\rho_a)}, v_\omega\right), \tag{3.3}$$

and the insurable component is given by

$$\varepsilon_{i,t} \sim \mathcal{N}\left(-\frac{v_\varepsilon}{2}, v_\varepsilon\right).$$

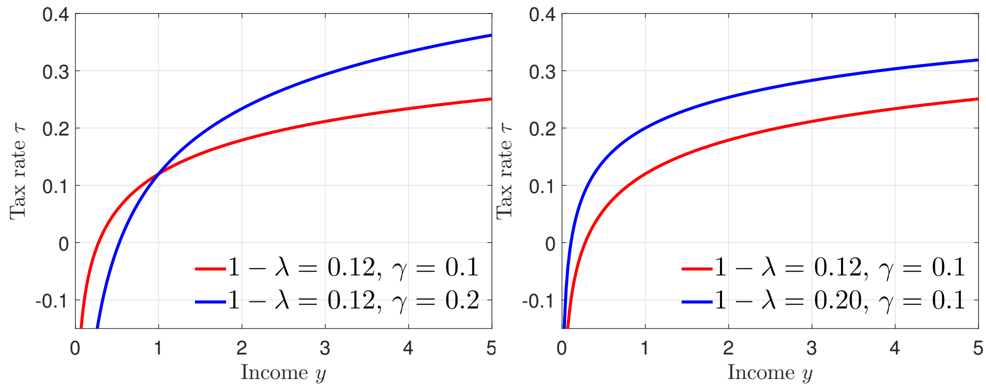
Government. The government raises taxes using the loglinear income tax function:

$$\mathcal{T}(y) = y - \lambda y^{1-\gamma}. \tag{3.4}$$

y denotes pre-tax income and $\lambda y^{1-\gamma}$ is after-tax income, so that $\mathcal{T}(y)$ describes the tax payment of a household with income y. Tax rates are governed by two parameters. γ pins down the progressivity of the tax rates schedule. If γ is positive, average and marginal tax rates are increasing in income. If γ is zero, tax rates will

[2] Heathcote et al. (2017) consider human capital accumulation and preference heterogeneity, which we abstract from for simplicity and to focus attention on the effects of introducing transfers.

Figure 3.2 – The Loglinear Tax Function



(a) Varying γ **(b)** Varying λ

Notes: This figure shows average tax rates implied by different parameter combinations for the loglinear tax function.

be flat; if γ is negative, tax rates will be regressive. The parameter λ determines the level of the tax schedule. In the case of zero progressivity, $1 - \lambda$ is the flat average and marginal tax rate. Average tax rates for different combinations of λ and γ are shown in Figure 3.2.

The government has to finance exogenous spending G. The government's budget constraint is therefore given by

$$G = \int (z_{it} n_{it})\, di - \lambda \int (z_{it} n_{it})^{1-\gamma}\, di. \tag{3.5}$$

There is no government debt and no capital.

Equilibrium. We make a crucial assumption for tractability: we assume that households cannot borrow or save across periods. Note that if the uninsurable shock α_{it} was a random walk, a no-trade theorem would hold, such that households would be hand-to-mouth in equilibrium. Instead, we use an AR(1) process, which delivers cleaner closed-form expressions for welfare but breaks the no-trade theorem.[3] In the quantitative model of Section 3, we relax the hand-to-mouth assumption and allow for self-insurance through bond trading. In the meanwhile, insurable shocks are assumed for calibration purposes, to disentangle income inequality from consumption inequality, as in Heathcote et al. (2017).

Abstracting from trades insuring against ϵ shocks, households' budget constraint is

$$c_{it} = \lambda (z_{it} n_{it})^{1-\gamma}.$$

[3] We have derived formulas for welfare under the random walk assumption. The intuition is maintained, but the formulas become very cumbersome.

Under the joint assumptions of log separable preferences and no markets for uninsurable shocks, the first order conditions of the household imply labor supply in closed form:

$$n_{it} = \underbrace{\left(\frac{1-\gamma}{B}\right)^{\frac{1}{1+\varphi}}}_{n_{\mathrm{o}}^{\mathrm{RA}}(\gamma)} \exp\left[-\frac{\mathcal{M}}{\varphi+\gamma} + \frac{1-\gamma}{\varphi+\gamma}\varepsilon\right] \equiv n_{\mathrm{o}}(\gamma), \tag{3.6}$$

with $\mathcal{M} \equiv \frac{v_\varepsilon}{2}\frac{(1-\gamma)(1-2\gamma-\gamma\varphi)}{\varphi+\gamma}$. Assuming no insurable shocks, the labor supply policy is very simple, as it is independent of the realization of the uninsurable shock. It only depends on progressivity γ and preference parameters, as $n_{\mathrm{o}}^{\mathrm{RA}}(\gamma)$ shows. Importantly, labor supply is strictly decreasing in γ: Higher tax progressivity is a disincentive to work. Finally, insurable shocks matter for labor supply because the efficient response to these shocks, which do not affect consumption, is to work a lot when the realization is high and to work little when the realization is low.

Given the policy function for labor, output can also be expressed in closed form:

$$Y_t = \left(\frac{1-\gamma}{B}\right)^{\frac{1}{1+\varphi}} \exp\left[-\frac{\mathcal{M}}{\varphi+\gamma} + \frac{v_\varepsilon}{2}\frac{1-\gamma}{\varphi+\gamma}\frac{1+\varphi}{\varphi+\gamma}\right] \equiv Y_{\mathrm{o}}(\gamma). \tag{3.7}$$

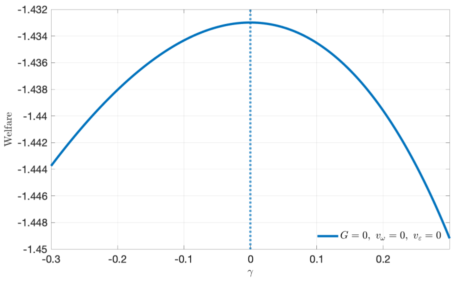
Given progressivity γ and government spending G, the government budget constraint then implies the level of taxes λ in closed form. Having solved for labor supply and the level of taxes, the individual budget constraint implies consumption. Hence, we can solve for all equilibrium objects analytically. Then, we can write welfare as a function of progressivity and government spending:

$$\mathcal{W}(\gamma, G) = \log\left(Y_{\mathrm{o}}(\gamma) - G\right) - \frac{1-\gamma}{1+\sigma} - (1-\gamma)^2\frac{v_\omega}{2(1-\rho_a^2)} \tag{3.8}$$

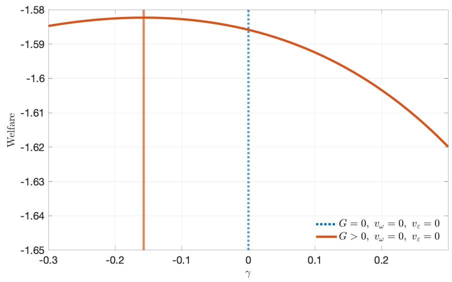
This expression decomposes the forces shaping optimal tax progressivity. The first two terms reflect efficiency concerns. The first term decreases with γ. Indeed, a higher tax progressivity discourages labor supply, reducing the *size* of the economy and thus reducing welfare. However, because labor supply reduces utility, higher progressivity has an upside by limiting *labor disutility*, which is captured by the second term. The third term, finally, captures the *redistribution* motive. More progressivity is positive for welfare because it helps to redistribute resources from rich to poor agents. The redistributive motive becomes stronger the more dispersed income is.

Numerical Illustration. We numerically illustrate the different forces in Figure 3.3. We choose the following parameters. To calibrate the other parameters we set tax progressivity γ to 0.18, in line with the empirical estimates of Heathcote

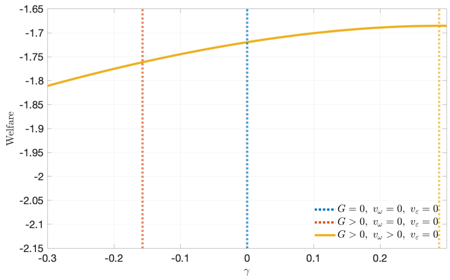
Figure 3.3 – Welfare without Transfers



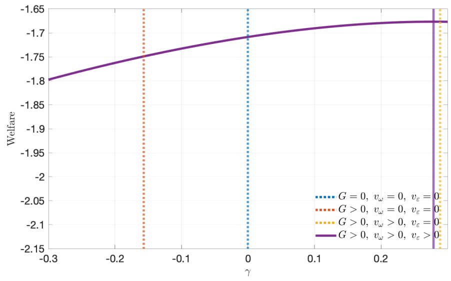
(a) No spending, no heterogeneity



(b) Spending, no heterogeneity



(c) Spending, uninsurable shocks



(d) Spending, all shocks

Notes: This figure shows welfare as a function of tax progressivity without a transfer.

et al. (2017). Furthermore, we set the Frisch elasticity $\varphi^{-1} = 0.4$. The labor disutility parameter is chosen to match $n_{\mathrm{o}}^{\mathrm{RA}}(\gamma) = 0.3$. G is set to match a spending to output ratio $G/Y = 0.15$. We choose a persistence of idiosyncratic wages of $\rho_a = 0.92$ and set the standard deviation of the innovations to match the variance of log consumption and log income in the data.

The first panel shows that optimal tax progressivity in the absence of exogenous government spending and heterogeneity is zero. There is no need to raise taxes for spending and no desire to redistribute in a representative-agent economy. The second panel illustrates what happens in the representative agent model with positive exogenous government spending. The optimal tax progressivity is negative, to induce the representative agent to work and to ease the financing of the spending. The third panel introduces heterogeneity through uninsurable idiosyncratic wage shocks. Hence, the redistribution motive becomes operational, which raises optimal tax progressivity. Finally, in the fourth panel we add insurable shocks. Insurable shocks tend to lower optimal progressivity, though this effect is quantitatively limited, because progressivity distorts the efficient choice that agents with high realizations of the shock supply more labor. In total, optimal progressivity is positive.

2.2 Adding Transfers

Environment, Equilibrium, and Welfare. We now modify the environment by giving the government access to lump-sum transfers in addition to the loglinear tax function. Apart from the lump-sum transfer, everything else is as before.

The individual budget constraint now reads

$$c_{it} = \lambda (z_{it} n_{it})^{1-\gamma} + T \tag{3.9}$$

and the government budget constraint is given by

$$G + T = \int y_{it} di - \lambda \int y_{it}^{1-\gamma} di. \tag{3.10}$$

With transfers we cannot solve in closed form for labor supply anymore. Still, using the implicit function theorem we can approximate labor supply as follows, with $\hat{T} \equiv T/\lambda$:

$$\hat{n}_{it} \approx n_{\mathrm{o}}(\gamma) \left[1 - \frac{\hat{T}}{1+\varphi} \left[\frac{1-\gamma}{B} \right]^{-\frac{1-\gamma}{1+\varphi}} \exp\left[-\mathcal{M} - (1-\gamma)\,\alpha \right] \right] \tag{3.11}$$

It is easy to see from this expression that a positive transfer leads to lower labor supply relative to the case without a transfer. This approximation allows us to obtain welfare $\hat{\mathcal{W}}(\gamma, \hat{T}, G)$ in the neighborhood of $\hat{T} = 0$ following similar steps as above.

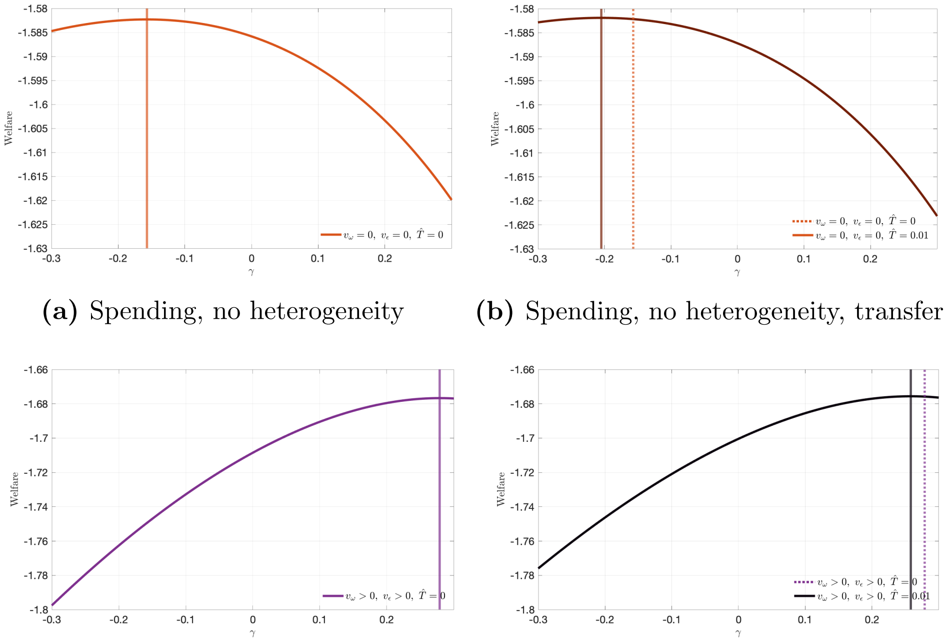
Let $\eta \equiv \exp\left((1-\gamma) \frac{v_\omega}{(1-\rho_a^2)} \right)$ and $\mathcal{N} \equiv \exp\left(\frac{v_\varepsilon}{2} \frac{1-\gamma}{(\varphi+\gamma)^2} \left(\varphi + 2\gamma + \varphi\gamma \right) \right)$. Then, we can write welfare as

$$\begin{aligned} \hat{\mathcal{W}}(\gamma, \hat{T}, G) &= \log\big(Y_{\mathrm{o}}(\gamma) - G \big) - \frac{1-\gamma}{1+\varphi} - (1-\gamma)^2 \frac{v_\omega}{2(1-\rho_a^2)} \dots \\ &+ \hat{T}\mathcal{X}\Big[- \frac{n_{\mathrm{o}}^{\mathrm{RA}}(\gamma)}{Y_{\mathrm{o}}(\gamma) - G} + (1-\gamma)\,\eta\mathcal{N}^{-1} + (\varphi+\gamma)\left[\eta - \eta^{\gamma} \right] \mathcal{N}^{-1} \Big], \end{aligned} \tag{3.12}$$

with $\mathcal{X} = \frac{1}{1+\varphi} \left[\frac{1-\gamma}{B} \right]^{\frac{\gamma-1}{1+\varphi}} \eta^{-\frac{\gamma}{2}} \exp\left[-\mathcal{M} \right] \mathcal{N}$.

The three terms in the first row are the same as without transfers. The lump sum transfer adds additional terms to the expression for welfare, which we discuss now. First note that $\mathcal{X}$ is strictly positive, so that for signing the effects of the transfer it is sufficient to sign the terms in the bracket. The first term in the bracket, which is again a *size* term, is negative. Labor supply is going down with a positive transfer, so that the size of the economy goes down, which is bad for welfare. The second term, which is another *labor disutility* term, is positive. Higher progressivity, and thus lower labor supply, is beneficial in that it reduces labor disutility. The third term, a

Figure 3.4 – Welfare with Transfers



(a) Spending, no heterogeneity **(b)** Spending, no heterogeneity, transfer

(c) Spending, all shocks **(d)** Spending, all shocks, transfer

Notes: This figure shows welfare as a function of tax progressivity with a transfer.

redistribution term, is also positive. Introducing a transfer compresses consumption inequality, which improves welfare.

We now investigate how the optimal progressivity of the tax function is affected by the presence of the lump-sum transfer. For that purpose, consider first the case in which we shut down heterogeneity. In that case, the redistribution terms in the welfare formula disappear and the expression in the bracket simplifies to

$$-\frac{G}{n_{\mathrm{o}}^{\mathrm{RA}}(\gamma) - G} - \gamma.$$

Hence, a positive transfer leads to higher efficiency costs of high progressivity. Intuitively, the transfer works as additional spending that has to be financed. It is optimal to incentivize households with lower progressivity to work more to ease the financing of the transfer. Relative to exogenous spending, this logic is strengthened by the fact that a transfer lowers labor supply. Hence, absent any redistributional concern, purely for efficiency reasons, the optimal relationship between the size of the lump-sum transfer and the progressivity of the tax function is negative.

Consider finally the redistribution term in the welfare formula. To see how redistributional concerns affect the relation between transfers and progressivity, consider the extreme case in which γ is equal to one. Then, after-tax incomes of all households are equalized. The redistribution term disappears from the formula. Indeed, there is zero gain from having the transfer. More generally, the lower progressivity γ, the larger the gain from the transfer. In other words, with a transfer in place that already provides some redistribution, higher progressivity of the tax rates schedule is less valuable. Therefore, also for redistribution reasons there is optimally a negative relationship between the size of the lump sum transfer and the progressivity of the tax rates schedule.

Numerical Illustration. We numerically illustrate how the presence of the lump-sum transfer affects the optimal progressivity of the tax rates schedule. The parameterization is as before. In Figure 3.4, we start from the case in which there is no heterogeneity but positive government spending. We know from above that in this case the optimal progressivity is negative to incentivize labor supply, easing the financing of the spending. When introducing a transfer into this representative agent economy, the optimal progressivity goes down even more as fiscal pressure rises. In the bottom two panels, we show the effect of the transfer in the heterogeneous agent economy. In the left panel, we show the optimal progressivity without a transfer. In the right panel, we show that this progressivity is lower when a transfer is introduced.

2.3 Global Solution

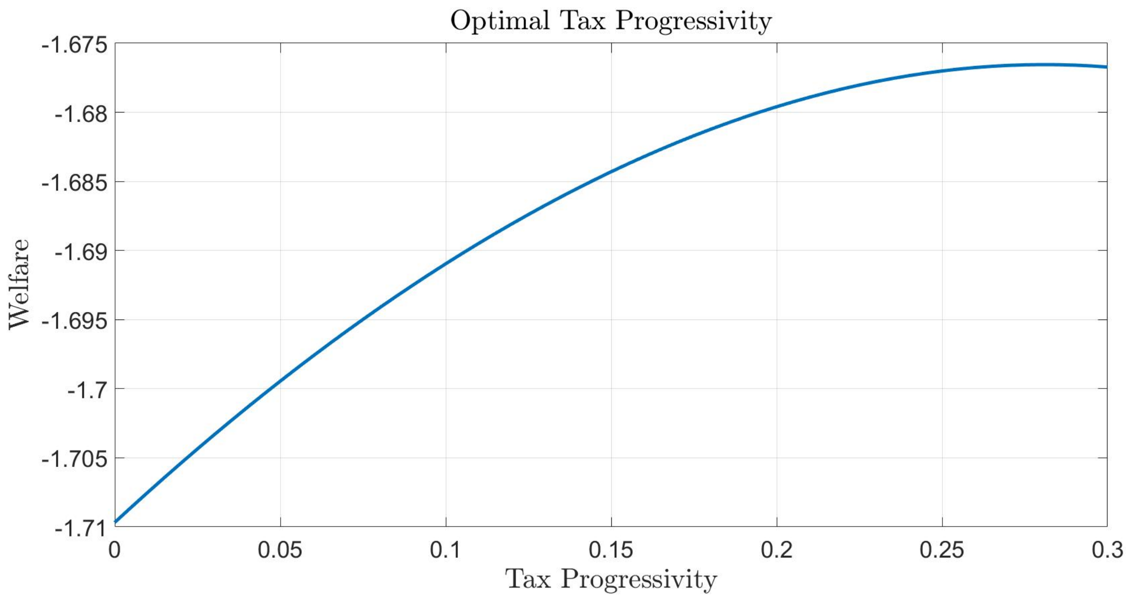
The findings in the previous section show that using a lump-sum transfer in addition to the loglinear tax function leads to optimally lower progressivity of the tax function. However, as these analytical results are based on local approximations around a zero transfer, we cannot use them to infer the optimal size of the transfer and the associated progressivity of the tax function. To achieve this, we solve the model numerically.

As a benchmark, we first show the optimal progressivity when no transfer is available to the government (Figure 3.5). We find that the income tax schedule should be progressive. The optimal value of tax progressivity is 0.27.

Figure 3.6 shows the marginal and average tax rates along the income distribution implied by this tax schedule. Marginal and average tax rates are strongly increasing in income. Note that this tight link between marginal and average progressivity is a consequence of the functional form assumption. With the loglinear tax function, if the planner wants to redistribute through increasing average tax rates, this necessarily implies increasing marginal tax rates. Furthermore, average and marginal tax rates have to be monotonic.

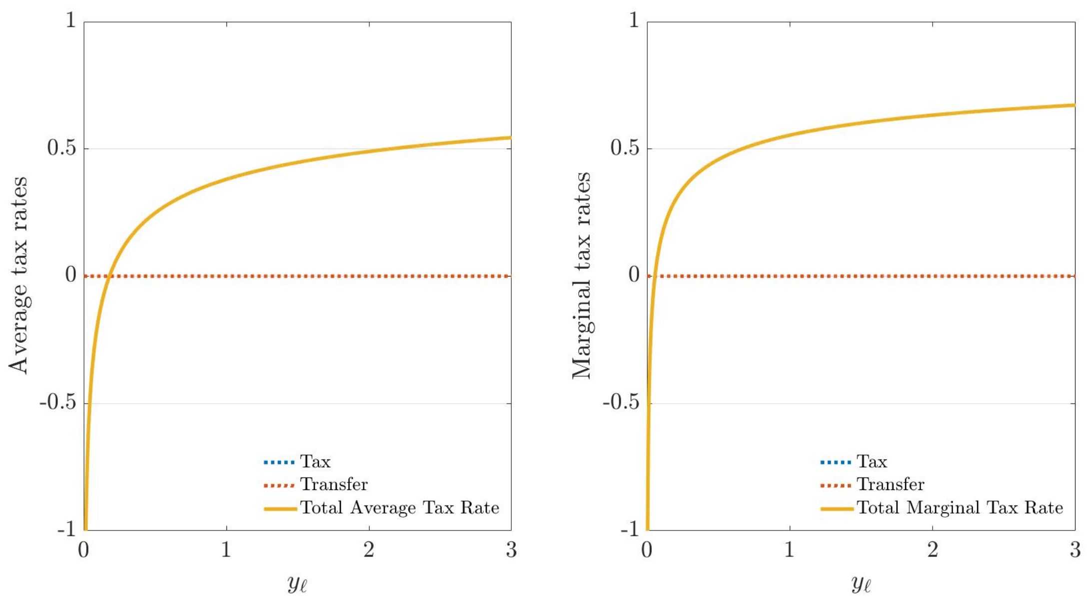
Finally, we compute numerically the globally optimal combination of progressivity and the lump-sum transfer. Figure 3.7 shows optimal progressivity of the tax

Figure 3.5 – Optimal Progressivity without Transfers



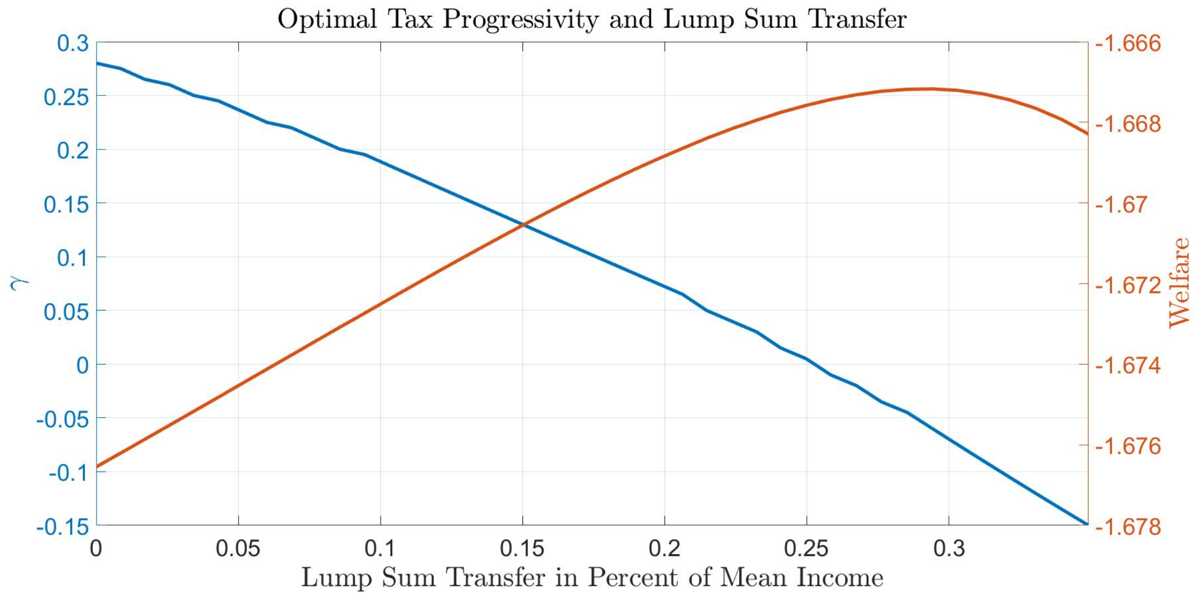
Notes: This figure shows the optimal tax progressivity when no transfer is used.

Figure 3.6 – Optimal Progressivity without Transfers: Implied Rates



Notes: This figure shows the average and marginal tax rates implied by the optimal tax system when no transfer is used.

Figure 3.7 – Optimal Progressivity with Transfers



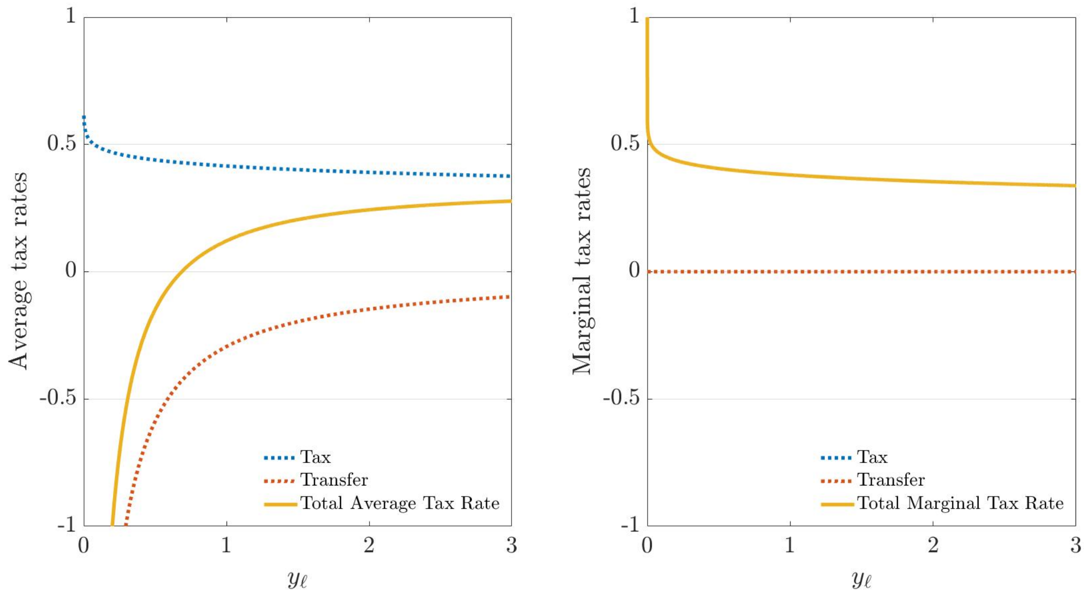
Notes: This figure shows the optimal combination of progressive taxes and lump sum taxes.

function depending on the size of the lump-sum transfer (blue line). Optimal progressivity is monotonically decreasing in the size of the transfer. In addition, the figure also shows the welfare level associated with each combination of transfer and progressivity (red line).

The optimal lump-sum transfer is quite sizable, amounting to 28% of mean income. The associated optimal tax rates schedule is regressive. This finding is consistent with the intuition built with the analytical formulas derived above. It is restrictive to just use the loglinear tax function because it does not allow to differentiate between progressivity in marginal and average tax rates. With only the loglinear tax function available, it is optimal to have a progressive tax rates schedule because this is the only way of achieving redistribution of resources from the rich to the poor. However, this way of redistributing has relatively high efficiency costs because it implies high marginal tax rates for top earners, who are very productive. Introducing the lump-sum transfer allows to have progressive average tax rates, but is associated with much lower marginal tax progressivity to avoid distorting top earners' incentives to supply labor. Therefore, the optimal tax-and-transfer system features increasing average tax rates in combination with decreasing marginal tax rates (see Figure 3.8).

Importantly, regressive marginal taxes do not imply low average taxes at the top of the income distribution. Indeed, high marginal tax rates at the bottom increase average taxes at the top without distorting labor supply of the most productive. As such, to finance generous transfers, it is efficient to raise fiscal revenues from

Figure 3.8 – Optimal Progressivity with Transfers: Implied Rates



Notes: This figure shows the average and marginal tax rates implied by the optimal tax system with the loglinear tax function and a lump sum transfer.

high-income earners, and it is efficient to do so through high marginal tax rates on low levels of income.

3 Quantitative Model

The analysis of jointly optimal taxes and transfers in the simple, tractable model so far shows that there is optimally a negative relationship between the progressivity of the tax rates schedule and the size of the lump sum transfer. Using a transfer and the tax rates schedule allow to disentangle marginal and average progressivity of the overall tax-and-transfer system. We now quantify the optimal tax-and-transfer system in a quantitative heterogeneous agent model. Importantly, we allow for additional flexibility in the tax-and-transfer system by replacing the lump-sum transfer with a targeted transfer that phases out with income. We proceed in two steps. We first perform the analysis in a standard incomplete markets model to relax the hand-to-mouth assumption, and then extend the model in several dimensions to have a framework that is quantitatively consistent with the U.S. economy.

3.1 Baseline Model

The baseline model is an incomplete-market model in the tradition of Bewley (1977), Huggett (1993), and Aiyagari (1994) with endogenous labor supply as in Pijoan-Mas (2006). Time is discrete and indexed by $t = 0, 1, 2, \ldots$. The economy is populated by a continuum of households, a representative firm, and a government. The firm has access to a constant returns to scale technology in labor and capital given by $Y = K^{1-\alpha}L^{\alpha}$, where K, L and Y stand for capital, labor, and output, respectively. Both factor inputs are supplied by households. We assume constant total factor productivity.

Households. Households have preferences over sequences of consumption and hours worked given as follows:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^{1-\sigma}}{1-\sigma} - B\frac{n_t^{1+\varphi}}{1+\varphi} \right] \tag{3.13}$$

where c_t and n_t stand for consumption and hours worked in period t. Households have access to a one period risk-free bond, subject to a borrowing limit $\underline{a}$. Their idiosyncratic labor productivity x follows a Markov process with transition probabilities $\pi_x(x', x)$.

Let $V(a, x)$ be the value function of a worker with level of assets a and idiosyncratic productivity x. Then,

$$\begin{aligned} V(a,x) = & \max_{c,a',n} \left\{ \frac{c^{1-\sigma}}{1-\sigma} - B\frac{n^{1+\varphi}}{1+\varphi} + \beta\mathbb{E}_{x'}\left[V\left(a',x'\right)|x\right] \right\} \\ & \text{s.t.} \\ & c + a' \leq wxn + (1+r)a - \mathcal{T}(wxn, ra) \\ & a' \geq 0, \end{aligned} \tag{3.14}$$

where w stands for wages and r for the interest rate. We impose an exogenous borrowing limit of zero. Households face a distortionary tax $\mathcal{T}(wxn, ra)$, which depends on labor income wxn and capital earnings ra separately. We will be more specific on the concrete functional forms for taxes and transfers below. Every period, households face the problem in (3.14) and make optimal labor, consumption, and saving decisions accordingly. Let $n(a, x), c(a, x)$ and $a'(a, x)$ denote the optimal policies.

Firms. Every period, the firm chooses labor and capital demand in order to maximize current profits,

$$\Pi = \max_{K,L} \left\{ K^{1-\alpha}L^{\alpha} - wL - (r+\delta)K \right\} \tag{3.15}$$

where δ is the depreciation rate of capital. Optimality conditions for the firm are standard: Marginal productivities are equalized to the cost of each factor.

Government. The government's budget constraint is given by:

$$G + (1+r)D = D + \int \mathcal{T}(wxn, ra)d\mu(a,x) \tag{3.16}$$

where D is government's debt and $\mu(a,x)$ is the measure of households with state (a,x) in the economy. Government spending G is kept constant.

Stationary Equilibrium Definition. Let A be the space for assets and X the space for productivities. Define the state space $S = A \times X$ and $\mathcal{B}$ the Borel $\sigma-$algebra induced by S. A formal definition of the competitive equilibrium for this economy is provided below.

A **recursive competitive equilibrium** for this economy is given by: value function $V(a,x)$ and policies $\{n(a,x), c(a,x), a'(a,x)\}$ for the household; policies for the firm $\{L, K\}$; government decisions $\{G, B, \mathcal{T}\}$; a measure μ over $\mathcal{B}$; and prices $\{r, w\}$ such that, given prices and government decisions: *(i)* Household's policies solve its problem and achieve value $V(a,x)$, *(ii)* Firm's policies solve its static problem, *(iii)* Government's budget constraint is satisfied, *(iv)* Capital market clears: $K + D = \int_{\mathcal{B}} a'(a,x)d\mu(a,x)$, *(v)* Labor market clears: $L = \int_{\mathcal{B}} xn(a,x)d\mu(a,x)$, *(vi)* Goods market clears: $Y = \int_{\mathcal{B}} c(a,x)d\mu(a,x) + \delta K + G$, *(vii)* The measure μ is consistent with household's policies: $\mu(\mathcal{B}) = \int_{\mathcal{B}} Q((a,x),\mathcal{B})d\mu(a,x)$ where Q is a transition function between any two periods defined by: $Q((a,x),\mathcal{B}) = \mathbb{I}_{\{a'(a,x)\in\mathcal{B}\}} \sum_{x'\in\mathcal{B}} \pi_x(x',x)$.

3.2 New Tax Functions

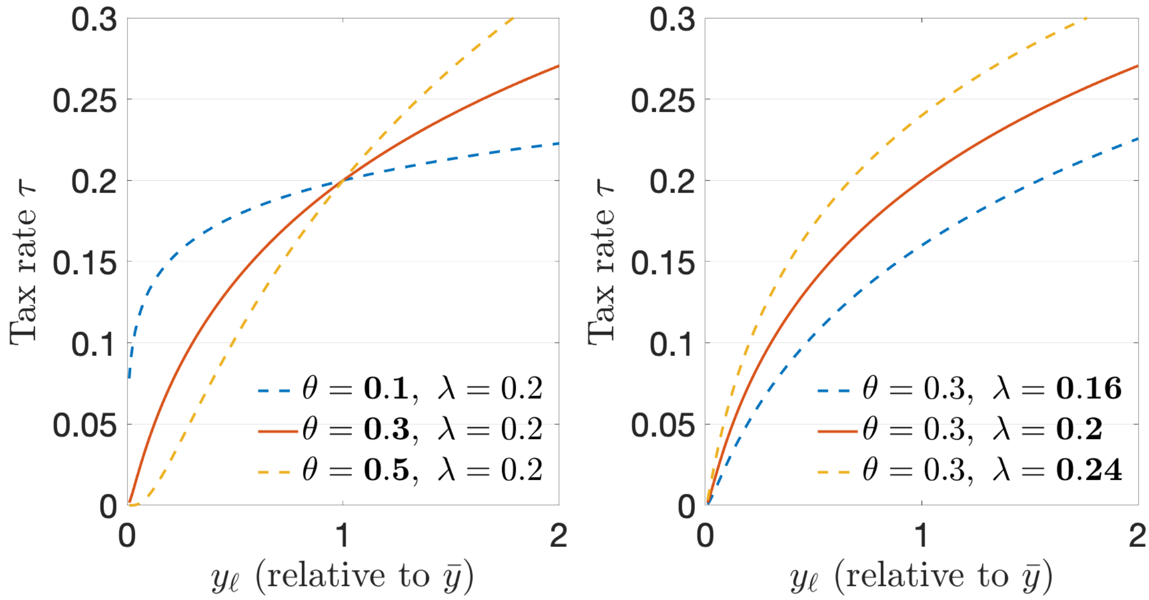
We now introduce the functional forms for taxes and transfers that we use in the quantitative model. While we do not focus on capital taxes, we allow for a linear tax on capital income τ^k.

The first new functional form that we introduce is for the labor income tax. The loglinear function used so far is designed to approximate the entire tax-and-transfer system. It implies negative tax rates at the bottom of the income distribution, thereby providing a transfer to poor households. Given that we model transfers explicitly, we do not want to allow for negative tax rates. Therefore, we use the following tax function to tax labor income:

$$\tau(y_\ell) = \exp\left(\log(\lambda)\left(\frac{y_\ell}{\bar{y}}\right)^{-\theta}\right) \tag{3.17}$$

As for the loglinear tax function, λ is a level parameter governing the overall level of the tax rates schedule. θ is the progressivity parameter of this function. We use a different letter to describe the progressivity parameter than with the loglinear

Figure 3.9 – New Tax Function



Notes: This figure illustrates the new labor income tax function.

function to make clear that its level is not directly comparable to γ in that case. However, the qualitative interpretation is the same. Positive θ implies rising average and marginal tax rates, $\theta = 0$ implies a flat tax, and negative θ implies regressive average and marginal tax rates.

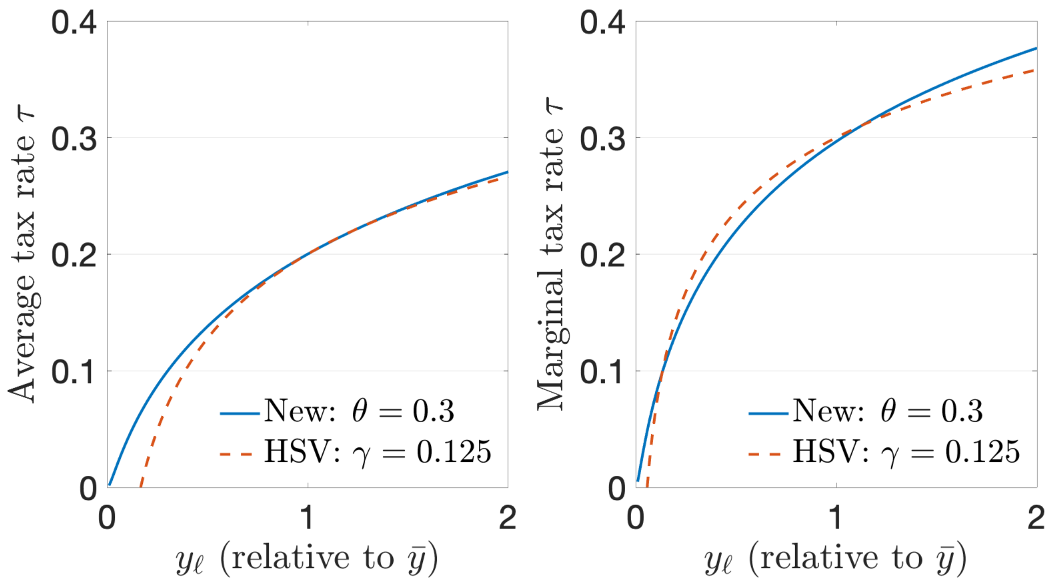
We illustrate how average tax rates vary with θ and λ in Figure 3.9. We show in Figure 3.10 that the new tax function resembles the loglinear function for appropriately chosen parameters over a wide range of incomes. However, while the loglinear function turns negative at low income levels, the new tax function implies positive rates everywhere.

In addition to income taxes, we model targeted transfers. The functional form for transfers is

$$T_t(y) = m_t \frac{2\exp\left\{-\xi_t\left(\frac{y}{\bar{y}}\right)\right\}}{1+\exp\left\{-\xi_t\left(\frac{y}{\bar{y}}\right)\right\}}. \tag{3.18}$$

The parameter m_t governs the generosity of the transfer. Specifically, m_t is the level of the transfer at zero income, expressed relative to median income. The effect of changing m_t is shown in the left panel of Figure 3.11. The parameter ξ_t determines how quickly the transfer is phased-out with income. A higher ξ_t implies a quicker phase-out. This is shown in the right panel of Figure 3.11. This functional form is motivated by the fact that income security programs in the U.S. are means tested. Furthermore, while the lump-sum allows for breaking the tight link between average and marginal tax rates implied by just the tax rates schedule, the phasing out of

Figure 3.10 – New Tax Function vs. Loglinear Function



Notes: This figure compares the new labor income tax function to the loglinear tax function.

the transfer allows for non-monotonic marginal rates of the entire tax-and-transfer system, as will become clear when we look at the optimal fiscal system below.

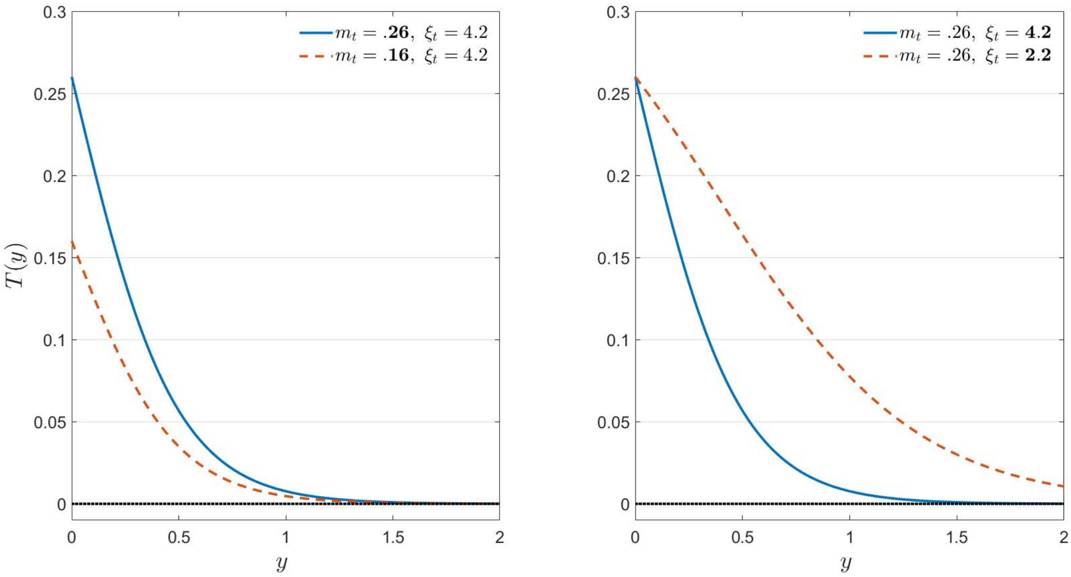
3.3 Calibration

We calibrate the model to the U.S. economy in 2004. A model period is a year. We fix the preference parameters governing the intertemporal elasticity of substitution $\sigma = 2$ and the Frisch elasticity $\varphi^{-1} = 0.4$. We set the parameters of the income process $\rho_x = 0.92$ and $\sigma_x = 0.25$, in line with the estimates of Floden and Lindé (2001). The production side parameters are set as $\alpha = 0.64$ and $\delta = 0.08$.

We calibrate the parameters of the tax-and-transfer system such that the model produces average tax and transfer rates by income quintile in line with the evidence shown in Figure 3.1. The capital tax rate is fixed at $\tau^k = 0.3$. The parameters of the labor income tax function are $\lambda = 0.16$ and $\theta = 0.4$ The parameters of the transfer function are $m_t = 0.22$ and $\xi_t = 4.8$. The tax and transfer rates are compared to the data in Table 3.1. Also, marginal and average tax rates implied by the tax and transfer functions along the income distribution are shown in Figure 3.12.

Finally, we calibrate the discount factor β, the labor disutility parameter B, and government debt D such that the real interest rate is 2.5%, average labor supply is 0.3, and the debt-to-output ratio is 60%. Residually, the government budget constraint implies a level of government spending G such that the spending-to-

Figure 3.11 – New Tax Function



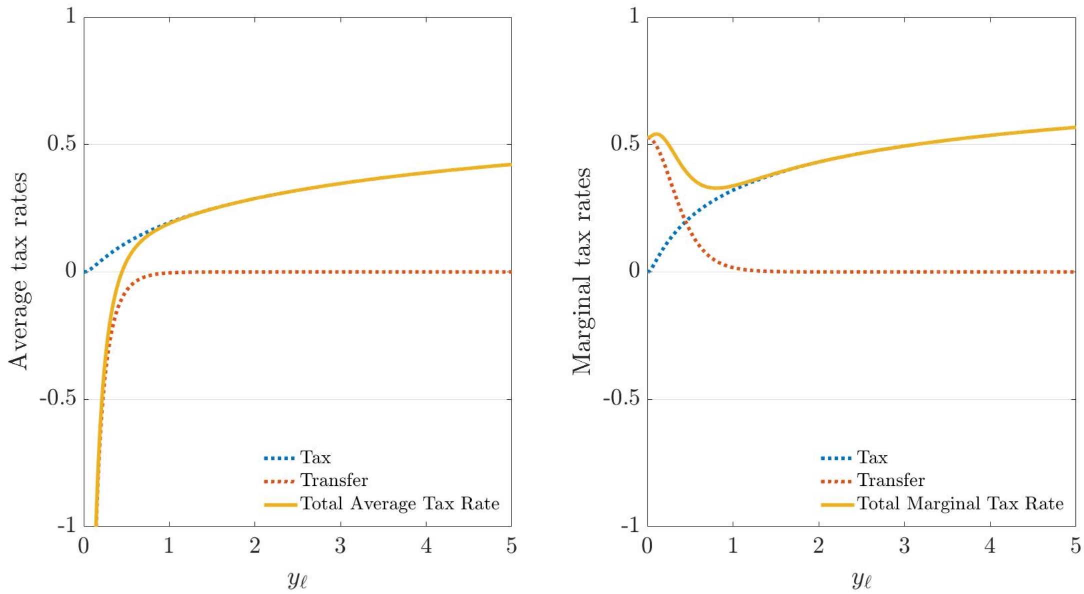
Notes: This figure illustrates the targeted transfer function.

Table 3.1 – Average Tax and Transfer Rates

Data	Q1	Q2	Q3	Q4	Q5
Tax rate	5.45%	11.57%	16.79%	19.88%	25.64%
Transfer rate	21.29%	1.78%	0.25%	0.04%	0.01%
Model	Q1	Q2	Q3	Q4	Q5
Tax rate	11.04%	15.30%	18.72%	22.21%	30.45%
Transfer rate	20.67%	3.82%	0.69%	0.10%	0.00%

Notes: This table shows average tax rates paid and transfer rates received per income quintile. Data: CBO 2004, working-age households. Model: tax parameters: $\theta = 0.4$, $\lambda = 0.19$; transfer parameters: $m_t = 0.22$, $\xi_t = 4.8$.

Figure 3.12 – Tax and Transfer Rates: Calibration



Notes: This figure shows average and marginal tax rates implied by the calibrated tax functions.

output ratio is roughly 15%, in line with the data.

Table 3.2 shows the income and wealth distributions in the calibrated economy and compares them to the data. As is well known, the standard incomplete markets model is not capable of replicating the concentration of income and wealth at the top of the distribution. Still, we will first use this well-known model to perform optimal tax exercises to make transparent the forces at work. Then, we will extend the model in several dimensions to improve the quantitative fit and redo the optimal tax analysis.

Table 3.2 – Income and Wealth Distributions

Data	Q1	Q2	Q3	Q4	Q5
Income	3.58%	8.39%	13.07%	20.14%	54.82%
Net worth	-0.24%	1.18%	4.32%	11.81%	82.93%
Baseline	Q1	Q2	Q3	Q4	Q5
Income	6.14%	11.45%	15.92%	23.00%	43.49%
Net worth	0.34%	4.12%	11.53%	24.43%	59.58%

Notes: This table shows the income and wealth shares of different parts of the distributions. Authors' calculations based on the SCF 2004 for households with age between 25 and 60.

3.4 Optimal Tax Policy in the Baseline Model

We now turn to the optimal taxation exercises in the baseline quantitative incomplete markets model. We consider three fiscal reforms. First, we consider the case in which the government does not have access to the fiscal functions we propose but only to the loglinear income tax function. This is to compare to a large literature in quantitative macro that considers this tax instrument. Second, we allow the government to use optimally our new labor income tax function and a lump sum transfer. Third, the government can optimize all the parameters of the income tax function and the targeted transfer.

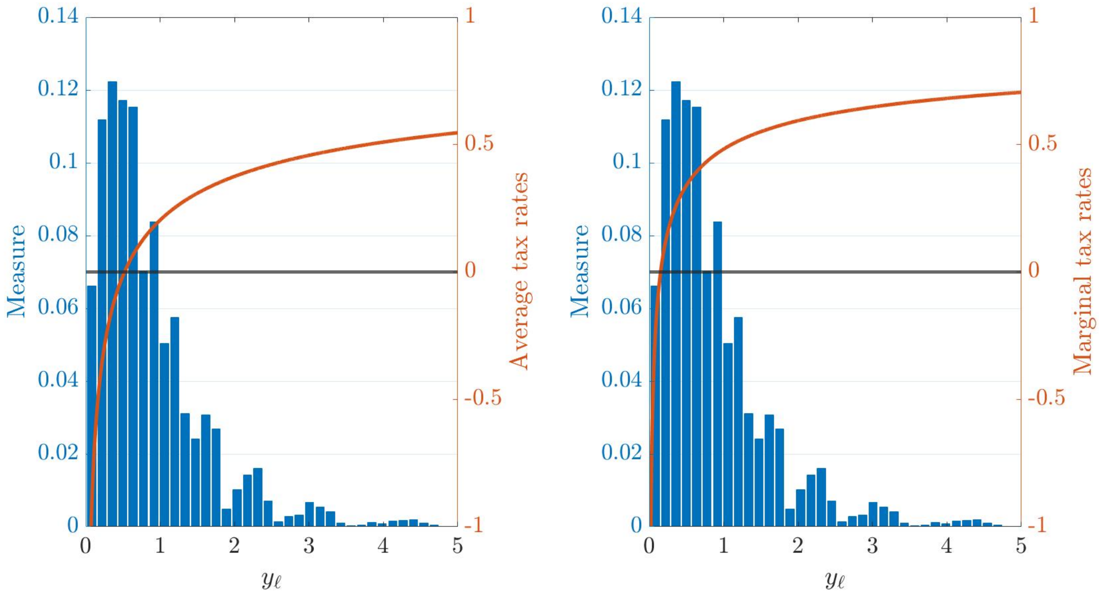
For all the optimizations we take into account transitional dynamics. Specifically, the government can once-and-for-all change the parameters of the fiscal system. Then, the economy will transition towards a new steady state. When choosing the optimal parameters for the fiscal system, we account for the transitions to the new steady states.

Loglinear system. The first experiment is to optimize the tax progressivity γ when only the loglinear income tax function is available to the government. The optimal progressivity is 0.35. Note that this much higher than what it would be if we were to just optimize steady state welfare, in which case it would optimally be 0.22. It is optimal to have higher progressivity when taking into account transitions because higher tax rates at the top and better insurance reduce savings in the economy, so that some part of the capital stock can be consumed while transitioning from the initial to the final steady state. Only considering steady states is misleading because, in that case, the final economy is larger than the initial one. In the optimal steady-state, the final economy features higher capital stock, output, and welfare. However, reaching this steady-state becomes costly when taking into account the transitions, as individuals need to save more and consume less to build the higher capital stock.

Marginal and average tax rates implied by this tax are shown in Figure 3.13. As discussed in the analytical part, marginal and average progressivity are closely linked. Both marginal and average rates are strongly rising with income. It can be seen in the figure that even though there is no explicit transfer in this economy, the loglinear tax function implies a net transfer for a significant share of the population. It is, however, much smaller than what can be achieved with the transfer function.

Figure 3.14 shows the welfare gains of different households under this reform. The gains are expressed in consumption equivalent terms. On aggregate, the consumption equivalent gain is -0.84%. That is, the reform is detrimental for welfare. Sticking with current U.S. policy is preferable to switching to the optimal loglinear fiscal plan.

Figure 3.13 – Optimal Loglinear Fiscal Plan



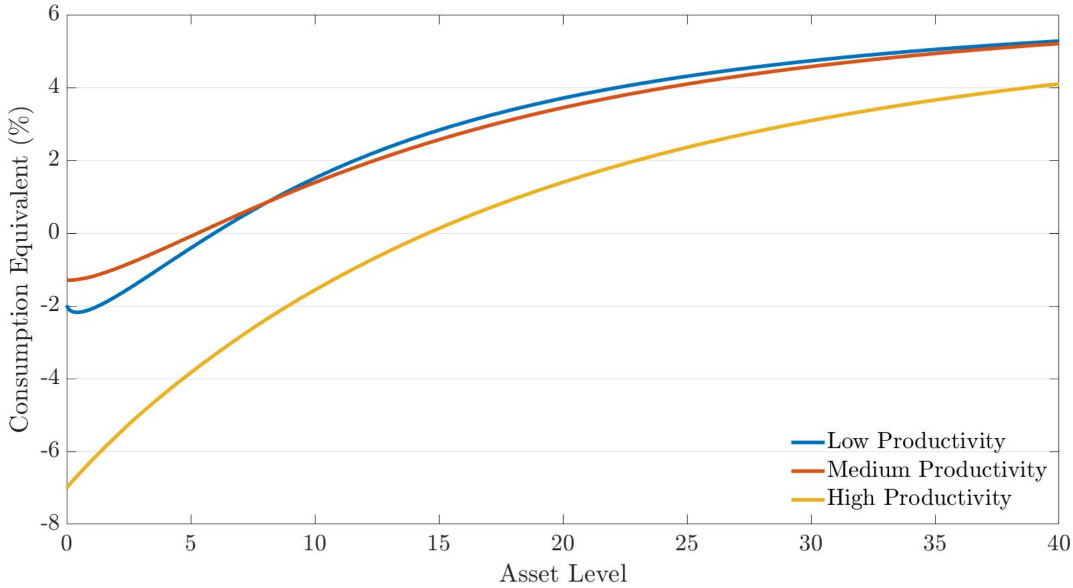
Notes: This figure shows the optimal loglinear fiscal plan taking into account transitional dynamics.

To understand the welfare loss, it is important to recall that the baseline economy features two flexible instruments, transfers and income taxes. In contrast, under this reform, the government is restricted to use only one instrument, the log-linear fiscal plan. In line with the discussion in Section 2, the tight link between marginal and average tax rates imposed by this tax function is actually restrictive.

There is, however, significant heterogeneity in the welfare gains and losses across households. Asset rich households gain because the interest rate is going up after the reform. Poor and low productivity households lose because the transfer implied by the loglinear function is lower than the explicitly modeled transfer in the calibration. The group that loses most under the reform is the group of high productivity households with little assets. This group works a lot because they want to save for times when they are less productive but now face a very high tax rate implied by the high progressivity of the loglinear income tax schedule.

Progressive taxes and a lump sum transfer. In a next step, we allow the government to use the new tax function and a lump sum transfer. The optimal lump sum transfer is sizable and combined with regressive tax rates. Specifically, the transfer amounts to 32% of the median income of the calibrated economy, and the parameter θ governing the progressivity of the tax function is -0.2. This optimal tax system, which is depicted in Figure 3.15, is much more generous than the optimal loglinear fiscal plan through the large lump sum transfer. It is optimal to finance this

Figure 3.14 – Optimal Loglinear Fiscal Plan: Consumption Equivalents



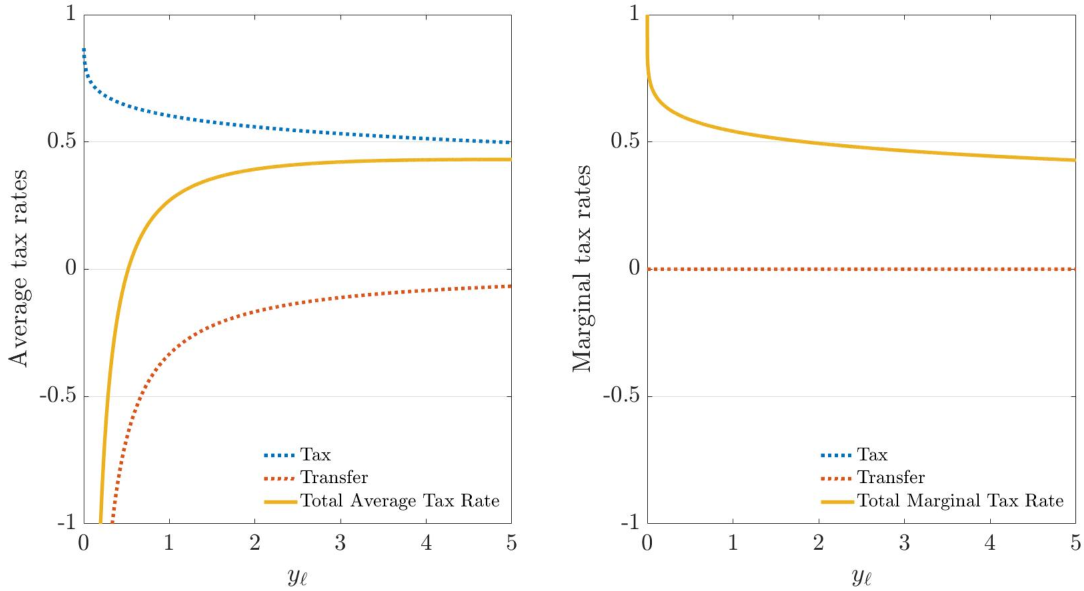
Notes: This figure shows consumption equivalent welfare gains under the optimal loglinear fiscal plan.

large transfer with regressive taxes, in line with the analytical results. Redistribution is achieved through the transfer, so that less need for redistribution through tax rates exists. Additionally, the large lump sum has to be financed and it is optimal to incentivize labor supply especially of very productive households with regressive taxes. The more generous welfare state at the bottom of the distribution is financed with lower marginal tax rates at the top. While in the loglinear case top marginal tax rates reach 75%, they are below 50% here. This shows again the importance of being able to disentangle progressivity in average and marginal rates.

Figure 3.16 shows the consumption equivalent gains and losses for this reform. On aggregate, the gain is 1.56%, which is large. Again, there is large heterogeneity in the welfare effects. The biggest beneficiaries of this reform are asset poor, low productivity households because they obtain a much more generous transfer than in the calibrated economy. Asset rich households also generally gain because they receive a higher interest rate. Losses are still concentrated among high productivity, asset poor households. However, their losses are much smaller than with the optimal loglinear reform because they face lower tax rates compared to that case.

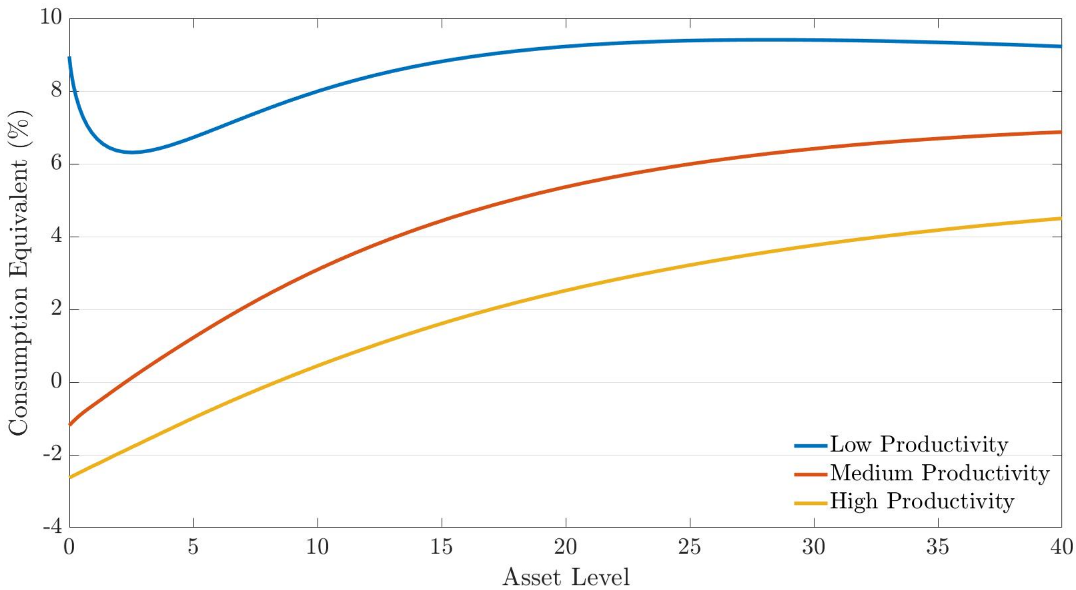
Progressive taxes and a phasing-out transfer. Finally, we allow the government to also phase-out the transfer. The level parameter of the transfer function is almost the same as in the case with the lump sum transfer. However, the government chooses to phase-out the transfer, albeit slower than in the calibration.

Figure 3.15 – Optimal Taxes and Lump-Sum



Notes: This figure shows the optimal combination of taxes and a lump sum taking into account transitional dynamics.

Figure 3.16 – Optimal Taxes and Lump-Sum: Consumption Equivalents



Notes: This figure shows consumption equivalent welfare gains under the optimal combination of taxes and a lump sum taking into account transitional dynamics.

Progressivity of the tax rates schedule is higher than in the previous case such that tax rates are slightly progressive. Phasing out transfers eases fiscal pressure because less spending has to be financed, so that progressivity of tax rates is optimally higher. Furthermore, the phasing-out of the transfer translates into higher marginal tax rates at the bottom, calling for higher progressivity to avoid increasing further marginal tax rates at the bottom.

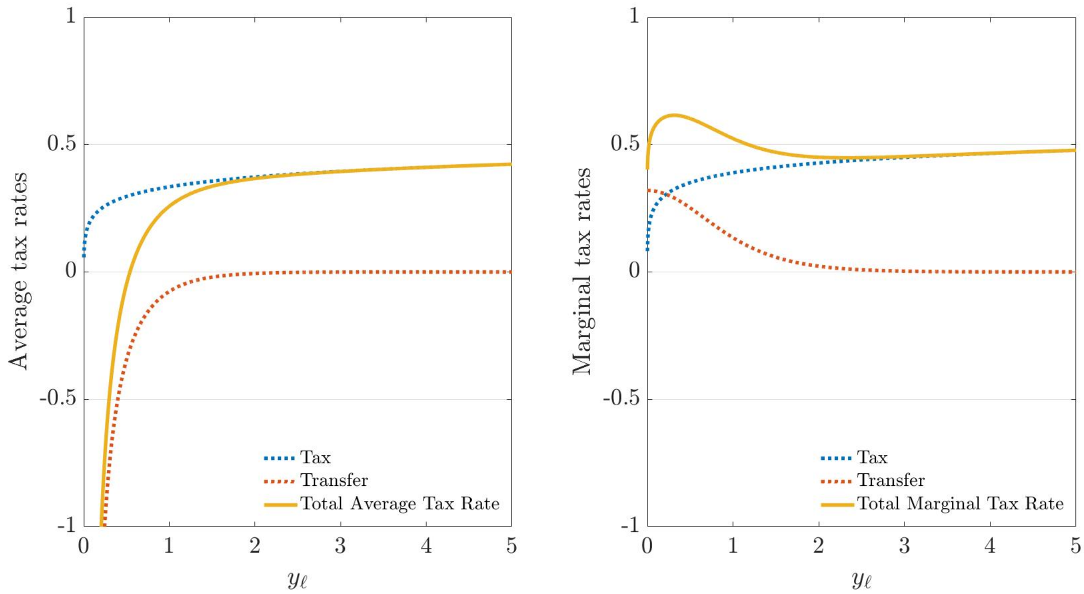
The optimal tax system is shown in Figure 3.17. This tax system improves welfare further compared to the tax system with just a lump sum. The aggregate consumption equivalent gain is 1.77%, with a similar distribution of winners and losers as before. It should be noted that the large welfare gain is not exclusively driven by large gains for few poor households. Around 70% of households would support the reform. Why is this reform preferable to the previous one? The lump sum transfer allows to break the tight link between progressivity in average and marginal tax rates. This is crucial to achieve the largest part of the welfare gains. However, it is still the case with the lump sum that marginal tax rates have to be monotonically increasing, flat, or monotonically decreasing. With the targeted transfer it is possible to achieve non-monotonic marginal tax rates.Marginal tax rates are high at the bottom of the income distribution, where the phase-out of the transfer implies large marginal rates. This is useful because the distortions to the least productive households are not very costly in aggregate terms. The large marginal tax rates at the bottom increase average tax rates everywhere above in the income distribution, so that large transfer payments and exogenous spending can be easily financed. In parts of the distribution where distortions are more costly the planner can then have lower marginal tax rates. However, rates are rising again at the top because of the progressive income tax function.

We conclude from the standard incomplete markets model that optimal transfers are large with a slow phase-out rate. The optimal progressivity of the tax rates schedule is moderate and much lower than under the optimal loglinear system. The optimal fiscal plan delivers large welfare gains and the majority of households benefit. Much of the welfare gains can be achieved with a lump sum and the tax rates schedule; allowing for targeted transfers rather than a lump sum yields moderate additional gains.

3.5 A Richer Quantitative Model

Finally, we add some features to the model to improve the fit for the distributions of income, wealth, and income risk. We model unemployment risk to better account for earnings dynamics at the bottom of the distribution. We add a Pareto tail to the productivity distribution to improve the fit for the top of the income distribution.

Figure 3.17 – Optimal Taxes and Targeted Transfer



Notes: This figure shows the optimal combination of taxes and targeted transfer taking into account transitional dynamics.

Last, we introduce preference heterogeneity in the form of stochastic discount factors in order to better match the wealth distribution.

Consider first unemployment risk. Using U.S. social security data Guvenen et al. (2019) show that earnings risk is not well described by log-normal income processes such as the one we considered so far. Instead, the majority of people usually only has very small changes to their incomes, but every once in a while experiences a large change. These large changes often are negative. In technical terms, the earnings growth distribution exhibits excess kurtosis and left-skewness. A key feature to explain this is unemployment. Therefore, we introduce unemployment risk into the model.

We use data from the 2004 Survey of Income and Program Participation (SIPP) to discipline how we model unemployment. The upper part of Table 3.3 shows the probability of an agent experiencing at least a one week unemployment spell during a year conditional on the wage quartile. The table shows that the unemployment probability is much higher at the bottom of the hourly wage distribution and rather flat at low levels in the top half of the distribution. Motivated by that, we model the probability of having an unemployment spell depending on idiosyncratic productivity x. We obtain a non-linear estimate of the unemployment probability by hourly wage group, controlling for observables that are not modeled, and map this into unemployment probabilities for the different productivity levels.

Table 3.3 – Unemployment probability and duration

Wage quartile	Q1	Q2	Q3	Q4
Unemployment probability	19.7%	11.2%	7.7%	7.1%
Weeks, conditional on spell	Q1	Q2	Q3	Q4
Mean unemployment duration	6.4	5.4	6.4	7.3
Median unemployment duration	4	3	4	5
75th percentile unemployment duration	10	8	9	10
90th percentile unemployment duration	14	12	15	16

Notes: Unemployment probability and duration by hourly wage. Data: SIPP 2004, heads of household with age between 25 and 60.

The bottom part of the table shows moments of the distributions of unemployment durations conditional on having an unemployment spell by wage quartile. These distributions are very similar across groups, so that we model the distribution of unemployment durations in the model as independent of productivity. Conditional on drawing the unemployment shock, there are three potential unemployment durations.

In the extended model we also model unemployment benefits. We assume that 58% of the unemployed are eligible for benefits and that 45% take-up benefits (Birinci and See, 2018). We set a replacement rate of 45% but cap benefits at 50% of median income. This is consistent with the SIPP data.

To improve the match for the income distribution, we add a Pareto tail to the productivity distribution. We follow Hubmer et al. (2020) in adjusting the productivity of the top 10% of the productivity distribution to follow a Pareto distribution with tail parameter 1.6 (Aoki and Nirei, 2017).

Finally, we add stochastic discount factors in the spirit of Krusell and Smith (1998). Specifically, we allow for two discount factor realizations, between which households transition. We set the parameters of this process to match the quintiles of the wealth distribution.

Apart from these additions, the calibration strategy is the same as in the baseline incomplete markets model. The fit for the income and wealth distributions is shown in Table 3.4. The fit is very good for the entire distributions, except for the very top of the wealth distribution. The fit for the tax and transfer rates is shown in Table 3.5. All parameter values are shown in Table 3.6.

Table 3.4 – Income and Wealth Distributions

Data	Q1	Q2	Q3	Q4	Q5	Top 10%	Top 1%
Income	3.58%	8.39%	13.07%	20.14%	54.82%	38.17%	15.99%
Net worth	-0.24%	1.18%	4.32%	11.81%	82.93%	65.05%	33.78%
Model	Q1	Q2	Q3	Q4	Q5	Top 10%	Top 1%
Income	5.39%	9.83%	14.16%	20.13%	50.49%	36.28%	12.31%
Net worth	0.01%	0.73%	3.61%	12.91%	82.72%	64.88%	16.38%

Notes: Income and wealth shares earned by different parts of the income and wealth distributions. Data: SCF 2004, households with age between 25 and 60.

Table 3.5 – Average Tax and Transfer Rates

Data	Q1	Q2	Q3	Q4	Q5
Tax rate	5.45%	11.57%	16.79%	19.88%	25.64%
Transfer rate	21.29%	1.78%	0.25%	0.04%	0.01%
Model	Q1	Q2	Q3	Q4	Q5
Tax rate	9.77%	13.37%	16.00%	19.24%	30.07%
Transfer rate	23.05%	3.79%	0.79%	0.10%	0.00%

Notes: Average tax rates paid and transfer rates received per income quintile. Data: CBO 2004, working-age households. Model: tax parameters: $\theta = 0.3$, $\lambda = 0.15$; transfer parameters: $m_t = 0.26$, $\xi_t = 4.2$.

Table 3.6 – Parameter Values

Parameter	**Interpretation**	**Value**
Preferences		
β_H	High discount factor	0.987
β_L	Low discount factor	0.948
π_β^{HH}	Prob. of β remaining high	0.999
π_β^{LL}	Prob. of β remaining low	0.991
σ	Risk aversion	2.000
φ	Labor supply elasticity	2.500
B	Disutility of labor	85.000
Income Process		
ρ	Persistence	0.920
σ_x	Standard deviation	0.250
κ	Pareto tail parameter	1.600
U_{DUR}	Unemployment durations	0.06, 0.17, 0.31
U_{DP}	Duration probs. cond. on spell	0.63, 0.16, 0.21
U_{PR}	Probability of unemployment spell	Dependent on x
Production		
α	Labor share	0.640
δ	Depreciation rate	0.080
Government		
D	Public debt	0.520
G	Government spending	0.125
θ	Tax progressivity	0.300
λ	Tax level	0.150
τ_k	Capital tax rate	0.300
m_t	Transfer level	0.260
ξ_t	Transfer phase-out	4.200
b_{EL}	Unemployment benefit eligibility	0.580
b_{TU}	Unemployment benefit take-up	0.550
b_{RR}	Replacement rate	0.450
b_{CAP}	Max. UI benefit as fraction of median income	0.500

(a) Notes: This table summarizes the parameter values for the calibrated steady state economy.

3.6 Optimal Tax Policy in the Richer Model

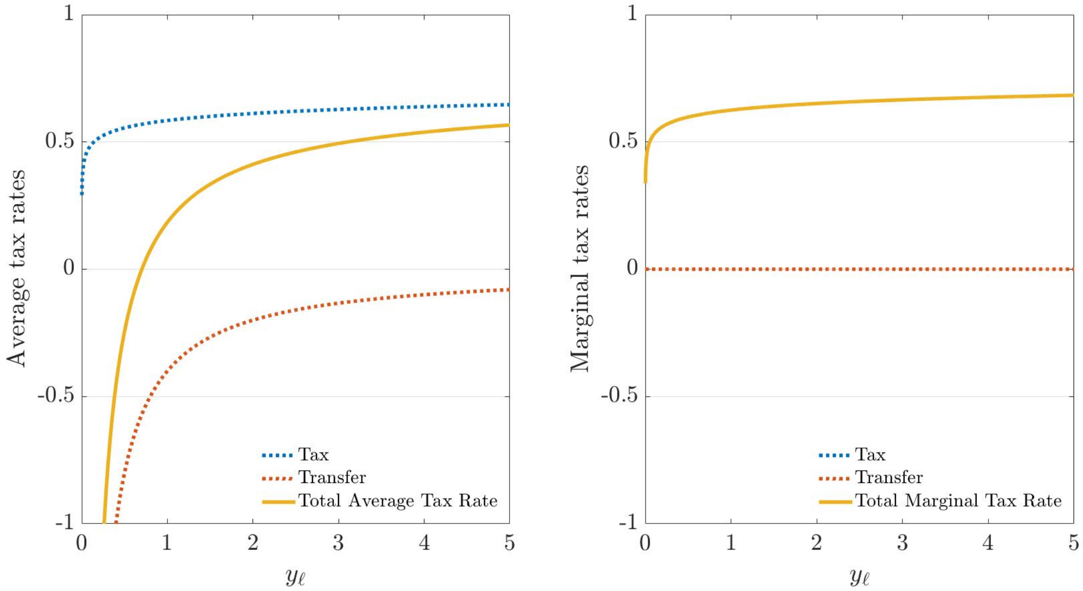
Loglinear system. The extended model features substantially more inequality and risk than the baseline model. Which of these model elements matters most for the optimal fiscal plan? Recall that when just considering steady states the optimal loglinear plan has a progressivity of 0.22 in the baseline model. Adding just the Pareto tail to the income distribution increases this optimal parameter to 0.31 and is thereby very important for desired redistribution. Adding unemployment risk, by contrast, does not matter very much in our current calibration, so that optimal progressivity of the loglinear function in steady state remains at 0.31 when introducing unemployment risk. Discount factor heterogeneity increases further this value to 0.34. In line with the baseline model, when taking into account the transitional dynamics, the optimal progressivity increases to 0.46. The intuition behind this result remains the same. Steady-state analysis overlooks the transitional cost of building a high capital stock. Accounting for the transitional gains of consuming capital on the way increases optimal tax progressivity. Importantly, more redistribution reduces savings and the economy shrinks in the long run.

Progressive taxes and a lump sum transfer. We now repeat the optimal tax exercises of first optimizing the new tax function and a lump sum and then optimizing the new tax function and the targeted transfer in the full model, always taking into account transitions. When just having access to the lump sum transfer, the optimal transfer amounts to 40% of median income in the calibrated economy and the progressivity is mildly positive with $\theta = 0.13$. Note that the relationship between the size of the transfer and the progressivity of the tax rates schedule highlighted in the analytical part holds also in the rich quantitative model. The larger the lump sum transfer, the lower the optimal progressivity of income taxes. However, given the large amount of inequality in the U.S. the optimal system features a very large transfer with still mildly progressive taxes. The rates are shown in Figure 3.18.

Progressive taxes and a phasing-out transfer. When allowing the government to phase-out transfers, the optimal transfer at zero income is even larger, but it is phased out. Tax progressivity is moderate with $\theta = 0.33$. Again, relative to using a lump sum transfer it is beneficial to phase out transfer to ease the financing burden. Then, optimal progressivity is higher, both because of the lower fiscal burden and because of the substitutability between the income tax progressivity and the transfer phasing-out. The aggregate consumption equivalent gain is 2.11%.

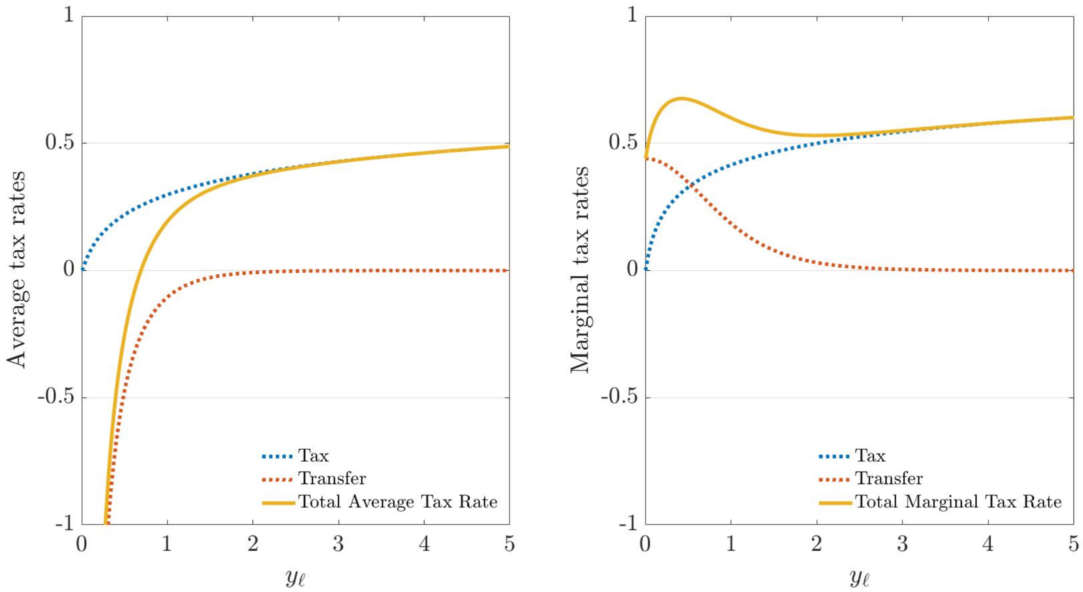
Table 3.7 shows the implied tax and transfer rates by income quintile under the optimal system and compares them to the data. The optimal system is much more

Figure 3.18 – Optimal Taxes and Lump-Sum



Notes: This figure shows the optimal combination of taxes and a lump sum taking into account transitional dynamics in the richer quantitative model.

Figure 3.19 – Optimal Taxes and Targeted Transfer



Notes: This figure shows the optimal combination of taxes and a targeted transfer taking into account transitional dynamics in the richer quantitative model.

Table 3.7 – Average Tax and Transfer Rates

Data	Q1	Q2	Q3	Q4	Q5
Tax rate	5.45%	11.57%	16.79%	19.88%	25.64%
Transfer rate	21.29%	1.78%	0.25%	0.04%	0.01%
Optimal	Q1	Q2	Q3	Q4	Q5
Tax rate	16.71%	22.26%	26.96%	31.48%	42.76%
Transfer rate	118.67%	46.14%	19.10%	4.74%	0.28%

Notes: This table shows tax and transfer rates by income quintile in the data and according to the optimal fiscal system in the rich quantitative model.

generous than what is currently in place in the U.S. The optimal transfer rates are very large in the bottom two income quintiles. It is important, however, that tax rates are also high, even at the bottom. High marginal tax rates at the bottom drive up average tax rates at the top with little distortion to the labor supply of the most productive, as their marginal tax rates increase only slightly. This allows to finance this very large welfare state.

4 Conclusion

The U.S. federal government redistributes resources through both a progressive income tax and a large system of targeted transfers. In this paper we analyze the interaction of these two instruments and their joint optimality. We show theoretically that the optimal progressivity of the tax rates schedule should be lower when the government also uses transfers. This is due to both efficiency and redistribution reasons. The government lowers progressivity optimally to increase labor supply, making it easier to finance the additional expenditure. The transfer already reduces consumption inequality, reducing the gains from more progressive taxes.

Quantitatively, the optimal fiscal system in an incomplete markets model with realistic distributions of income and wealth features generous transfers with slow phase-out. The progressivity of the tax rates schedule is moderate. It is crucial to be able to disentangle average and marginal progressivity. This cannot be achieved with just a loglinear income tax function, but with an income tax function in combination with a lump-sum transfer. Using these tools optimally yields large welfare gains. Allowing the transfer to be means tested yields additional moderate welfare gains because it allows not only to have more progressive average than marginal tax rates, but also to have nonmonotonic marginal tax rates schedules.

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