Essays on Life-Cycle Choices

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Chapters

What does Academic Mismatch Mean?

Abstract

I examine the causes and macroeconomic consequences of academic mismatch—that is, the measured departure from perfect assortative matching—between student ability and college quality. I build a general equilibrium heterogeneous-agent model with college enrollment decisions. Agents receive noisy signals about their ability and face borrowing limits, psychic costs of education, and college capacity constraints. I estimate the model to match enrollment at colleges across student ability and ability premia across college quality. I find that the primary source of mismatch is the interaction of psychic costs (idiosyncratic tastes for colleges) with capacity constraints. If psychic costs are eliminated but capacity constraints are not relaxed, then mismatch rises by 15%. Capacity constraints themselves only account for 3% of the mismatch. However, if both psychic costs and capacity constraints are removed, mismatch falls by 40%. Noisy signals about ability account for 7%, and borrowing limits have little effect. I also find that the measure of mismatch does not help predict changes in output and welfare; output and welfare could go up or down in response to a fall in the measured mismatch. If mismatch increases due to a change in psychic costs, output also increases. In addition, if agents are sorted by ability and placed into colleges by decreasing quality, retaining the capacity constraints, mismatch falls to its minimum level, but welfare also falls.

Unemployment Insurance and COVID-19

with Geoffrey Byrle Carr [1]

Abstract

This paper examines the welfare implications of the unemployment insurance expansion policy under COVID-19. We build an equilibrium search and matching model with an incomplete market structure. We find that the expansion harmed households by an average of $2,400. Much of the benefits are paid to wealthy households choosing not to work during the pandemic due to health risk and large costs are imposed by the accumulation of government debt. We also find that UI expansion had little to no effect on the unemployment rate.

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What does academic mismatch mean?[1]

1 Introduction

Does it matter how students are allocated to colleges? Given the evidence for complementarity between student ability and education quality (Abbott et al. 2019; Dillon and Smith 2019; Reihl 2017), human capital gains would increase if high-ability individuals were educated at high-quality colleges. For instance, Dillon and Smith (2019) find strong complementarity in long-term earnings.[2] However, it is common that high-ability students do not go to college at all or enter two-year colleges, or relatively low-ability students frequently attend selective colleges (Cooper and Liu 2019; Roderick et al.2008; Smith et al.2013). Considering the quality—in terms of human capital production—among four-year colleges, many high-ability students end up enrolling at low-quality colleges when they could get into high-quality colleges (Bowen et al.2009; Dillon and Smith 2017, 2019; Mattern et al.2010). While there is no clear-cut definition of academic mismatch, the broad idea is that if the distance between student ability and college quality is large enough, it is considered a mismatch. The extent of mismatch documented in the literature is over 40% (Dillon and Smith 2017, 2019; Roderick et al.2008; Smith et al.2013). In this paper, I ask how academic mismatch is connected to aggregate output and welfare.

I build a general equilibrium heterogeneous-agent model of college choices. Education options are no college, two-year college, four-year less/non selective college, and

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[2]Using the National Longitudinal Study of Youth 1997, they find that a student at the median ability would gain $1,480 more annually in 2010 dollars 10-11 years after students begin college if college quality increases by 10 percentile points. Also, at the median of college quality, earnings at 10-11 years increase by $417 for a 10-percentile-point increase in student ability. They find these results by examining four-year college starters. Complementarity would be larger if those who either went to two-year colleges or did not go to college are included.

four-year selective college. I consider more margins than simply making the choice binary—going to college or not—since the costs and returns vary depending on the college quality. Based on college's selectivity classified by Barron's profile of American Colleges, Hoxby and Avery (2013) show that "Most Competitive" colleges costs approximately 1.7 times more than "Less Competitive" colleges.[3] Chakrabarti and Jiang (2018) find that attendees of selective colleges earn 20% more than nonselective college students 10 years after enrollment. In my model, colleges are technologies that transform ability into units of human capital. Agents can always choose to attend a two-year or four-year less selective college, but are not guaranteed entry into a selective college due to capacity constraints. Espinosa et al.(2019) document around 57% of undergraduates attend selective college in the academic year 2015-2016.The capacity constraint at a selective college is modeled through an admission probability that increases in the ability of agents. Agents become skilled workers if they have a four-year degree and unskilled otherwise. The college wage premium is endogenously determined by the relative supply of skilled and unskilled workers. There are several papers on college choice that use general equilibrium models to capture changes in relative wages. [4]However, none of these papers consider the selectivity of four-year colleges and capacity constraints. I investigate the role of capacity constraints at selective colleges and their interactions with other factors affecting college decisions. I also contribute to the literature on academic mismatch by explicitly modeling college capacity constraints. Dillon and Smith (2017) document the important determinants of academic mismatch with a rich set of covariates. However, they do not directly control for capacity constraints, which turn out to be a critical source of mismatch.

There are two types of mismatch. Overmatch occurs when relatively low-ability students attend high-quality college. Overmatched students are more likely not to complete four-year colleges than high-ability students. Also, given the capacity constraints at selec-

[3]See Table 1 in Hoxby and Avery (2013) for details. The cost of education increases in college selectivity.

[4]Examples include Abbott et al.(2019), Akyol and Athreya (2005), Johnson and Keane (2013), Krueger and Ludwig (2016), Winter (2014).

tive colleges, replacing overmatched students with high-ability students would increase output. Undermatch means when relatively high-ability students are either not going to college or going to lower-quality colleges. Given the complementarity, output would increase if undermatch is reduced. However, fixing both overmatch and undermatch does not necessarily lead to an increase in welfare.

Academic mismatch can occur as a result of four factors in the model: misperception of ability, borrowing limits, the psychic cost of education, and capacity constraints at four-year selective college. I quantitatively decompose the magnitude of each source of mismatch and investigate how these factors interact with each other. Goodman (2016) argues that students misperceive their ability, and the state mandate requiring high school students to take a college entrance test would provide better information about their ability. In my model, students make a college choice based on the signal about their ability. Mismatch occurs when high-ability individuals who think their ability is low do not attend selective colleges. Likewise, low-ability students with a high signal are mismatched if they enroll in high-quality schools.

Much of the literature has focused on borrowing constraints, college attendance, and educational attainment (Cameron and Tabe 2004; Johnson 2013; Keane and Wolpin 2001; Lochner and Monge-Naranjo 2011; Navarro 2011). Students who are financially constrained might not be able to smooth consumption during college years or afford the cost of education at colleges. Hence, they attend lower-quality colleges that are relatively cheaper than the selective ones or enter the labor market with a high school diploma, which generates a mismatch. Note that borrowing limits as a source of mismatch are primarily relevant for high-ability students, because mismatch for low-ability students occurs when they attend selective colleges.

Capacity constraints produce a mismatch if high-ability students are not admitted because all available seats were filled by lower-ability students. Lastly, psychic costs of education play an important role in college decisions, as shown by Cunha et al.(2005)

and Heckman et al.(2006). They find that psychic costs explain why students who face high returns choose not to go to college. Agents in my model have different psychic costs for different types of college. Mismatch would be generated if high-ability students who could easily get into selective colleges do not want to go to college. Psychic costs are residuals that capture all of the other factors.

To discipline the model, I measure academic mismatch using the National Longitudinal Study of Youth 1979 (NLSY 1979). Restricted geocode data enables me to pair individuals with the colleges they started at, transferred to, and finished. College data are drawn from the Integrated Postsecondary Education Data System. I find that about 43.9% of students are mismatched, and most of the mismatch is undermatch. In the estimation of the wage process, I find evidence of complementarity between student ability and college quality. A 10-percentile-point increase in ability increases earnings by 6.6% if one graduated from a two-year college and 8.2% if one went to a four-year selective college. I also estimate the aggregate human capital function parameters by regressing relative wages on relative human capital levels. The estimated elasticity of substitution between unskilled and skilled labor is 1.9, a number that falls within the range of estimates in the literature.In addition, I match enrollment rates by student ability quartile and education options using the method of moments estimation. The estimation shows that the noise accounts for 20% of the ability signal. The mean and variance of psychic costs vary by type of college. For instance, the mean of psychic costs for nonselective college is the largest, and the variance for selective college is the largest. The role of means is to match the overall enrollments across colleges, whereas differences in variances capture the difference in enrollments across abilities. For example, large variance of psychic cost for selective college captures 1) low-ability students who enjoy high utility gain (psychic benefit) from attending selective college and 2) high-ability students who do not go to selective school because of huge psychic costs.

I conduct several simulation exercises with the estimated model. By shutting down each factor that affects college decisions, I find that the interaction of psychic costs with capacity constraints is the main driver of mismatch. The enrollment rates at all education options across student abilities change substantially if psychic costs are eliminated. Four-year selective college becomes very attractive with no psychic costs. As a result, over 80% of the total students apply to a selective school. Due to capacity constraints, enrollment at four-year less/non-selective college spikes up since students who are not admitted to selective colleges attend nonselective colleges. As a result, mismatch increases by 15%. However, if both psychic costs and the capacity constraints are removed, mismatch falls by 40%. The fall in the mismatch is driven by two groups of students. On the one hand, most students with ability higher than the median attend selective colleges, lowering the mismatch. On the other hand, those in the lowest ability quartile shift their choice from college to no college because of the rise in the unskilled wage rate.

If all the noise are eliminated, mismatch falls by 6.8% because students are better sorted. As a result, output rises by 0.6% and welfare by 2.1%. Borrowing constraints barely affect the mismatch, consistent with Cooper and Liu (2019). Capacity constraints account for 3.0% of the measured mismatch. If capacity constraints are eliminated, students who would not have gone to selective college go to selective college and earn more. Output and welfare increase by 1.8% and 1.6%, respectively. The decomposition results indicate important policy implications. If we can reduce through policies reducing academic mismatch caused by inefficient factors such as noise in one's signal and borrowing limits, students would be better off as well as get a boost in labor income. One example of policies is a state-wide mandate that requires high school students to take a college entrance exam like the SAT or the ACT. Goodman (2016) shows that enrollments at the selective college increase by 10 to 20% depending on the measure of selectivity of college. Hoxby and Turner (2013) show that informational intervention could induce high-achieving, low-income students to attend selective colleges. Several papers document the effectiveness of informational intervention other than making students better understand themselves. Bettinger et al.(2012) find that college enrollments would increase if students were better informed about available financial aid programs and received help in submitting application processes. Dillon and Smith (2017) argue that going to high schools where many graduates attend colleges and the share of college graduates in the student's census tract helps students be well-informed about colleges.

Measured mismatch does not help predict changes in output and welfare; output and welfare could go up or down in response to a fall in measured mismatch. If mismatch falls due to the elimination of either noise about ability, borrowing limits or capacity constraints, both output and welfare increase. However, output can move in the same direction as measured mismatch if the psychic costs of education change. For example, if there are no psychic costs for two-year college, mismatch rises by 25.3% because a large number of individuals who would have attended a four-year college switch to a two-year college. Also, many of those who would have chosen no college attend a two-year college, instead. The net result is that output increases by 1.5%. Welfare can also change in the same direction as mismatch. If students are re-sorted by ability and college quality in an assortative manner, mismatch falls to its minimum level and output increases by 4.3%, but welfare falls.[5] Therefore, policies that reduce the measure of mismatch would not necessarily make people better off.

There are heterogeneous effects of each source across ability. An incorrect prediction about ability matters more for lower-ability students. Removing the noise reduces mismatch by 15.3% for students below the median ability and 1.8% for students above the median. Psychic costs at four-year colleges dampen the effect of noisy signals for relatively high-ability students. Borrowing limits matter more for high-ability students. Mis-

[5]Dillon and Smith (2019) show the implications of academic mismatch on aggregate output by eliminating mismatch completely among college starters in a partial equilibrium context. Their counterfactual exercise is mainly different in two important ways. First, they only focus on four-year college starters. Also, they do not allow relative wages to change in response to changes in the relative supply of labor. In my analysis, if students are sorted by ability, and relative wages change, welfare falls by 4.4% compared with when relative wages remain fixed. Output response is the same regardless of changes in the relative prices because students are forced to attend their matched college. However, in other exercises, output response is dampened because of the changes in relative wages.

match would barely change for low-ability students if borrowing limits are relaxed, but mismatch falls by 1.4%, and welfare rises by 0.4% for the highest ability quartile group. The effects of capacity constraints vary significantly across the ability quartile. If capacity constraints are eliminated, the mismatch goes up by 9.6% for the second-lowest ability quartile since they benefit from selective schools with guaranteed admission. However, mismatch falls by 12.1% for the highest ability quartile.

The rest of the paper is organized as follows. Section 2 describes the data and measures academic mismatch. Section 3 describes the model and defines the stationary equilibrium. Section 4 estimates the model parameters, and Section 5 conducts simulations and presents results. Section 6 concludes.

2 Evidence of mismatch

Existing literature documents that there is a substantial mismatch between student ability and college quality. Academic mismatch refers to cases in which 1) high-achieving students attended relatively low quality colleges or did not go to college at all (referred to as undermatch), and 2) low-achieving students enrolled in relatively high quality colleges (referred to as overmatch). Focusing only on four-year colleges in the National Longitudinal Study of Youth 1997, Dillon and Smith (2017) show that over half students are mismatched (28% overmatched, 24% undermatched). Smith et al. (2013) expands the scope of academic mismatch by including students going to two-year colleges and students who did not choose to go to college. They show that about 41% of students are undermatched. Notice that outcomes of the match are irrelavant because the characteristics of students and colleges are what determines a mismatch. Therefore, all the measured mismatch do not mean inefficient allocation since students could still be mismatched with all the necessary information and no frictions. For example, students are undermatched if they fail to receive an admission from top schools because of capacity constraints.

In this section, I measure the mismatch between student ability and college quality in order to discipline the model described in the next section. College quality is classified into four categories as in the model: no college, two-year college, four-year less/non selective college, and four-year selective college.

2.1 Data

I draw information from the NLSY 1979 which includes 12,686 American youth who were 14 to 22 years old in the beginning of 1979. The participants were followed annually from 1979 to 1994, and biannually since then. I exclude military samples and economically disadvantaged, non-black/non-Hispanic samples as they were not interviewed since 1990. I use the base year weight constructed by the Bureau of Labor Statistics.

The NLSY 1979 contains a rich set of data on individual and family background, educational attainment, and labor market outcomes. Since my focus is on the college choice including not attending a college, I exclude individuals who do not have a high school diploma or GED. Furthermore, I did not include those who started a college after 21 years of age because their starting lines are different from most of college-ready individuals who are between 18 - 20. Ability is measured by the Armed Force Qualification Test (AFQT), which is widely used measure of cognitive ability in the fields of social science. The AFQT test includes Arithmetic Reasoning, Word Knowledge, Paragraph Comprehension, and Numerical Operations. Since the scores are not directly comparable across people of different ages, I follow Altonji et al. (2012) to adjust scores. After dropping observations without the AFQT score the number of samples becomes 6,081.

The restricted use of the NLSY 1979 geocode enables me to keep track of colleges individuals ever enrolled. I observe not only the institutions individuals started for the first time but also institutions they transfer.[6] I use the college data from the Integrated

[6] One problem in the NLSY 1979 geocode is that the college information was collected starting in 1984 when most individuals started college between 1980 and 1984. I infer the year individuals started college by looking at other information such as the highest grade compeleted and highest degree attained.

Postsecondary Education Data System (IPEDS) and merge it with the NLSY 1979. The selectivity among four-year colleges are based on the median SAT/ACT scores that colleges report.[7] I follow the Barron's criterion to determine the selectivity among four-year colleges. [8] Colleges are classified as selective if the median SAT score is greater or equal to 1000 (ACT 21). All the other four-year colleges are less/non selective including colleges that do not require the SAT or the ACT scores, and colleges with open admission policy.

2.2 Measuring mismatch between student ability and college quality

Academic mismatch is lack of assortative matching between student ability and college quality. There is no clear-cut definition of mismatch and papers employ different definitions of mismatch.[9]

I divide students into four-groups by ability, and measure the mismatch as follows. If a students who belongs to the lowest ability quartile and attend any college, then she is mismatched (overmatch). If one's ability is the second quartile and attends either a nonselective or a selective four-year college, then it is a mismatch (overmatch). If individuals whose ability is within the third quartile do not attend any four-year colleges, then they are mismatched (undermatch). Lastly, if someone in the highest ability quartile does not attend four-year selective college, then it is a mismatch (undermatch).

Table 1 shows how students of different ability quartiles are distributed into different levels of education. Numbers are head counts and the numbers in brackets are the share of students with the same ability quartile. Students tend to receive better education as

[7]One limitation is that the earliest score reports available from IPEDS was the academic year 2001/2002. Given that most of the individuals in NLSY 1979 made their college decisions in the early 1980s, this limitation could lead to an incorrect measure of selectivity. However, I believe that the college quality would remain fairly unchanged since I divide all four-year colleges into two categories.

[8]Barron's College Admission Selector use several criteria including high school ranking, grade point average, and median SAT/ACT score. I only use the median SAT/ACT score.

[9]For example, focusing only on four-year college starters, Dillon and Smith (2017; 2019) create measures of student ability and college quality on a scale of 1–100, and call it a mismatch if the difference between the two measures are over 20.

Table 1: Educational level (initial choice) by ability quartile, NLSY 1979

	Education level				
Ability quartiles	No college	Two-year	Four-year non-selective	Four-year selective	Total
1st quartile (lowest)	1,009	**324**	**166**	**50**	1,549
	(65.1)	(20.9)	(10.7)	(3.2)	(100)
2nd quartile	655	397	**259**	**133**	1,444
	(45.4)	(27.5)	(17.9)	(9.2)	(100)
3rd quartile	**491**	**428**	303	344	1,566
	(31.4)	(27.3)	(19.3)	(22.0)	(100)
4th quartile (highest)	**168**	**332**	**299**	723	1,522
	(11.0)	(21.8)	(19.6)	(47.6)	(100)
Total	2,323	1,481	1,027	1,250	6,081
	(38.2)	(24.4)	(16.9)	(20.5)	(100)

Note: Samples have a non-missing AFQT score and hold a high school diploma or a GED. Individuals who started college after 21 are excluded. Numbers in parentheses are the shares of individuals for each ability quartile.

ability quartile gets better. Only 50 students among the first ability quartile are enrolled in selective schools, while 723 students in the highest ability quartile attend selective colleges. The reverse is also true. 65% of students from the lowest ability group choose not to go to any college, whereas only 11% in the highest ability group pick no college option.

According to the definition above the size of mismatch (numbers in bold) is 43.6%. Note that the size of mismatch increase if I add more category for four-year colleges and define mismatch more strictly. However, the focus of the paper is not on the measuring the mismatch precisely, but on quantifying the size of each source of mismatch and examining if mismatch is welfare-reducing. To that end, I build a structural model of college choice and have the model reproduce Table 1.

3 Model

3.1 Set up

One period corresponds to two years, and agents live infinitely many periods. Each individual has preference over consumption c:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{1}$$

where γ denotes the coefficient of relative risk aversion. Based on the existing literature I set $\gamma = 2$[10]. The utility function is additively separable and the discount factor is β.

The life-cycle of agents consist of three stages: they make an education choice in the first stage, continuing at four-year college in the second stages, and work until they are replaced by the new-borns in the final stage. Agents are young for two periods (new-born in the first period and young in the other period) and they become an adult in the subsequent periods. In every period, adults are subject to the mortality rate ρ, so the size of ρ new-born agents arrive to the economy, replacing the adults. Therefore, at any point in time there are ρ fraction of new-born, ρ young agents, and $1-2\rho$ adult agents. New-borns receive asset a from adults who die.

All agents are heterogeneous in ability denoted by θ, which follows normal distribution with mean zero and variance σ_θ^2. Agents just born receive a noise signal about their ability $\tilde{\theta}$, which satisfies:

$$\tilde{\theta} = \theta + \zeta \tag{2}$$

where the noise ζ is normally distributed with mean zero and variance σ_ζ^2. I assume that both θ and ζ are independent.

Newborns make an education decision out of four options: no college ($D = 1$), two-year college ($D = 2$), four-year non/less selective college (4-LS) ($D = 3$), and four-year

[10]See, for example, Aiyagari and McGrattan (1998)

selective college (4-S) ($D = 4$). I consider more margins than simply making the choice binary—going to college or not—since the costs and returns vary depending on the college quality.[11] Categorizing four-year colleges is also crucial as it provides a more accurate picture of the size of the mismatch, making it possible to analyze the implications of the mismatch. [12]

As analyzed in Keane and Wolpin (2001) and Cunha et al.(2005) the psychic costs of education (college preparedness or taste for education) are important elements in college choices. In the model, agents have idiosyncratic tastes for each college ϵ_D for $D = \{2, 3, 4\}$. Some agents gain utility from going to college, while others receive disutility. The preference for no-college is set to be zero. All ϵ_D are independent and normally distributed with mean μ_D and variance σ_D^2.

I do not model colleges as economic agents who make admission decisions based on student ability. Rather, colleges are technologies which transform ability into units of human capital. Therefore, agents may attend whichever college they prefer among their choice set except selective schools due to the capacity constraints which restrict the maximum number of students. The capacity constraint is modeled indirectly through the admission probability $p_A(\theta)$. Agents who choose four-year selective college are subject to $p_A(\theta)$ which is increasing in ability θ, making high-performing students more likely to get into selective school. Those who are not admitted to selective college attend less/non selective college as they have an intention to be educated at four-year college.

One important feature about college data in the NLSY 1979 restricted geocode is that it contains names of colleges respondents started at, transferred to, and finished. Interestingly, more than half of students either dropout or transfer up/down. Hence, in the model agents are subject to a transition matrix $\pi_D(e, \theta)$ –a function of one's initial choice

[11] See Table 1 in Hoxby and Avery (2013) for differences in costs, and Chakrabarti and Jiang (2018) for differences in returns to college.

[12] Cooper and Liu (2019) measure mismatch for 21 countries using OECD data. However, the size of mismatch is small because they consider only two options: no education and four-year college degree. In addition, mismatch is generated only from individuals whose ability is below 20th and above 80th percentile in the ability distribution based on their measure of mismatch.

D, final education, e, and ability θ– which incorporates both dropout and transfer. The transition matrix is exogenously given since I have no data on reasons why students drop out or transfer up/down. Conditional on D, dropout probability decreases in ability. As Stinebrickner and Stinebrickner (2003) document that the median time to drop out is two years, all dropouts occur one period after making college choices. I also assume that all transfers happen at the end of the first period. Education outcome e is determined after all transitions occur. The education outcome for those who choose not to attend college or fail to graduate from any college becomes $e = 1$. The education level of two-year college graduates is $e = 2$, and the education level becomes $e = 3$ or $e = 4$ if one graduates from less/non selective or selective colleges, respectively.

The cost of education T_D for $D = \{2, 3, 4\}$ includes tuition, required fees, books, and other expenses. T_D increases as D increases, and the cost of college is paid every period. Therefore, a dropout student from a four-year college does not pay the cost in the second period. The equal amount of grants $\mathfrak{g}_D$ are given to every student. Like the cost of education, the amount of grants also increases in D. College students have a borrowing limit, so they can only borrow up to $\bar{a}$.

Human capital, $H(e,\theta)$, is an effective unit of labor and accumulated through education. Human capital is increasing both in education outcome e and ability θ. I assume the following form for human capital function:

$$H(e,\theta) = \theta^{\lambda_e} \tag{3}$$

where λ_e is the ability gradient. λ_e for each e are to be estimated outside the model. I describe the details in the estimation section.

Education outcomes are finalized in the first period if one chooses no college or in the second period after the transition occurs. Agents provide labor inelastically and make consumption/savings decisions until they are replaced by a new generation. Agents with

$e = 1$ or $e = 2$ become unskilled and those with a Bachler's degree $e \in \{3, 4\}$ become skilled workers. The steady-state wage rates for unskilled and skilled labor are given by w_u and w_s, respectively. Labor income is determined by one's human capital and skill type. For example, an agent with a BA degree earns $(1-\tau)w_s H(e, \theta)$, where τ is the income tax rate. The interest rate r is exogenous and remains constant as the change in the interest rate in response to education choice is marginal. I set $r = 0.0816$ which reflects the annual rate of 0.04.

3.2 Education

Newborns make an education choice given the perceived ability $\tilde{\theta}$, asset holdings a, and taste shock ϵ_D for each college . The value function for is written as:

$$V_{nb}(a, \tilde{\theta}, \epsilon_2, \epsilon_3, \epsilon_4) = \max_{D=1,2,3,4} \{EV_{nb}^D\} \tag{4}$$

where V_{nb}^D is the value of the option D and the expectation is computed based on the conditional distribution of ability.

The value of not going to college, V_{nb}^1 satisfies:

$$V_{nb}^1(a, \theta) = \max_{c, a'} u(c) + \beta V_y^1(a', \theta) \tag{5}$$

$$s.t.$$

$$c + a' = (1 + r)a + (1 - \tau)w_u H(1, \theta)$$

where w_u is the wage rate for those who do not have college degree and V_y^1 is the value of young agents with $e = 1$. Agents who choose not to go to college start working. Since the psychic cost of education is zero for those who do not receive higher education, I drop the ϵ in the value function.

The value of two-year college V_{nb}^2 is:

$$V_{nb}^2(a,\theta,\epsilon_2,\epsilon_3,\epsilon_4) = \max_{c,a'} u(c) + \epsilon_2 + \beta \sum_{e=1,2,3,4} \pi_2(e,\theta) V_y^e(a',\theta,\epsilon_3,\epsilon_4) \tag{6}$$

$$s.t.$$

$$c + a' + T_2 = (1+r)a + \mathfrak{g}_2, \qquad a' \geq \bar{a}$$

where π is the transition matrix and V_y^e is the value of the young agents with the education outcome e. The transition matrix takes into account all the possible outcomes for agents given their initial college choice and the ability. Psychic cost, ϵ_2 is directly added to the current utility, and agents might incur psychic costs for nonselective ϵ_3 or selective college ϵ_4 if they transfer to four-year colleges.

The value of four-year non/less selective college V_{nb}^3 is the same as V_{nb}^2 if the subscripts in the psychic cost, transition matrix, cost of education, and grants are 3 instead of 2. The value of four-year selective college V_{nb}^4 is similar to V_{nb}^3, but due to the capacity constraint, agents who choose selective college face an admission probability $p_A(\theta)$. Agents who apply selective college solve the following problem:

$$V_{nb}^4(a,\theta,\epsilon_3,\epsilon_4) = \max_{c,a'} p_A(\theta) W_{nb}^4(a,\theta,\epsilon_3,\epsilon_4) + (1-p_A(\theta)) V_{nb}^3(a',\theta,\epsilon_3,\epsilon_4) \tag{7}$$

where W_{nb}^4 is defined similarly as V_{nb}^2 except the subscripts.

$$W_{nb}^4(a,\theta,\epsilon_3,\epsilon_4) = \max_{c,a'} u(c) + \epsilon_4 + \beta \sum_{e=1,2,3,4} \pi_{4e}(\theta) V_y^e(a',\theta,\epsilon_3,\epsilon_4) \tag{8}$$

$$s.t.$$

$$c + a' + T_4 = (1+r)a + \mathfrak{g}_4, \qquad a' \geq \bar{a}$$

The value of young agents with $e = 1$ or $e = 2$ is:

$$V_y^e(a,\theta) = \max_{c,a'} u(c) + \beta V_A^e(a',\theta) \tag{9}$$

subject to $c + a' = (1+r)a + (1-\tau)w_u H(e,\theta)$. V_A^e is the value of adult agents with the education achievement e. Since agents with $e = 1$ or $e = 2$ do not have bachlor's degree, they receive the wage rate for unskilled workers. The value of young agents for $e = 3$ or $e = 4$ is defined differently since they still at four-year college in the second period. The value of young agents at any four-year college ($e = 3$ or $e = 4$) satisfies:

$$V_y^e(a,\theta,\epsilon_e) = \max_{c,a'} u(c) + \epsilon_e + \beta V_A^e(a',\theta) \tag{10}$$

subject to $c + a' + T_e = (1+r)a + \mathfrak{g}_e$ and $a' \geq \bar{a}$. The psychic costs of education affect agents' flow utility again since they are at college. The value of adult agents V_A^e is

$$V_A^e(a,\theta) = \max_{c,a'} u(c) + \beta(1-\rho)V_A^e(a',\theta) \tag{11}$$

subject to $c+a' = (1+r)a+(1-\tau)w_j H(e,\theta)$, where $j = u$ if $e = 1$ or $e = 2$ and $j = s$ otherwise. $(1-\rho)$ is the survival rate for adults, and hence the effective discount rate is $\beta(1-\rho)$.

3.3 Production

There is a representative firm which hires workers in a competitive labor market and operates in a competitive market. The firm has a Cobb-Douglas production function $F(K,\mathcal{H}) = K^\alpha \mathcal{H}^{1-\alpha}$. The capital share $\alpha = 0.36$ as in Kydland and Prescott (1982). There are five inputs: capital and four labor.

Following Katz and Murphy (1992) the aggregate labor input $\mathcal{H}$ is a constant elasticity of substitution aggregator.

$$\mathcal{H} = \{s_u(H_1+H_2)^\mu + (1-s_u)(H_3+H_4)^\mu\}^{\frac{1}{\mu}} \tag{12}$$

where H_e is an aggregate labor input for workers with the education outcome e, s_u is a share of unskilled labor and μ governs the elasticity of substitution between unskilled and skilled labor. The unskilled and skilled labor are imperfectly substitutable. μ and s_u are estimated using the NLSY 1979. I explain the details in the estimation section.

3.4 Equilibrium

The stationary recursive competitive equilibrium of the economy is computed numerically. Given prices individuals maximize their expected lifetime utility by choosing the best education option, consumption and savings. Firm maximizes its profits by choosing capital and labor inputs. All markets are clear except the capital market since the interest rate r is exogenous.

Let $X = \Theta \times A \times \Sigma_2 \times \Sigma_3 \times \Sigma_4$ be the state space, where Θ is support of θ, A denotes the domain of asset holdings, Σ_i is the domain of each preference shock ϵ_i. Let χ_B be the Borel σ-algebra on X. The measure of agents on (X, χ_B) is denoted by Φ. A stationary equilibrium is a set of value functions $(V_{nb}, V_{nb}^D, V_y^e, V_A^e)$ for $D \in \{1,2,3,4\}$ and $e \in \{1,2,3,4\}$, prices (w_u, w_s, r), policy a' and a measure of Φ that satisfy the following:

1. The policy function for the asset choice is optimal given prices.

2. The firm maximizes profits. Labor inputs H_1, H_2, H_3, H_4 satisfy:

$$w_u = \frac{\partial F(K, H_1, H_2, H_3, H_4)}{\partial (H_1 + H_2)} \text{ and } w_s = \frac{\partial F(K, H_1, H_2, H_3, H_4)}{\partial (H_3 + H_4)}$$

3. The labor market clears for both unskilled and skilled workers.

$$\text{unskilled labor: } H_1 + H_2 = \rho \int \theta^{\lambda_1} d\Phi^* + \rho \sum_{D=2,3,4} \int_{e \in \{1,2\}} \theta^{\lambda_e} \pi_D(e, \theta) d\Phi^* + (1-2\rho) \int_{e \in \{1,2\}} \theta^{\lambda_e} d\Phi^*$$

$$\text{skilled labor: } H_3 + H_4 = (1 - 2\rho) \int_{e \in \{3,4\}} \theta^{\lambda_e} d\Phi^*$$

The first term in the unskilled labor clearing condition is for newborns who choose not to go to college, and the second term is the sum of agents whose education outcome is either $e = 1$ or $e = 2$ in the second stage. Last term is the sum of unskilled adult workers. For the skilled labor, there are $1 - 2\rho$ fraction of adults who have a Bachelor's degree.

4. The government budget is constant every period.

$$G = \tau\{w_u(H_1 + H_2) + w_s(H_3 + H_4)\} - \rho \sum_{D=2,3,4} \int \mathfrak{g}_D d\Phi^* - \rho \sum_{D=3,4} \int \mathfrak{g}_D d\Phi^*$$

where the first term is the tax revenue from the labor income and the next two terms are grants distributed to college students, one to newborn students and the other to young agents who continue at four-year colleges.

5. Φ^* is a stationary probability measure.

4 Estimation

In this section, I describe how to estimate and parameterize the model parameters. There are three sets of parameters. First sets of parameters are specified in advance such as the elasticity of substitution between capital and labor and intertemporal elasticity of substitution. Second sets of parameters are estimated outside the model using the NLSY 1979. These include parameters for wage processes and the aggregate production function. The rest of the parameters are estimated by the method of moments estimation.

4.1 Parameters set in advance

Borrowing limits. College students have borrowing limits. In 1986-1987, the subsidized loan limits for dependent students for two years are $10,900 adjusted in 2010 dollars, according to Trends in Understanding Borrowing: Federal Student Loans published in 2000. Therefore, students at any college can borrow up to $\bar{a} = \$10,900$.

Signal about ability. Noisy signals agents receive are from the adjusted AFQT score distribution. The mean and standard deviation of the distribution are 163.5 and 30.4. I assume that true ability has the same mean as the signal and standard deviation σ_θ. I further assume both true ability and noise are normally distributed.

Mortality rate. Infinitely lived agents are replaced by newborns every period at the rate of ρ. Newborns are college-ready when they arrive to the economy. I set $\rho = 0.038$ to reflect the fact that the mean age of mothers for all births is around 26 (Mathews and Hamilton 2002, 2016).

Cost of education and grants. Most individuals in the NLSY 1979 started colleges between 1980 and 1984. The earliest data available with detailed information about the cost of education is for the academic year 1986-1987. A Report of the 1987 National Postsecondary Student Aid Study (1987 NPSAS) contains detailed data on average amount of expenses by types of expense, housing status, and level of institution. Moreover, it contains students enrollment by the level and the control of institutions. The cost of education is the sum of tuition and fees, and other expenses (transportation, books and supplies, and other miscellaneous personal expenses). 70% of students attend public colleges and the other 30% students private-not-for-profit colleges among four-year students. I use these shares to compute the cost of education for four-year colleges. The cost of four-year college for two-years is $\$18,300$ and that of two-year college T_2 is $\$8,750$. Data from the Integrated Postsecondary Education Data System (IPEDS) shows that the selective colleges cost approximately 1.45 times more than non/less selective colleges. In the NLSY 1979, 45% of students went to 4-NS and 55% of students went to 4-S. Using these information, I set the cost of education for 4-LS, $T_3 = \$14,700$ and for 4-S, $T_4 = \$21,300$. Grants are computed similarly using the data from 1987 NPSAS. I compute that $\mathfrak{g}_2 = \$1,500$, $\mathfrak{g}_3 = \$4,250$, and $\mathfrak{g}_4 = \$6,150$.

4.2 Ability gradient

I use the NLSY 1979 to estimate the effect of ability and education outcome on log wages. Ability θ is proxied by AFQT scores. There are two measures for wages in the NLSY 1979: 1) hourly rate for the first five jobs, 2) total earnings and total hours worked in the previous calendar year. Since the first measure of wages contains lots of missing information, I use the second measure. The number of individuals with positive wage rate is 6,056 and the number of individual-time pair is 115,543. I drop observations with positive wage during college years as assumed in the model, which makes the the number of individuals 6,036 (102,738 i-t pairs). I exclude observations if hourly rate is less than \$1 or greater than \$500 adjusted in 2010 dollar. The number of individuals becomes 6,029 (101,985 i-t pairs).

I control for various covariates, including family and individual characteristics. Although all the covariates except ability exist in my structural model, in order to better capture the effect of ability on earnings, I control for these variables that could potentially affect earnings. The endogeneity coming from the education choices disappears as I separately estimate the effects of ability, λ_e by education outcomes, $e \in \{1,2,3,4\}$. Assuming that the error term is uncorrelated with the covariates as in the model, I run a simple OLS regression of log earnings on log AFQT scores with controls.

Table 2 shows the resulting estimates. All the coefficients on ability are statistically significant at 1% level. The ability gradient increases in education outcome, which is an evidence of a strong complementarity in earnings between student ability and quality of education. A 10-percentage point increase in ability will increase earnings by 6.7% if one graduated from two-year colleges and 8.2% if one went to four-year selective colleges. This finding is in line with Dillon and Smith (2019) and Abbott et al.(2019).

4.3 Aggregate Production Function

Table 2: Ability Gradient λ_e for each education outcome

	No College	Two-year	Four-year less selective	Four-year selective
Ability	0.588	0.664	0.777	0.817
	(0.056)	(0.168)	(0.202)	(0.170)

Note: Standard errors are clustered at the individual level and reported in parentheses.

The labor input in the aggregate production function takes the CES form as in the equation (12). Using the first order conditions the log relative wage rate for unskilled and skilled labor is written as the following:

$$\log \frac{w_{ut}}{w_{st}} = \log \frac{s_u}{1-s_u} + (\mu - 1)\log \frac{H_{1t}+H_{2t}}{H_{3t}+H_{4t}} \tag{13}$$

where w_{ut} and w_{st} are the price of labor for unskilled and skilled workers, respectively.

I estimate μ and s_u based on the above equation. To that end, I first filter out the effects of time-varying covariates from individual log wages. Then, I take the first difference to eliminate any effect of time-invariant covariates including one's ability. Time series for changes in prices can be estimated through time dummies. Lastly, I can recover all the market prices with a normalization of the wage rates. The log relative labor supply in time t is the sum of individuals' human capital, which is computed by equation (3) in the model.

I use the total head count for each human capital stock as an instrument for the relative labor supply to avoid a potential endogeneity problem. The IV estimate for μ is 0.475 making the elasticity of substitution between unskilled and skilled labor 1.90, which falls in the range of estimates reported in the literature.[13] The estimated values for shares for unskilled and skilled workers are $s_u = 0.59$, $s_s = 0.41$.

[13] Katz and Murphy (1992) report 1.44. Based on three-type classfication of labor – high school dropouts, high school graduates, and college graduates – Goldwin and Katz (2007) estimate the elasticity of substitution between college and non-college workers to be 1.64. The estimate in Card and Lemieux (2001) is 2.5.

4.4 Method of moments estimation

Given the pre-set and estimated parameters explained above, the rest of the model parameters are to be estimated using the method of moments. The idea is to find a set of parameters that minimize the difference between data moments and the model counterparts. I target the wealth-income ratio to match the time discount factor β and 12 enrollment rates that vary by ability quartile and education level. The model is overidentified as there are 9 parameters and 13 moments. In addition, The distance between data and model moments is measured by percent differences. I use an identity matrix to weigh each moment.

Table 3 shows the list of parameters and their estimated values. I assume that both the noise and the ability follow a normal distribution. The mean and variance of the signal are the mean and variance of the AFQT score distribution. Given that the variance of the signal is 30.4, the estimated standard deviation for ability implies that 20.2% of the the variance in the signal is noise.

ξ is the parameter that governs the admission probability at selective colleges to indirectly model the capacity constraints. Specifically, I choose the following functional form for the admission probability:

$$p_A(v(\theta)) = \frac{1}{\xi - 1}(\xi^{v(\theta)} - 1), \xi > 1$$

where v is the cumulative density of ability θ. The idea behind the admission probability is that high-ability agents are more likely to be admitted to selective college than low-ability agents. In order to capture one's ability relative to others', I use the cumulative density which takes a value between zero and one. Note that p_A is a convex, $p_A(0) = 0$ and $p_A(1) = 1$.

There are six parameters – mean and variance – for the psychic costs at two-year college, four-year non/less selective college, and four-year selective college. Psychic costs are utility costs that are added to the flow utility. The mean of psychic cost for two-year college is the lowest since it takes lesser time than four-year colleges to graduate. μ_3 is the larger in magnitude than μ_4 for two reasons. First, μ_4 does not need to be big in order to match the fact that the total enrollment at four-year selective school is relatively low because the capacity constraint reduces the enrollments to some extent. Also, the expected return to one's time and effort of attending four-year less selective college is low relative to going to four-year selective college. Conditional on not being admitted to four-year selective college, agents are better off by choosing two-year college instead of four-year less selective college. The enrollment rates for two-year college for the third and the fourth ability quartile are higher than four-year non selective college as in Table 3.

The standard deviation at four-year selective college, σ_4 is very big relative to σ_3. The intuition of high variance at selective college is to capture low ability students attending selective college and high ability students not attending selective college. σ_4 needs to be big so that low ability students with big psychic benefits attend four-year selective college even with low ability probability and high ability students do not go into selective college because of high psychic costs.

Table 3: Estimated parameters

Parameter	Description	Value
β	Time discount factor	0.9694
σ_θ	Standard deviation of ability	27.19
μ_2	Mean of the psychic cost for two-year college	-0.021
σ_2	Standard deviation of the psychic cost for two-year college	0.045
μ_3	Mean of the psychic cost for 4-LS	-0.093
σ_3	Standard deviation of the psychic cost for 4-LS	0.012
μ_4	Mean of the psychic cost for 4-S	-0.045
σ_4	Standard deviation of the psychic cost for 4-S	0.135
ξ	Parameter governing the admission probability	1.01

The top panel of Table 3 shows the enrollment rates in the data and the bottom panel shows the enrollment rates in the model. Following the definition of mismatch in section

2 the size of mismatch is 43.6% in the data and 43.9% in the model. One can also see the fit of the model by examining the size of undermatch and overmatch. 28.3% of agents are undermatched in the data, while 27.4% are undermatched in the model. The overmatch is 15.3% in the data and 16.5% in the model. The target ratio of wealth and income is 4 and the model moment for it is 4.7. Given that the model is overidentified and no weighting matrix is used, the difference in each moment shown in Table 4 seems small.

Table 4: Enrollment rates

Education level (Data)				
Ability quartile	No college	Two-year	Four-year non/less selective	Four-year selective
1	0.166	0.053	0.023	0.008
2	0.108	0.065	0.043	0.034
3	0.073	0.070	0.050	0.057
4	0.028	0.054	0.049	0.119

Education level (Model)				
Ability quartile	No college	Two-year	Four-year non/less selective	Four-year selective
1	0.151	0.053	0.039	0.006
2	0.116	0.068	0.043	0.024
3	0.069	0.072	0.050	0.059
4	0.031	0.069	0.032	0.117
Total	0.367	0.262	0.164	0.206

4.5 Identification

The key of identification lies in understanding the role of each parameter. To that end, first I describe how the psychic costs work in the model and then show the response of moments to local variations in parameters.

Under the assumptions that all the psychic costs are normally distributed, I can compare the two education options at each time and compute the exact probability of choosing one over the other given a state. For given two options, i and j, the probability that an agent with a state variable (a,θ) chooses option i over j is

$$p_{ij} = Pr(V(a,\theta,i) + x_i > V(a,\theta,j) + x_j)$$

where $V(a,\theta,k)$ is the value of option k and x_k is the random variable for the psychic cost of option k. Since x_i and x_j follow normal, the difference between the two also follows normal.

$$p_{ij} = Pr(x_j - x_i < V(a,\theta,i) - V(a,\theta,j)) \tag{14}$$

where $x_j - x_i$ has mean $\mu_j - \mu_i$ and variance $\sigma_i^2 + \sigma_j^2$.

The probability of choosing option i over option j increases when $\mu_j - \mu_i$ decreases. For example, when the mean of psychic cost for two-year college increases, then p_{12} decreases. Figure 1 depicts how enrollment rates change in response to a change in parameters. I randomly draw means (μ_2, μ_3, μ_4) holding other parameters fixed. Each point in a graph shows an enrollment rate for a given set of parameters. As μ_2 increases, the share of those who choose no college option falls, whereas the enrollment rates at two-year college rises. A rise in μ_2 mostly affect the education options between no college and two-year college. However, it has almost no effects on the enrollments at four-year colleges because the changes in μ_3 and μ_4 cancel the effect of rising μ_2. The responses of the enrollment rates when μ_3 and μ_4 change are similar. These two primarily affect the enrollments at four-year colleges as shown in the Appendix.

The role of σs can also be seen in the equation (14). If the difference in values $V(a,\theta,i) - V(a,\theta,j)$ is larger than the difference in the means $\mu_j - \mu_i$, then an increase in the variance would reduce p_{ij}. Conversely, if the difference in values is smaller than the difference in the means, p_{ij} would increase in variance.

I randomly draw the σs around their estimated values holding other parameters fixed, and see how the enrollment rates change. Figure 2 shows responses in enrollment rates

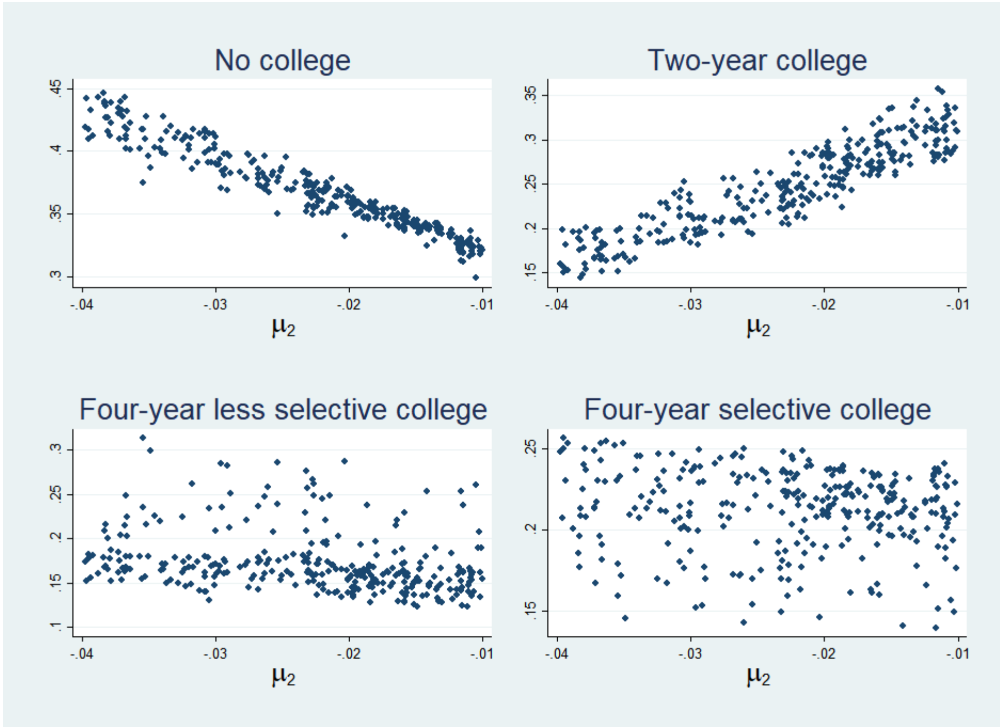

Figure 1: Enrollment rates in response to changes in μ_2. Each dot represents enrollment rates for a different values of (μ_2, μ_3, μ_4). Other parameters are held constant.

for various education options in response to changes in σ_2. The fact that two-year college enrollments are decreasing in σ_2 indicates that the value difference is larger than the mean difference.

Interestingly, changes in enrollments become larger with higher student ability. Figure 3 shows the relative changes in enrollment rates at selective college by ability quartile in response to changes in σ_4. The fall in enrollments is the smallest for the first (lowest) ability quartile and largest for the fourth (highest) quartile. The value difference for any two education options gets larger with θ due to the complementarity between ability and quality. Therefore, the changes in enrollments are the largest for the fourth quartile students.

The responses of enrollments at other education options are found in Appendix.

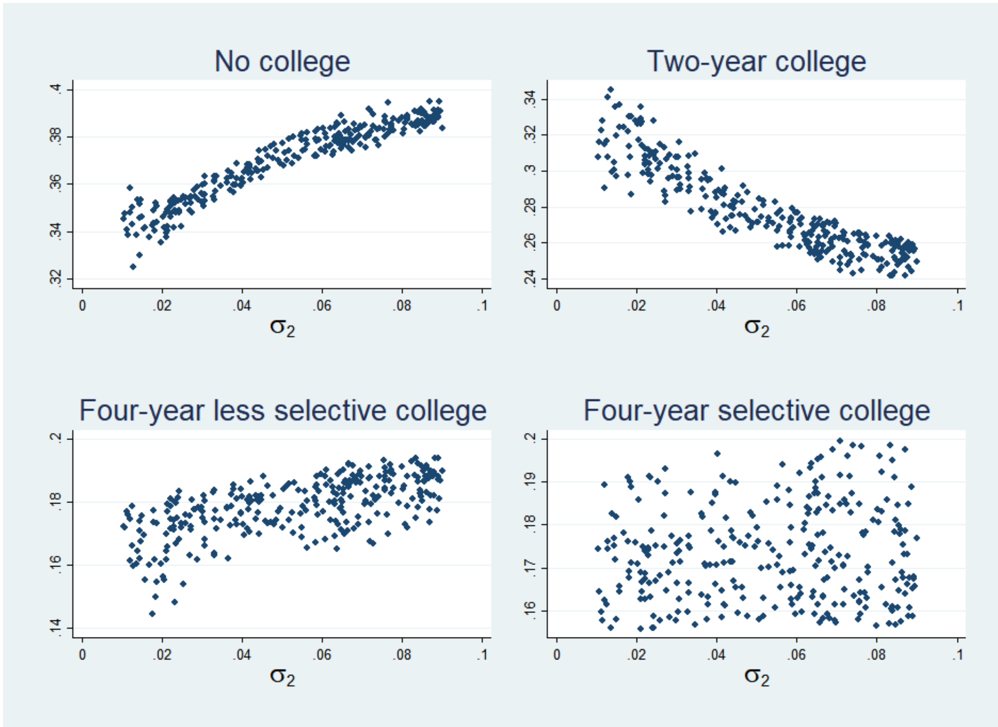

Figure 2: Enrollment rates in response to changes in σ_2. Each dot represents enrollment rates for a different values of $(\sigma_2, \sigma_3, \sigma_4)$. Other parameters are held constant.

5 Simulation

In this section, I run a series of simulation exercises in order to better understand the implications of output and welfare in response to changes in mismatch and the role of each source of mismatch. To that end, I investigate the implications of the economy by turning off each source of mismatch. I also consider the case in which students are resorted into college by ability in an assortative manner, and a hypothetical world with different psychic costs of education. In each simulation, the government keeps its budget unchanged to the level at the benchmark economy by adjusting the labor tax rate. Then, the steady-state outcomes in the simulated world are compared with outcomes in the benchmark economy.

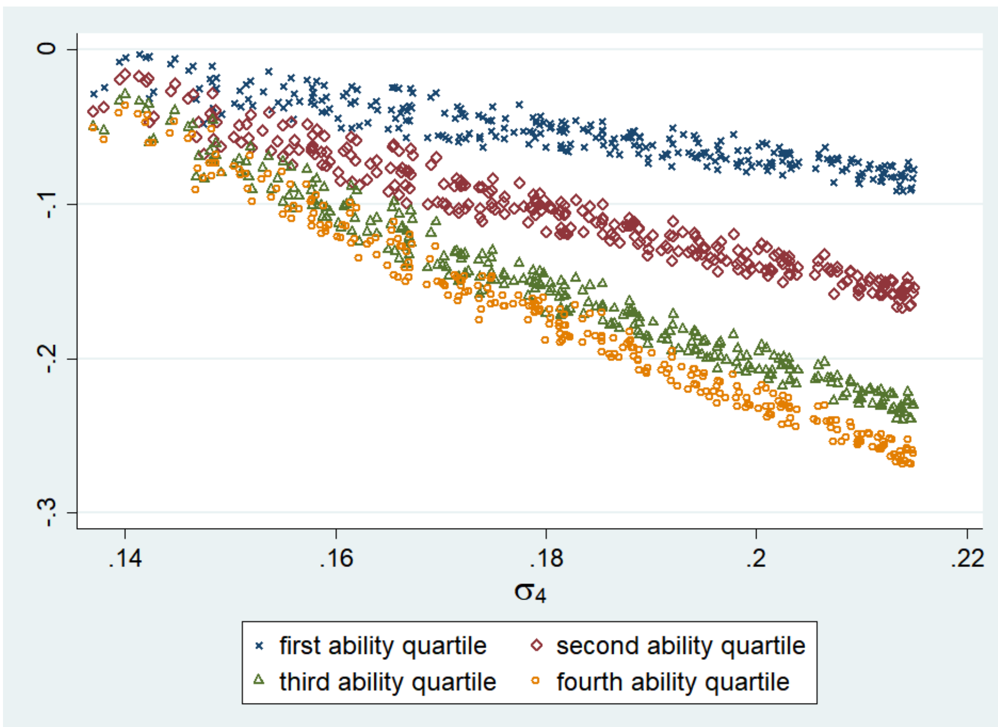

Figure 3: Changes of enrollment rates at selective college from the data counterparts in response to changes in σ_4. Each dot represents enrollment rates for a different values of $(\sigma_2, \sigma_3, \sigma_4)$. Other parameters are held constant.

5.1 Summary

I find that the primary source of mismatch is the interaction of psychic costs with capacity constraints. If psychic costs are eliminated but capacity constraints are not relaxed, then mismatch rises by 15%. Capacity constraints themselves only account for 3% of the mismatch. However, if both psychic costs and capacity constraints are removed, mismatch falls by 40%. Effects of other sources are not that big. Noisy signals about ability account for 7%, and borrowing limits have little effect.

I also find that the measure of mismatch does not help predict changes in output and welfare; output and welfare could go up or down in response to a fall in the measured mismatch. If mismatch increases due to a change in psychic costs, output also increases. In addition, if agents are sorted by ability and placed into colleges by decreasing quality, retaining the capacity constraints, mismatch falls to its minimum level, but welfare also falls.

There are heterogeneous effects of each source across ability. Misperception about ability causes mismatch by 15% for students below the median ability and 2% for students above the median. Psychic costs at four-year colleges dampen the effect of noisy signals for relatively high-ability students. Borrowing limits are primarily relevant for high-ability students because mismatch for low-ability students occurs when they attend high-quality colleges. Capacity constraints also matter more for high-ability students because of the complementarity between ability and quality.

5.2 Welfare measure

When evaluating a new world with different sets of policies we are interested in how the welfare changes relative to the benchmark economy. The notion of welfare measure I use is the consumption equivalence under the veil of ignorance. The consumption equivalence is the proportional increment/decrement of consumption in the initial economy that make an agent indifferent between being born in the initial world and a world with a proposed policy. Let $\mathcal{V}(c;x^*)$ be the expected lifetime utility of an individual with initial states x^* and Φ^* be the stationary distribution in the economy. The consumption equivalence ω satisfies:

$$\int \mathcal{V}^A(c^A(1+\omega);x^{*,A})d\Phi^{*,A} = \int \mathcal{V}^B(c^B;x^{*,B})d\Phi^{*,B}$$

where A denotes the benchmark economy and B a world in which a proposed policy B is in place. A positive ω implies that the proposed policy B improves welfare by ω percent, and a negative ω means the opposite. The CRRA utility function makes it possible to rewrite the above equation as follow:

$$(1+\omega)^{1-\gamma}\int \mathcal{V}^A(c^A;x^{*,A})d\Phi^{*,A} = \int \mathcal{V}^B(c^B;x^{*,B})d\Phi^{*,B}$$

5.3 No noise in the ability signal

A noise in the ability signal can lead to education mismatch. For instance, a high-ability indiviual might receive a signal which makes her think that she has a low-ability, and therefore, she decides not to go to any college. In this exercise, I eliminate the noise and see its implications in the economy.

Table 5 shows the effects of eliminating the noise in the ability signal. All entries are percent changes from the benchmark economy. With the perfect knowledge about one's ability, the matchings between student ability and college quality improve. As a result, the size of mismatch is reduced by 6.9%, which means that the misperception about one's ability explains 6.9% in the total mismatch observed in the data. A large fraction of those in either the first and the second ability quartile who would have enrolled into four-year colleges do not choose to go to four-year colleges. The third ability quartile group switches from two-year college to four-year colleges. For the highest group, the enrollment at two-year college increases mainly because of those who would have chosen no college when there is noise. Also, there are students switching four-year non/less selective college into two-year college. These students chose four-year non selective college over two-year college because the difference in utility from consumption was large enough to cover the difference in the psychic costs in the benchmark economy. However, when the noise is removed, the difference in utility gets smaller as the expected wage increases. The difference in utility from consumption is lowered, and thus, it is better for students to go to two-year college that incurs less psychic costs of education. Enrollment rates at four-year selective college also increases, which lowers the size of mismatch among the fourth ability quartile.

The improved sorting increases welfare for all ability quartile groups. High-ability individuals consume more through increased wages with the higher level of human capital. Also, low-ability individuals are better off by not going to college, avoiding dropout, which is painful. The aggregate output is also increased under the perfect information. With the presence of the complementarity between student ability and college quality, the labor productivity is higher in the hypothetical economy, which raises the output. Skill premium falls by almost 3%. It is because the human capital of the unskilled workers decreases and that of the skilled workers increases. Increased human capital of college graduates is driven by the complementarity between ability and quality even though the total enrollment at both four-year colleges falls slightly.

Noise removal exercise shows the relationship between the size of mismatch, output and welfare. Lowered mismatch through improved sorting raises both output and welfare. It is not feasible to eliminate all the noise completely in the real world. However, this counterfactual exercise shows that there can be a large gain in both output and welfare if individuals can evaluate their ability more precisely. Any policies that could give a better understanding about one's ability such as the probabilities of getting admitted to selective colleges or likelihood of succeeding at colleges could lead to desirable outcomes. One example of policies of this sort is a state-wide madate that requires high school students take a college entrance exam like the SAT or the ACT. Goodman (2016) shows that the enrollment at the selective college increases by 10 to 20% depending on the measure of selectivitiy of college.

Table 5: Removal of noise

	% Changes from the benchmark economy							
Ability quartile	No college	Two-year	Four-year less selective	Four-year selective	Mismatch	Welfare	Output	Skill premium
1	8.2	-15.4	-9.0	-10.9	-12.6	0.8	–	–
2	10.6	0.8	-21.4	-15.5	-19.3	1.1	–	–
3	0.9	-6.5	2.9	4.3	-2.9	2.6	–	–
4	-17.9	10.9	-9.0	0.8	-0.7	4.5	–	–
Total	5.4	-1.8	-8.6	-0.4	-6.9	2.1	0.6	-2.9

5.3 No borrowing limits

Students who are financially constrained might not afford the cost of education. Here, I release the debt limits of college students and see its implications in the economy. Table 6 describes the changes from the benchmark economy. With no borrowing limits more students are able to attend two-year college and four-year selective college, while the enrollment rate at four-year less/non selective college and no college decrease. As a result, the mismatch is reduced by 0.5% (0.2 percentage point). Borrowing limits have little role in explaining the measured mismatch. Borrowing limits are primarily relevant for high-ability students. Mismatch would barely change for low-ability students if borrowing limits are relaxed, but mismatch falls by 1.4%, and welfare rises by 0.4% for the highest ability quartile group.

There are almost no change in welfare in the world without the borrowing constraints. However, the output rises by 0.2% and skill premium decreases by 1.4% due to higher attendance rates at four-year selective college. Labor productivity of skilled labor increases despite the decrease in the enrollment at four-year non/less selective college because of the complementarity between ability and quality. As in the zero noise exercise the measured mismatch and welfare/output move in opposite direction.

The role of the borrowing limits has long been studied. Although the importance of the borrowing limits grows in the recent years (Belley and Lochner 2007), studies that use the NLSY 1979 data have documented that the borrowing constraint have little effect on college attendance[14]. The effect of borrowing limits in my model could be seen somewhat small. However, once the assumption that students cannot work during the college-going years is released, the effect would be reduced just like the findings in the literature.

Table 6: Removal of the borrowing limits

					% Changes from the benchmark economy			
Ability quartile	No college	Two-year	Four-year less/non selective	Four-year selective	Mismatch	Welfare	Output	Skill premium
1	0.1	0.0	-0.3	-0.2	-0.1	-0.12	–	–
2	-0.6	0.8	0.0	0.6	0.2	-0.04	–	–
3	-1.2	1.4	-1.9	1.3	0.1	0.09	–	–
4	-8.8	1.7	-0.9	1.6	-1.4	0.37	–	–
Total	-1.1	1.0	-0.9	1.3	-0.4	0.06	0.2	-1.36

5.4 No psychic costs

Psychic costs are in utils and added to the flow utility. As seen in Table 3, the means of psychic costs at all the colleges are negative, and psychic costs at four-year colleges are big (in negative). In this exercise, I eliminate all the psychic costs from the model. Table 7 shows how enrollments and mismatches change. As predicted, all the four-year options become very attractive with no psychic costs. As a result, enrollment rates for no college and two-year college drop significantly. However, due to capacity constraints at selective college, those who fail to get in attend less/non selective college. Therefore, enrollments

[14]See Cameron and Heckman (1998, 2001) and Carneiro and Heckman (2002) for instance.

at four-year nonselective college increase significantly across all ability quartiles. Mismatch increases significantly by 14.6%.

Table 7: No psychic costs

	% Changes from the benchmark economy						
Ability quartile	No college	Two-year	Four-year less selective	Four-year selective	Mismatch	Output	Skill premium
1	-0.1	-100	129.7	39.5	-0.1	–	–
2	-84.9	-92.8	342.0	66.5	243.9	–	–
3	-81.3	-92.8	232.	11.6	-87.2	–	–
4	-65.7	-88.7	330.2	-21.5	18.9	–	–
Total	-47.6	-93.2	255.6	-0.1	14.6	4.4	-2.9

5.5 No capacity constraints at four-year selective college

In this exercise, I drop the capacity constraints at four-year selective college. Anyone who would like to attend top schools could simply attend as long as they can pay the cost of education.

Student prefer four-year selective college over non-selective college regardless of their ability. As predicted, the enrollment rate at four-year selective college spikes up, while the rates at the two-year and four-year non/less selective college plummets. As a result, both welfare and the aggregate output increase by over 1.5%, and the skill premium falls by 6.1% due to the higher supply of skilled workers. There are heterogeneous effects across ability quartiles. Mismatch rises by close to 10% for the second ability group, while it falls by over 12% for the fourth ability quartile. The overall change in a measured mismatch is a 3.0% decrease.

The drawback of this exercise is that the costs of education are unchanged. To maintain the quality of education, the costs at the selective college should be higher, along with a surge in the number of students. Changes in enrollment will be dampened if tuitions are endogenously determined. In sum, capacity constraints account for mismatch only by 3%. The role played by capacity constraints by itself would be smaller if tuitions are not fixed.

Table 8: No capacity constraints at selective college

Ability quartile	No college	Two-year	Four-year less/non selective	Four-year selective	Mismatch	Welfare	Output	Skill premium
	% Changes from the benchmark economy							
1	0.9	-2.2	-99.9	641.6	-1.4	1.5	–	–
2	-0.3	-8.8	-97.6	203.2	9.6	2.0	–	–
3	7.3	-9.8	-88.3	78.1	-1.5	2.3	–	–
4	20.9	9.6	-70.6	13.7	-12.1	4.9	–	–
Total	3.4	-5.3	-90.0	72.4	-3.0	1.6	1.8	-6.1

5.6 No psychic costs and no capacity constraints

In Table 7 and Table 8, I remove psychic costs and capacity constraints, respectively, and see how enrollment rates change. In order to see their interaction, I relax both psychic costs and capacity constraints in this exercise.

Table 9 shows the results. With no psychic costs, individuals choose four-year selective college options. Unlike the results shown in Table 7, capacity constraints are also removed, which leads to a substantial increase in selective enrollments. Mismatch falls by 40% in total, which is substantial given that mismatch rises for the second ability quartile. This exercise shows that the interaction of psychic costs with capacity constraints is the primary reason behind college decisions as well as mismatch.

Note that students in the first ability group choose no college. This is due to the rise in the unskilled wage rate due to the vast increase in human capital for skilled workers. Skill premium falls substantially by 33%. Therefore, even without psychic costs, they choose not to go to college.

Table 9: No psychic costs and no capacity constraints

	% Changes from the benchmark economy						
Ability quartile	No college	Two-year	Four-year less selective	Four-year selective	Mismatch	Output	Skill premium
1	44.6	-41.7	-100	-100	-68.5	–	–
2	-80.9	-13.5	135.6	190.6	215.2	–	–
3	-79.4	-96.6	78.3	144.2	-88.2	–	–
4	-62.4	-96.0	-1.4	73.7	-65.0	–	–
Total	-27.3	-63.8	34.8	102.2	-40.0	+7.1	-33

5.7 Perfect assortative matching

The counterfactual exercise in this subsection studies the implications when there is perfect assortative matching between student ability and college quality. Education decisions are imposed in a way that highest ability individuals are enrolled at the four-year selective college until the capacity constraints bind. Those who have relatively low ability among the fourth ability quartile attend four-year non/less selective college along with agents in the third ability quartile. Everyone in the second quartile is matched with two-year college, and students belonged to the lowest quartile do not receive college education. I also release the borrowing constraints to make the college options feasible to low asset students.

Table 10 describes how the hypothetical economy with perfect assortative matching would look like. The size of mismatch is only 4.4% because of the capacity constraint at the selective college. The aggregate output rises substantially by 4.3% and the skill premium falls sharply by 20.7%. Since high-ability agents receive high-quality education, human capital gains are gigantic due to the complementarity between ability and quality, and therefore, the marginal product of labor for the skilled labor falls. The welfare response is interesting. Those who do not go to four-year colleges are better off, but those who attend any four-year college are worse off. Overall welfare falls by 1.5%. Psychic costs of education for four-year colleges are responsible for the fall in welfare. Psychic cost seems large enough that it even surpasses the utility gains resulted from increased wages by attending four-year colleges. This exercise implies that the higher education policies aim at increasing enrollment rates should take psychic costs into consideration in order to avoid matchings that lower welfare.

The measured mismatch has little prediction power for welfare and output as seen in Table 10. Output and welfare move in opposite directions in response to a fall in measured mismatch.

Table 10: Perfect assortative matching

	Enrollment rates							
Ability quartile	No college	Two-year	Four-year less/non selective	Four-year selective	Mismatch	Welfare	Output	Skill premium
1	0.25	0	0	0	0	+4.3%	–	–
2	0	0.25	0	0	0	+2.2%	–	–
3	0	0	0.25	0	0	-6.8%	–	–
4	0	0	0.044	0.206	4.4%	-0.5%	–	–
Total	0.25	0.25	0.294	0.206	4.4%	-1.5%	+4.3%	-20.7

6 Conclusion

I study the implications of the academic mismatch on the aggregate output and welfare. With the structural model that includes four factors that could lead to the mismatch, I find that the measured mismatch is not an indicator of output and welfare. Depending on how the economy changes to decrease the size of mismatch output could rise or fall, and welfare could rise or fall. Also, I examine the magnitudes of each source of mismatch. The primary source of mismatch is the interaction between psychic costs of education with capacity constraints at selective colleges. If psychic costs are eliminated, then over 80% of individuals choose to attend a four-year selective college. However, due to the capacity constraints, they fail to get in, producing a substantial mismatch. If both psychic costs and capacity constraints are removed, then mismatch falls by 40%.

The misperception of one's ability explains 6.9 percent of the measured mismatch. The borrowing limits and the capacity constraint at four-year selective college explain the mismatch by 0.5 percent and 3.0 percent, respectively. Therefore, policies that focus on raising college attendances should be relevant to reducing misperception of ability, offering financial resources to low-income families, and providing more supply of high-quality colleges. Other policies should be implemented with care so that students who are mismatch due to the psychic costs would not be worse off.

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Appendix

In the appendix, I present how means and variances of psychic costs change in response to local changes in other parameters. Figure 4 and Figure 5 show changes in the enrollments when μ_3 and μ_4 change. The enrollment at the corresponding institution is increasing in the mean of psychic costs because utility gain increases. Enrollments seem not to be correlated with σ_3 because the estimated value itself is negligible in comparison to other σs as in Figure 6.

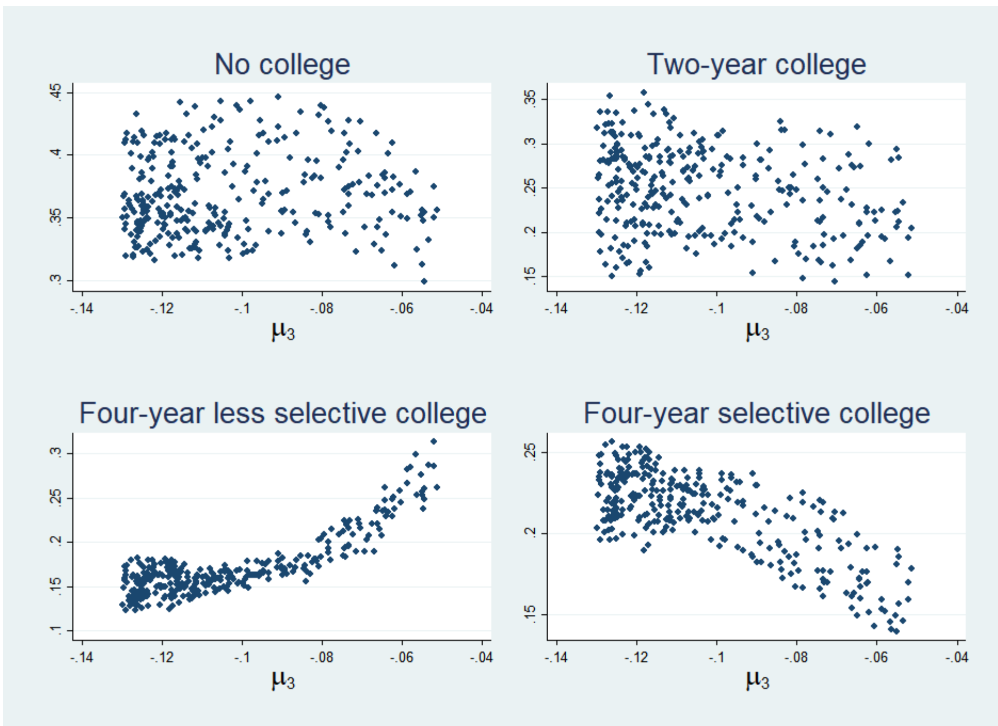

Figure 4: Enrollment rates in response to changes in μ_3. Each dot represents enrollment rates for a different values of (μ_2, μ_3, μ_4). Other parameters are held constant.

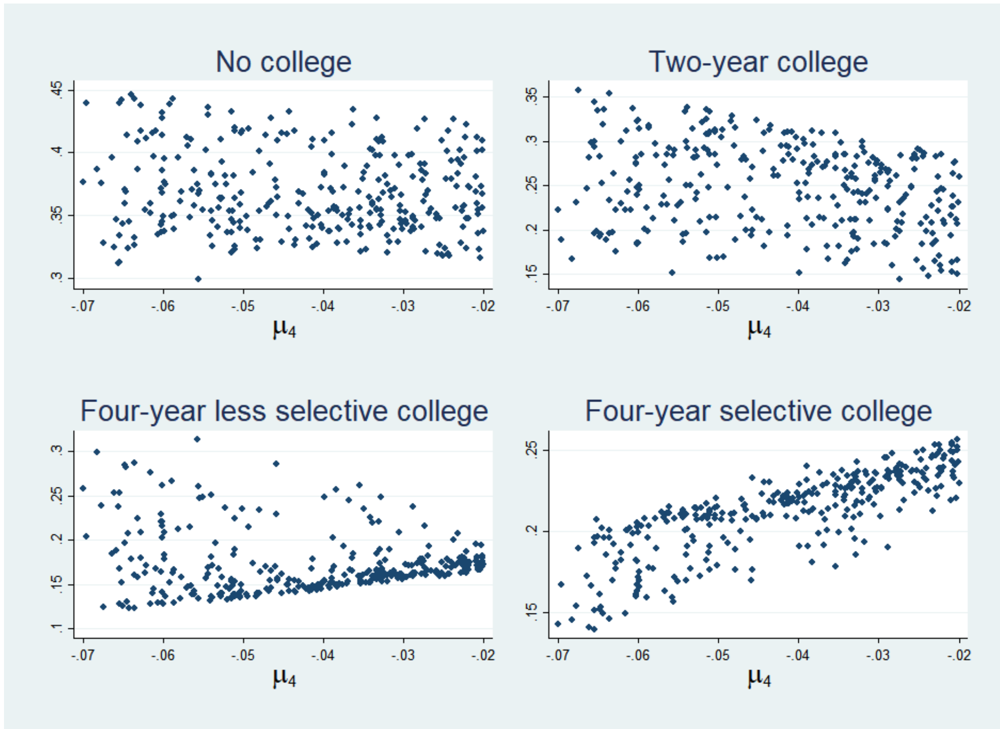

Figure 5: Enrollment rates in response to changes in μ_4. Each dot represents enrollment rates for a different values of (μ_2, μ_3, μ_4). Other parameters are held constant.

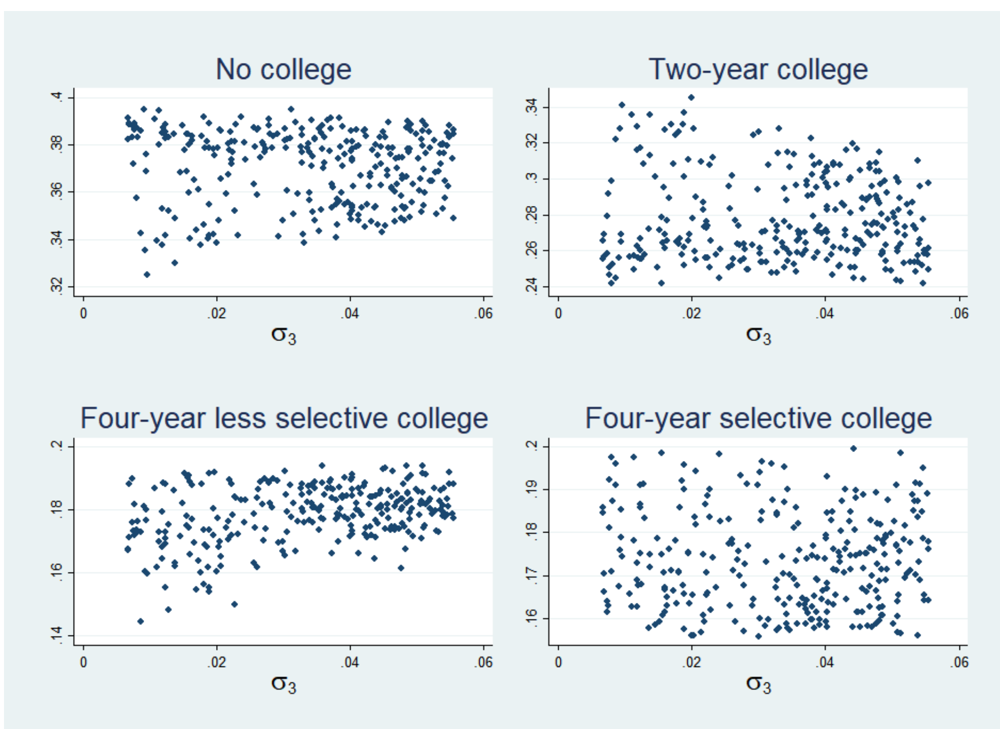

Figure 6: Enrollment rates in response to changes in σ_3. Each dot represents enrollment rates for a different values of $(\sigma_2, \sigma_3, \sigma_4)$. Other parameters are held constant.

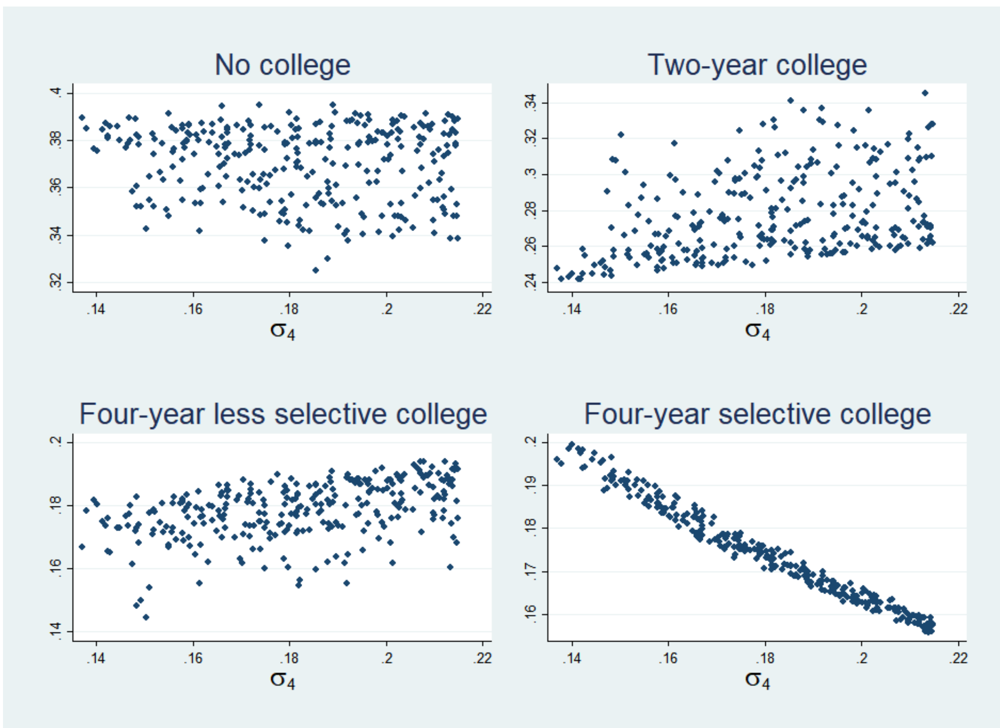

Figure 7: Enrollment rates in response to changes in σ_4. Each dot represents enrollment rates for a different values of $(\sigma_2, \sigma_3, \sigma_4)$. Other parameters are held constant.

Unemployment Insurance and COVID-19

1 Introduction

The unemployment rate spiked from 3.8% in the first quarter of 2020 to 13.0% in the second quarter with the onset of the COVID-19 pandemic in the US. Around 20 million jobs were lost in April 2020. In response to the unprecedented shock to unemployment, congress passed the CARES Act at the end of March 2020, which included the Federal Pandemic Unemployment Compensation (FPUC) and Pandemic Unemployment Assistance (PUA). FPUC provides an additional $600 per week and PUA relaxes eligibility guidelines for unemployment benefits. Households will respond to the expansion of the unemployment benefits differently depending on their characteristics such as education levels and wealth. In this paper, we study the effects of expanded unemployment insurance (UI) on labor market outcomes both in the aggregate and by groups of people. Furthermore, we examine the welfare consequences of UI during the pandemic and the process of recovery.

We build a Diamond-Mortensen-Pissarides (DMP) equilibrium search and matching model which incorporates an incomplete asset market structure and COVID shocks. Agents are heterogeneous in terms of ability and wealth and face two types of shocks: employment and COVID shocks. The former are idiosyncratic and exogenously separate workers from work, and the latter can lead to endogenous separations even after a match between a potential worker and a vacant firm is formed because there is no wage that makes both parties better off. The COVID shocks enter into the model by lowering the aggregate productivity and raising disutility from working. An increase in disutility captures the risks of being infected. Therefore, the shocks affect both the supply and the demand side of labor markets.

One of the key innovations in our model is that agents hold assets to insure against their risk of being unemployed. To our knowledge, there is no paper in the literature on UI during the pandemic with an equilibrium model that allows households to hold assets. We need assets in order to better analyze the effects of UI policy as labor supply decisions heavily depend on wealth. Also, we can focus on moral hazard issues of households in the presence of generous UI policy. Furthermore, in order to run a gigantic program like the CARES Act, which amounts to $2.2 trillion dollars, government needs to issue bonds to finance the program, which requires some agents to hold assets.

Households are different in terms of their innate abilities which affect the productivity of firms as well as labor income. Responses to COVID shocks and the value of compensation would be different. Our model can also capture the interesting trade-offs on wages that the COVID shocks generate. A falling productivity lowers wages, but a rise in disutility from working raises wages in order firms to hire workers.

We find that expanding UI had little to no effect on the unemployment rate, which is consistent with the literature (Altonji et al. 2020, Bartik et al. 2022, Boar and Mongey 2020, Finamor and Scott 2021). However, we find that the UI expansion harmed households by $2,400 on average for two reasons:

1. Many rich household choose to become unemployed due to the increased health risk of working. Most of the UI payments go to these rich households which have low marginal utilities of consumption.

2. The debt the government is forced to take on to finance the UI expansion crowds out capital, lowering wages and dividends over time and must eventually be repaid by future taxes.

This paper contributes to the growing literature on labor markets and pandemic (Atkeson 2020, Alvarez, Argente and Lippi 2021, Cortes and Forsythe 2020, Forsythe et al. 2020, Glover et al. 2020, Gupta, Simon and Wing 2020, Krueger, Uhlig and Xie 2020). More specifically, we contribute to the literature on UI and pandemic by allowing households to hold assets and government to finance its debt. There are several papers that have structural models but do now allow individuals to save (Fang, Nie and Xie 2020, Birinci et al. 2021, Mitman and Rabinovich 2021, Marinescu, Skandalis and Zhao 2021). Ganong et al. 2021 examine spending responses and job search efforts of individuals with different assets. However, they only focus on households and lack decisions of firms and government.

In Section 2, we describe the model and explain how it works. We analyze the model and present corresponding results in Section 3. We conclude in Section 4.

2 Model

2.1 Households

Agents are endowed with unchanging idiosyncratic ability z are either employed or unemployed. If unemployed, agents either receive unemployment benefits $h(z)$. If employed, agents receive wage w which is match specific and renegotiated each period. There are three assets: capital k, equity holdings x, and the government bond b. Agents hold equity with a share price p in all firms simultaneously and earn dividends d. Capital depreciates at rate δ and is rented at rate r. The face value of a government bond (with one period maturity) that sells for b is qb, where q is the price of bond. Assets have equal return so we can define:

$$a \equiv (1 + r - \delta)k + (p + d)x + qb$$

where the return on asset is defined as m and agents' positions on the assets are undetermined but their total holdings of a is known.

Agents choose their asset holdings next period a' to maximize their present value of utility from consumption, c. An employed worker solves the following problem:

$$W(a,z) = \max_{c,a'} u(c) - \rho + \beta[\Theta(1-\sigma)W(a',z) + \Theta\sigma U(a',z) + (1-\Theta)U(a',z)] \tag{1}$$
$$\text{subject to} \qquad c + a' = ma + (1-\tau)w$$

where ρ is the disutility a worker receives from working, σ is probability of exogenous separation from the firm, β is the discount factor, and Θ is an indicator function, detailed later, equal to zero if the match is endogenously separated. The match-specific wage is determined each period through Nash Bargaining. Lastly, τ is a tax rate on labor earnings. An employed household would stay employed if both endogenous and exogeneous separation do not occur. Otherwise, she becomes unemployed. Let the asset decision rule for employed workers be $a'_e = \varphi_e(a,z)$.

Unemployed agents receive income h, which indicates home production and social benefits from the government. The value function for an unemployed agent is:

$$U(a,z) = \max_{c,a'} u(c) + \beta[\lambda_w \Theta W(a',z) + (1-\lambda_w)U(a',z) + \lambda_w(1-\Theta)U(a',z)] \tag{2}$$
$$\text{subject to} \qquad c + a' = ma + h$$

where λ_w is the probability that an unemployed worker is matched to a job.

An unemployed agent would work if she is matched to a vacant firm and the match is profitable. Otherwise, she receives income h and stays unemployed in the next period. Let the asset decision rule for unemployed households be $a_u^{'} = \varphi_u(a,z)$.

2.2 Firms

Each firm employs a single worker and chooses the level of capital to rent from households at rate r. An agent at a job produces $zAF(k)$ where z is an idiosyncratic productivity. A is a deterministic aggregate productivity level, and $F(k)$ is a concave function of capital per filled job. A firm with a worker pays any flow profits in dividends to the shareholders. The value function for a firm with a filled position is:

$$J(a,z) = \max_k zAF(k) - rk - w + \frac{1}{m}[V + \Theta(1-\sigma)J(a',z) - V] \tag{3}$$

where V is a value of a vacant firm, which satisfies:

$$V = -\xi + \frac{1}{m}[V + \lambda_f \int \Theta J(\varphi(x),z)\frac{f_u(a,z)}{u}dadz] \tag{4}$$

where ξ is the cost of posting a vacancy and λ_f is the probability that a vacant firm is filled with a worker. $f_u(a,z)$ is the population of unemployed workers with asset holdings a and ability z, and u is the total unemployed workers. We assume free entry for new vacant firms so the value of a vacancy in equilibrium is equal to zero. The flow value of firm equity is the sum of matched firm profits minus the search costs of vacant firms.

2.3 Matching and wage negotiation

Unemployed workers will be matched with vacant firms according to a matching function: $M(u,v)$,where v represents the total measure of vacancies. We denote the probability that a vacant job is matched with a worker as $\lambda_f = M(u,v)/v = M(u/v,1) = M(1\backslash\theta,1)$ where $\theta \equiv v/u$, which indicates labor market tightness. A match between an unemployed worker and a vacant job will be completed if the following two conditions satisfy:

$$W(a,z) \geq U(a,z) \tag{5}$$

$$J(a,z) \geq V \tag{6}$$

The above two conditions guarantee that the both parties receive surplus from the match. $\Theta(a,z)$ is an indicator function with a value of 1 if there exists a wage that satisfies both conditions. If either condition does not satisfy, then the value of W becomes the same as U and $J(a,z) = 0$. An existing match will have the wage that solves:

$$\max_{w}\{W(x) - U(x)\}^{\kappa}\{J(x) - V\}^{1-\kappa} \tag{7}$$

where κ represents the bargaining power of the worker.

2.4 Government

The government issues one-period bonds b, taxes income τ, and pays social benefits in the form of unemployment compensation h. The government's budget constraint is:

$$\tau \int w(a,z)\frac{f_e(a,z)}{e}dadz + B' = hu + qB \tag{8}$$

where B is the total amount of government bonds and $f_e(a,z)$ is a distribution for workers with asset a and ability z. In steady state the government will be restricted to set $B = B' = 0$ and will do so by adjusting labor tax τ. During the pandemic and a transition phase after, however, the government will be allowed to increase its debt level.

3 Results

3.1 Steady State Calibration

We first solve the steady state of our model to serve as the bookends of the pandemic, and post-pandemic transition periods. We set utility and production functions:

$$u(c) = \frac{c^{1-\gamma}}{1-\gamma} \tag{9}$$

$$F(k) = k^{\alpha} \tag{10}$$

With $\gamma = 2$ and $\alpha = 0.3$. We set $\beta = 0.995$ and $\delta = 0.005$ since each time period is six weeks. Following Shimer (2005), we set the exogenous separation rate $\sigma = 0.05$ and choose the matching function:

$$M(u,v) = \chi u^{\eta} v^{1-\eta}$$

with parameters $\chi = 0.6$ and $\eta = 0.72$. We also set the parameter governing Nash Bargaining, $\kappa = 0.72$, using Hosios efficiency condition. Departing from Shimer and KMS we set the cost of posting a vacancy $\xi = 1$ in order to produce a labor market tightness consistent with pre-pandemic levels. In the steady state, unemployment benefits are equal to the 30% of the wage paid to workers of the same ability and asset holdings. In order to pin down the wage of a worker with no assets we set a minimum level of benefits which, in equilibrium, is equal to 30% of their wage. We assume that in the steady-state there is no disutility from working.

To solve the steady state we define value function analogues which take their future value from the actual value functions and are computed at a given wage:

$$\tilde{W}(a,z,w) = \max_{c,a'} u(c) - \rho + \beta[\Theta_e(1-\sigma)W(a',z) + \Theta_e \sigma U(a',z) + (1-\Theta_e)U(a',z)] \tag{11}$$

$$\text{subject to} \qquad c + a' = ma + (1-\tau)w$$

$$\tilde{U}(a,z,w) = \max_{c,a'} u(c) + \beta[\lambda_w \Theta_u W(a',z) + (1-\lambda_w)U(a',z) + \lambda_w(1-\Theta)U(a',z)] \tag{12}$$

$$\text{subject to} \qquad c + a' = ma + h$$

$$\tilde{J}(a,z,w) = \max_{k} zAF(k) - rk - w + \frac{1}{m}[V + \Theta(1-\sigma)J(\tilde{\varphi}_e(a,z,w),z) - V] \tag{13}$$

and then use Nash Bargaining to find the wage that maximizes:

$$(\tilde{W}(a,z,w) - \tilde{U}(a,z,w))^{\kappa}\tilde{J}(a,z,w))^{1-\kappa} \tag{14}$$

Using the fact that $V = 0$ in all states due to free entry. Once $w(a,z)$ is calculated we then calculate the value functions $W(a,z), U(a,z)$ and $J(a,z)$ and policy rules $\varphi_e(a,z)$ and $\varphi_u(a,z)$. We use this process to recalculate the wage at each iteration of finding the value functions. The steady state is then found as the pair of labor market tightness θ and capital K that sets the value of an entrant from equation (3) equal to zero and sets total asset holdings of households at the invariant distribution equal to the value of firm equity plus capital.

3.2 Transition

The transition starts with a population of firms and employed and unemployed workers with asset holdings determined by the steady state invariant distribution. The future value for value functions in teh final transition period are the steady-state value functions. The transition has five phases:

1. Pandemic phase

    - Aggregate productivity (A) falls
    - Disutility from working (ρ) rises

2. UI expansion phase

    - Occurs during the pandemic phase

3. Post-Pandemic

    - Aggregate productivity (A) instantly returns to its SS value
    - Disutility from working (ρ) instantly returns to zero
    - Government debt is rolled over

4. Taxation

    - Government debt is paid off with a new tax (τ_2) on firms and vacancies

5. Terminal Phase

    - A short phase to connect the taxation phase to the future steady-state values

The third phase is much longer than the others and has the purpose of lessening the importance to first-period welfare of the eventual tax policy. The optimal policy for repaying debts accrued during the pandemic is unclear, and in reality the debt is simply being rolled over. To use the zero-debt steady state value functions as an endpoint the debt must be paid off, so in phase 4 a flat tax is imposed on firms both vacant and full. Phase 5 allows the unemployment rate and asset distribution to recover towards the steady state.

We set the pandemic to last about two years, beginning February 2020 and ending February 2022. Phase 2 begins in the second period and the UI benefits expansion lasts 4 months. We do not include in our analysis the later, smaller, UI expansions that were not part of the CARES Act. The government runs up debt for ten years[1] before paying it off over the course of two years. Phase 5 is two years.

[1] We are experimenting with lengthening this phase.

To solve their problems, agents need to know next-period's value functions as well as the interest rate and matching probabilities, which can be calculated from labor market tightness. During phase 4 agents also need to know the amount of the tax. By assuming paths over time for i, θ, and τ_2 agents can negotiate wages and solve for their asset and employment decisions working backwards. The model is then simulated forward using asset and endogenous separation policy rules. The paths of i, θ, and τ_2 are updated to (1) clear the asset market (2) set the value of a vacant firm to zero, and (3) pay off the debt according to the rule:

$$B(t+1) = B(t)\frac{n-1}{n} \tag{15}$$

during phase 4 only, where n is the number of periods left to pay off the debt. In the last period of phase 4 the debt must be fully paid off.

3.3 Calibration

To calibrate the size of the shocks to productivity and disutility from working we use two data points: the 10 percentage-point increase in unemployment from January 2020 to March 2020 and the 7% increase in median real weekly earnings from Q4 2020 to Q2 2020 over the trend from the previous 2 years. We set the size of the UI benefit expansion to make total UI benefits equal to 100% of the steady-state median wage, following reporting on the motivation for the $600 per week expansion.

Figure 1 shows paths over time for the unemployment rate, labor market tightness, government debt, and the interest rate for the first 50 periods simulated by the model.

3.4 Counterfactual UI Levels

We simulate three alternative levels of UI expansion to compare welfare and simulated variables over different policy options.

1. No expansion: 30% Median UI

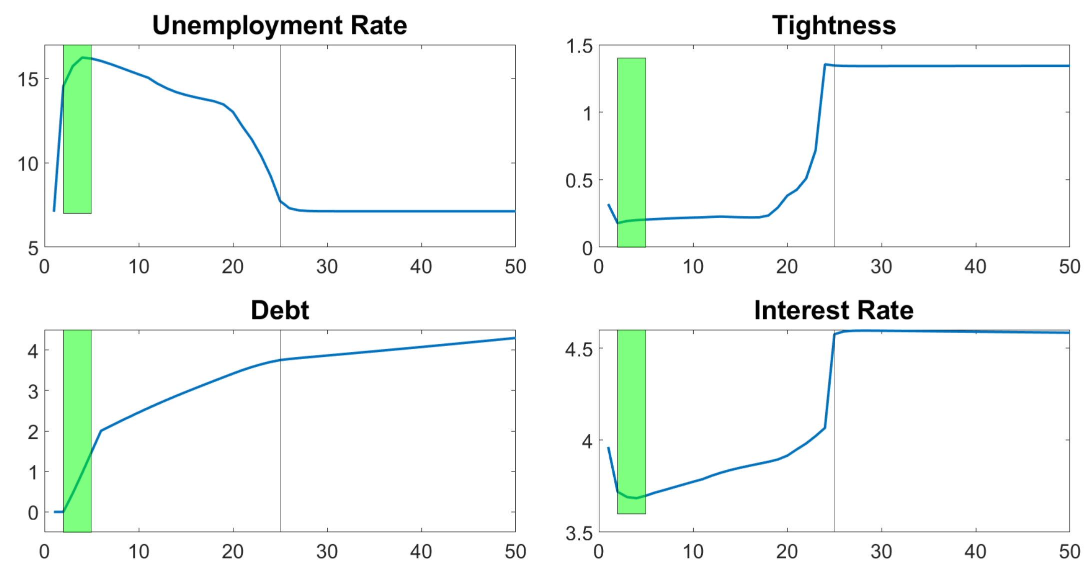

Figure 1: *Paths for unemployment, tightness, debt, and the interest rate over the first 50 periods, a little over 4 years, from the start of the pandemic. The vertical line marks the end of the pandemic and the green bar the duration of expanded benefits.*

2. Half expansion: 65% Median UI

3. Full expansion: 100% Median UI

4. Generous expansion: 135% Median UI

As shown in Figure 2 there is very little difference in the unemployment rate across different levels of unemployment benefits. The most generous benefits, equivalent to an additional $900 per week cause an additional 0.3 percentage point increase in the unemployment rate for two periods, but this difference disappears before the pandemic ends.

Figure 3 shows the path of average wages for low ability workers across the counterfactuals for the first 150 periods and Figure 4 shows the same for high-ability workers. While benefits are being paid, the difference across counterfactuals is compositional. Endogenous separation occurs from high asset individuals who are normally high wage earners. The slight differences in the unemployment rate across counterfactuals causes the slight difference in average wages. For these graphs, we

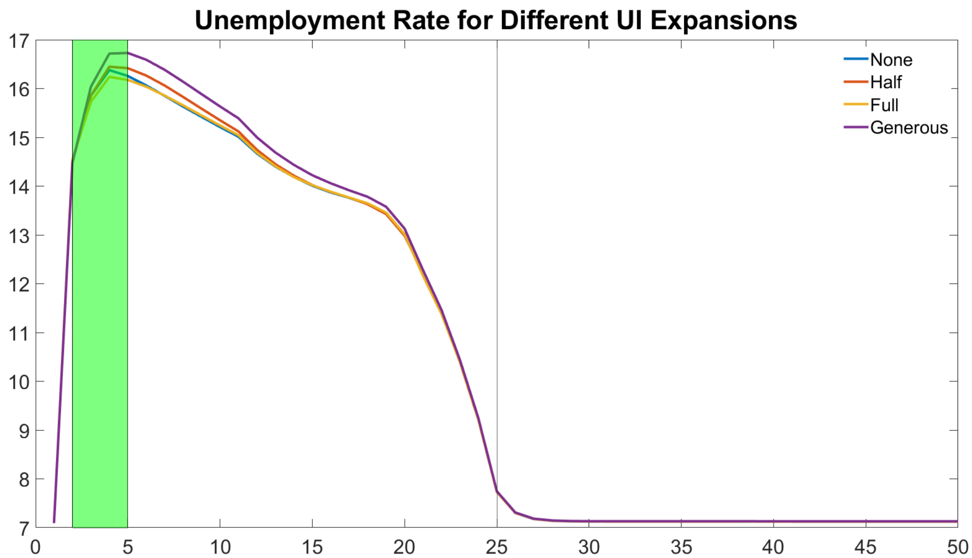

Figure 2: *Paths for unemployment across the four different levels of UI expansion*

include a longer time horizon to show how the higher debt level is depressing wages by crowding out capital. The most generous expansion causes a particularly large reduction in wages.

Intuitively, debt grows faster with higher benefits being paid. Even without any UI expansion the pandemic causes a deficit by increasing unemployment past the steady-state level the labor income tax is designed to fund. Post pandemic debt grows exponentially until it is forced down by policy.

Capital falls quickly during the pandemic as shown by 6 because output falls and households want to dissave. Post-pandemic capital rises, but is crowded out over time by government debt. In the most generous UI expansion, this crowding out is so severe that capital never grows post pandemic.

Next we calculate value function the of different agents, averaged over the initial asset distribution, across the counterfactuals. We find that all UI expansions reduce welfare for employed and unemployed individuals across ability types, with larger expansions being worse. We calculate equivalent variations from the counterfactual with no UI expansion and find that the $600 per week UI expansion policy was equivalent to

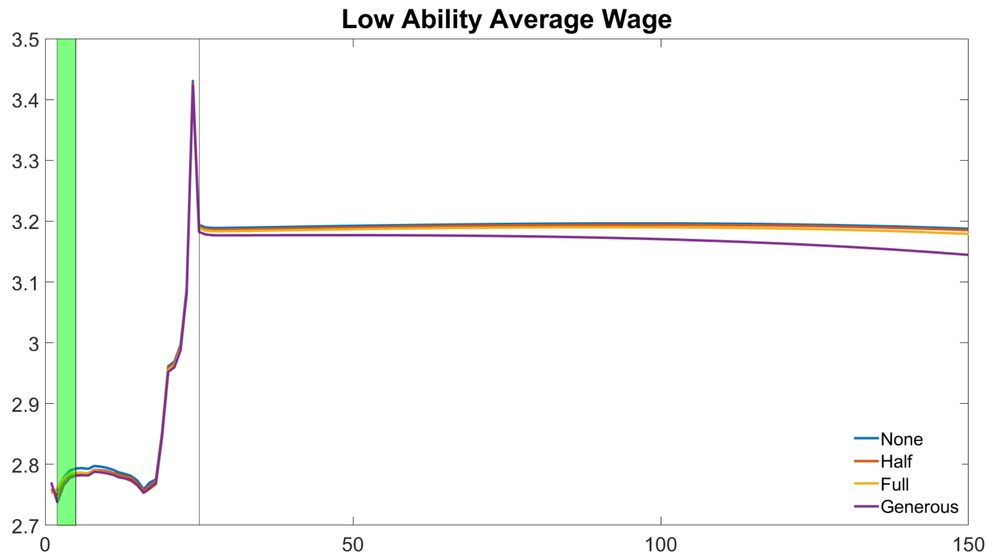

Figure 3: *Paths for average wages of low ability workers across the four different levels of UI expansion*

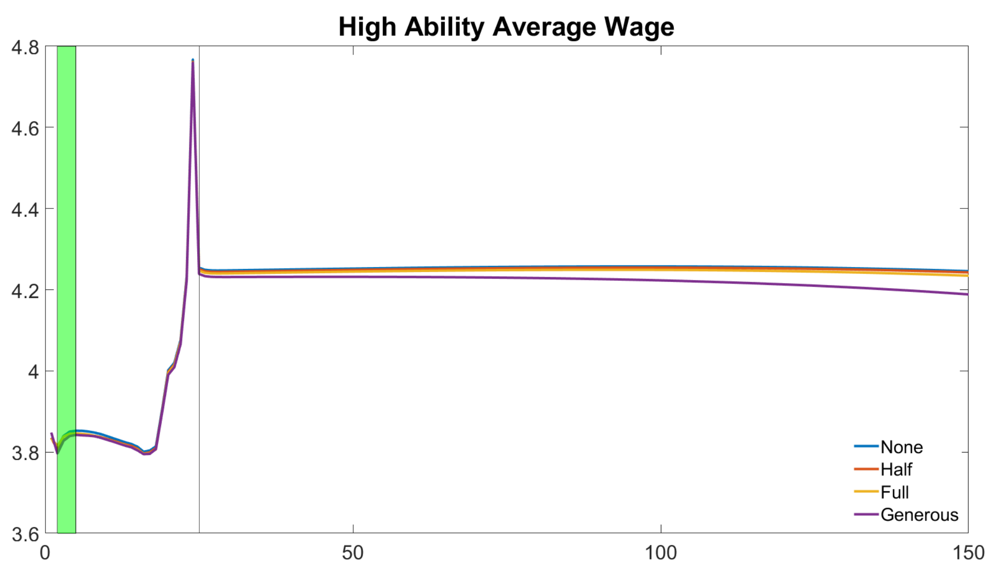

Figure 4: *Paths for average wages of low ability workers across the four different levels of UI expansion*

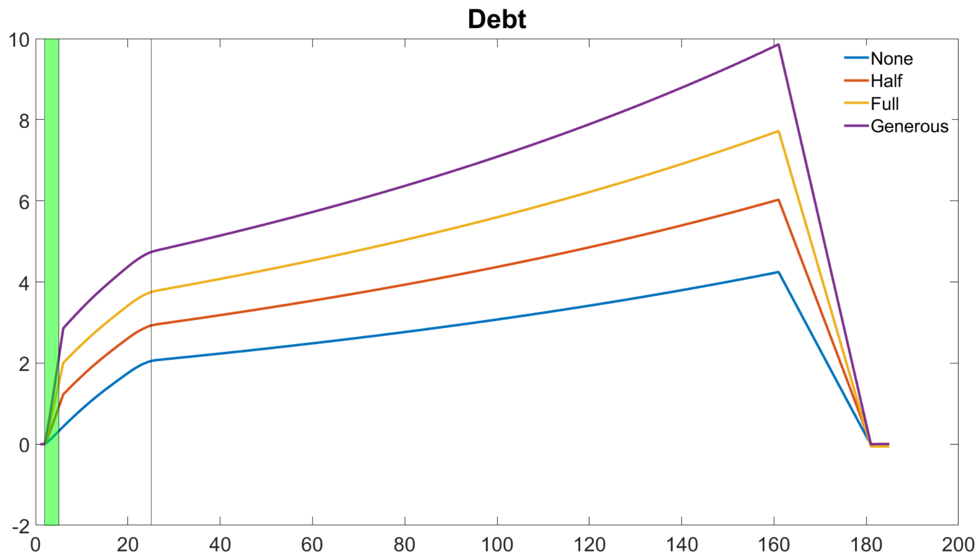

Figure 5: *Paths for government debt across the four different levels of UI expansion*

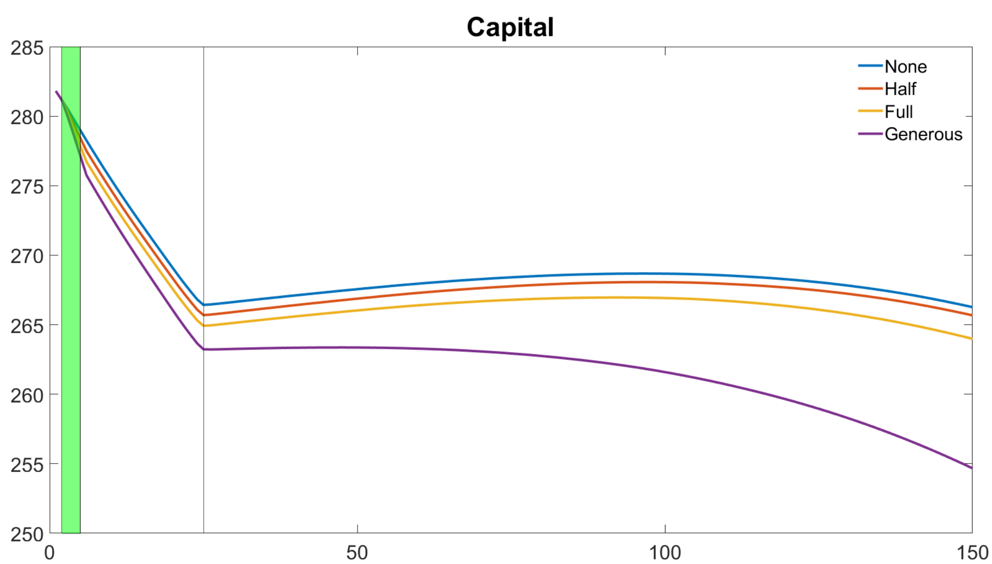

Figure 6: *Paths for capital across the four different levels of UI expansion*

a \$2,411.90 reduction in household wealth to the average household. Table 1 shows the equivalent variation for the different counterfactuals across different agent types.

Table 1: Equivalent Variation of UI Expansion

Type	\$300	\$600	\$900
High Ability Employed	-\$600.40	-\$2667.30	-\$5,250.80
Low Ability Employed	-\$440.10	-\$2,167.80	-\$6,843.70
High Ability Unemployed	-\$641.20	-\$2,740.70	-\$5,431.10
Low Ability Unemployed	-\$423.40	-\$1,964.10	-\$6,154.00

Equivalent loss of SS assets to implementing UI expansion, relative to counterfactual with no expansion.

It may seem counter intuitive to the reader that UI expansion would not even help low-ability unemployed workers on average. There are several factors at play:

- Agents are infinitely lived and only ever briefly unemployed, so unemployed households care greatly about the future value of being employed.

- Endogenous separation is occurring in high asset households, so most of the newly unemployed households in the pandemic are high ability, high wealth households choosing not to work.

- Most low ability households have sufficient assets to weather a temporary unemployment spell with the basic 30% UI benefits.

The second point is the key to understanding why even from a utilitarian standpoint the UI expansion has a negative effect. High wealth households quit their jobs to avoid paying the disutility from working. These households have the lowest marginal utility from consumption, yet they are allocated additional resources from the expansion at the

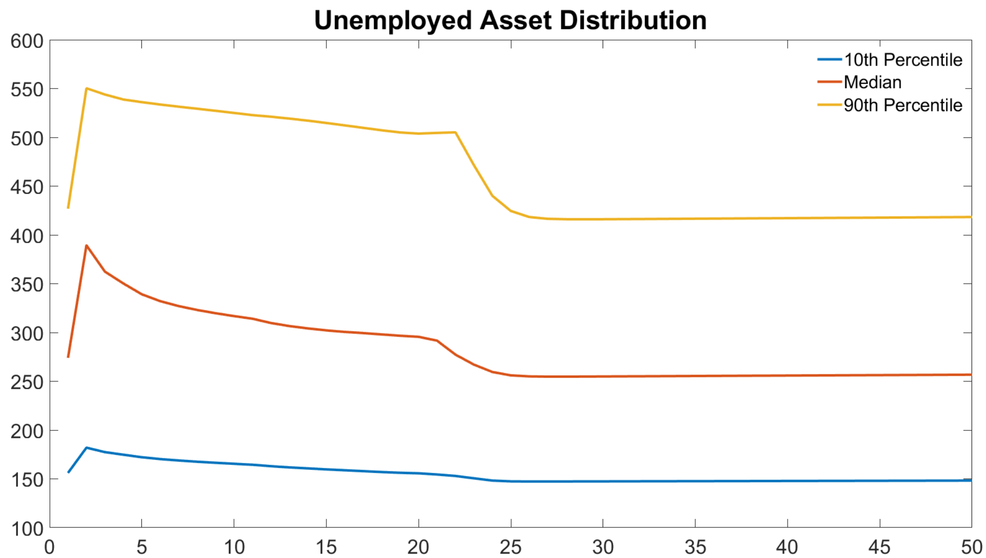

Figure 7: *Paths for top and bottom deciles and median asset holdings of unemployed workers.*

expanse of crowding out and eventual taxes faced by firms. Low ability households are particularly harmed by high levels of government debt because they face lower wages due to capital being crowded out and hold less asset so they do not gain from the slight increase in interest rates.

Figures 7 and 8 show the top and bottom deciles as well as the median asset holdings of unemployed and employed workers over time. Notice the surge of high wealth individuals becoming unemployed during the pandemic. Pre-pandemic the median asset holding of employed and unemployed workers is almost equal, during the pandemic the unemployed are much richer as a group than the employed. Over time, unemployed workers first dissave and then choose to accept employment when matched.

4 Conclusion

Expanding unemployment benefits in our model inefficiently transfers wealth to mostly rich households because they are the ones who choose to become unemployed in response to the increased health risk from working. These high wealth households do not

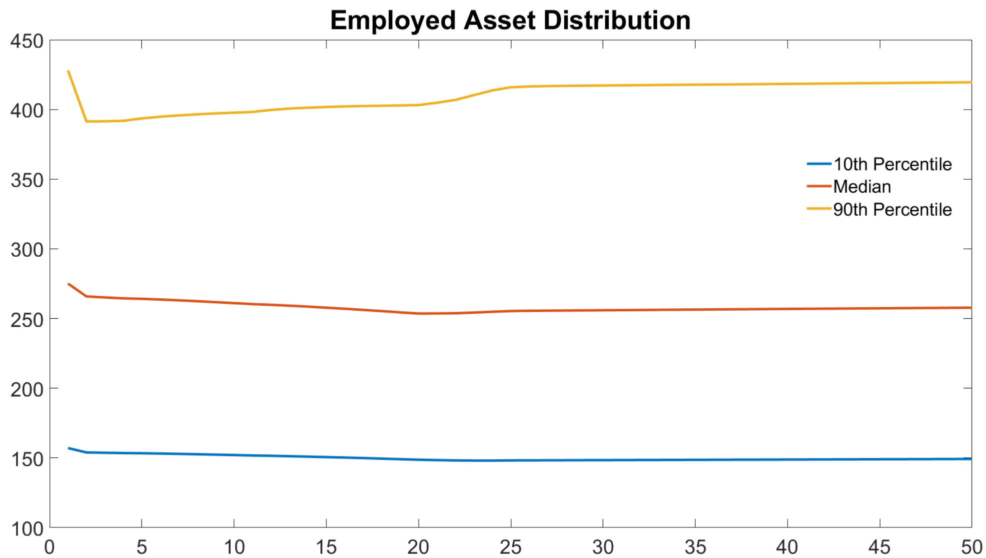

Figure 8: *Paths for top and bottom deciles and median asset holdings of employed workers.*

even benefit on average because over time the additional government debt crowds out capital, reducing wages and dividends, and must eventually be repaid with high taxes on firms. Even low ability agents who start the pandemic unemployed (before endogenous separation occurs) stand to lose on average because of the large costs of financing the program.

One limitation of our model is that we do not have endogenous job destruction for the lowest wage workers. Future work is needed to study the interplay between incomplete assets and mechanisms already in the literature, such as sector specific productivity shocks or costly technologies which reduce or eliminate the health risk of working.

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