FEDERAL STUDENT LOANS, COLLEGE CHOICE, AND STUDENT WELFARE

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ABSTRACT

Siddhartha Biswas: Federal Student Loans, College Choice, and Student Welfare
(Under the direction of Donna B. Gilleskie)

I examine the role of federal loans on access to higher education and student welfare by modeling students' postsecondary investments in human capital. I develop a dynamic discrete choice model of a student's decision to apply to college, to enroll in a college in which she is admitted, and to finance education, either by borrowing or working, in the presence of borrowing constraints. I estimate the structural parameters of this forward-looking decision process using data from two cohorts of students who enter college before and after a rare increase to federal loan limits in 2007 and 2008. Analysis of counterfactual policies shows that raising loan limits increases enrollment, specifically towards four-year non-elite colleges, and improves persistence of enrollment. While providing free non-elite college encourages enrollment, sorting to community colleges and four-year colleges by income may not reduce existing gaps in the quality of college attended. Welfare gains are concentrated among high-ability students, who benefit from relaxed credit constraints across the income distribution. Relative to free college, increasing borrowing limits provides 50 percent of the average welfare gains and more than 94 percent of the welfare gains for high-ability students at a fraction of the policy cost. However, accounting for supply side college pricing responses reduces welfare gains non-trivially, specifically for low-income students.

I supplement this analysis with a model of college admission and pricing decisions. Heterogeneous colleges try to attract a high-achieving student population and generate revenue while facing capacity constraints. Expansion in loans relax financial constraints and make expensive colleges more affordable, but colleges may increase tuition because they anticipate that students can borrow to pay higher tuition. I then provide a strategy to estimate the structural parameters of colleges' decision-making, which can be used to better evaluate hypothetical subsidies on student welfare.

To my parents, Amitabha and Indrani Biswas, for always encouraging me to pursue my dreams. This journey began with their support and with my father passing down his love of economics.

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CHAPTER 1: INTRODUCTION

Although college enrollment rates in the United States increased from 2000 to 2014, an enrollment gap by economic background persists: 65 percent of low-income students enrolled in college in 2014, compared to 83 percent of high-income students.[1] We observe further inequality along the intensive margin of the quality of colleges students attend. Enrollment rates at four-year institutions increased only for high-income students, while enrollment rates at two-year and for-profit institutions increased for all other students. As the cost of college attendance has simultaneously increased by 14 to 46 percent,[2] financial constraints have become a greater barrier to college access for recent student cohorts.

Federal financial aid policies aim to relax these financial constraints. While several studies show that price reductions (grants, scholarships, and tax credits) increase enrollment, we know surprisingly less about the effects of federal student loans. In comparison to price reductions, loans present unique economic mechanisms with different welfare implications, and represent the largest source of financial aid for undergraduates, ranging between 34 to 42 percent of total aid volume.[3] Federal loans also address a market inefficiency in human capital financing: a lack of collateral reduces access to private credit, resulting in sub-optimal levels of human capital accumulation (Friedman, 1955). Students still face financial frictions as the government sets borrowing limits

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[1]These rates measure college enrollment among recent high school graduates or equivalent in 2014 (Snyder et al., 2019). In 2000, 50 percent of low-income students (in the bottom household income quintile) and 77 percent of high-income students (in top quintile) enrolled in college.

[2]Cost of attendance includes tuition, fees, room, board, and additional materials such as books and supplies. From 2000 to 2014, the enrollment-weighted average cost (in 2016 dollars) for an in-state student to attend a four-year public college increased from $13,653 to $19,969 ($22,312 to $32,546 for out-of-state students). Four-year private college cost of attendance increased from $31,979 to $43,918.

[3]From 2000 to 2014, federal loans, institutional grants, and federal grants were, respectively, the three largest sources of total undergraduate aid by volume (Baum et al., 2019).

that determine students' access to loans. Limited variation in these policies have made it difficult to understand the empirical role of credit constraints in human capital investments. Therefore, I examine how federal loans impact students' postsecondary investments in human capital and the resulting student welfare.

The popular discussion on federal loans highlights a potential student debt crisis and focuses on student welfare after college, measured by labor market outcomes, consumption, and debt repayment.[4] However, federal policies determine the supply of loans and affect a student's welfare from the moment she leaves high school. Availability of loans impacts her enrollment and choice of college (that build human capital) and her annual borrowing decisions (that accumulate student debt). Similar to price reductions, economic intuition suggests that greater access to loans should increase a student's demand for postsecondary investments in human capital: she may attend college, she may choose a better and more expensive college, and she may borrow more.

The use of loans to finance higher education differs from other common education subsidies in two key dimensions. First, borrowing presents an endogenous decision while other types of price reductions generally do not. A model that includes student loans must consider that the student faces a trade-off between future wage gains from enrollment at a better college and repayment of accumulated student debt. Furthermore, as the student is responsible for her debt regardless of her education outcomes, borrowed funds to pay for education will have more persistent effects on continued college enrollment than price reductions. Second, expansion of federal loans affects a larger student population. In theory, any eligible student can borrow from the government, while grants and other scholarships often target low-income students. Thus, there may be distributional effects unique to loan policies.

Based on the current federal financial aid environment, I develop a dynamic discrete choice model of a student's decision-making with regard to college enrollment, college type, and college financing in the presence of borrowing constraints. Specifically, a student applies to college, chooses

[4] Increased loan availability generally leads to greater student debt and higher earnings after college (Black et al., 2020). However, high levels of debt can constrain career choices (Rothstein and Rouse, 2011), delay marriage (Sieg and Wang, 2018), and have small negative effects on homeownership (Mezza et al., 2020).

to enroll in a college from among her admissions, and (if matriculating) annually decides to borrow and work part-time in order to pay for college. She takes college prices (e.g., tuition and other college expenses) and government policies as given and evaluates, relative to the outside option of entering the labor market without further education, her alternatives based on expected earnings and non-pecuniary benefits of college completion from the specific institution, as well as the price of attendance and loan repayment. Furthermore, she receives shocks related to admissions, aid, and federally determined financial need that define her college choice set and her individual price of attending a particular college.

I estimate the structural parameters of this forward-looking discrete choice model using detailed information on student behaviors after high school from two nationally representative cohorts of high school students who enter college before and after an increase to federal borrowing limits in 2007 and 2008, the first such change since 1994. The data include information regarding student demographics, college applications, enrollment, student loan borrowing, and labor market outcomes. I supplement the student-level data with annual information on tuition rates and institutional aid for all colleges that participate in federal financial aid programs. I use the variation in loan environment that each cohort faces to identify the structural parameters that determine shifts in borrowing behavior and the distribution of enrollment across different institutions.

This paper offers a comparison of alternative education subsidies for their effects on student welfare. A structural model allows me to analyze various counterfactual policies and model their heterogeneous effects across the distribution of students. Specifically, I examine the policy changes in 2007 and 2008, further increases to federal borrowing limits, expansion of federal Pell grants, and proposals to subsidize public colleges. I also consider loan policies while acknowledging that colleges respond to expansion in federal financial aid by increasing tuition. I account for such pass-through in my welfare analysis by using existing estimates from the literature. Therefore, the model can be used to evaluate the effectiveness of various education subsidies at improving access to higher education and also to identify which students benefit most from each subsidy.

Policy analysis shows that relaxing credit constraints, through federal loan expansion, alters the student's enrollment decision. Specifically, a $4,000 increase in loan limits leads to a 4.2 percentage point (pp) increase in overall enrollment, with enrollment shifting towards four-year non-elite institutions. Furthermore, higher loan limits lead to greater persistence as shown by higher levels of enrollment in the second through fourth years of college. Expanding targeted education subsidies using federal Pell grants leads to greater community college[5] enrollment, with low-income students exhibiting the largest shifts in enrollment. Providing a free in-state non-elite public college education shows enrollment gains similar to that of increasing loan limits, but also results in sorting of students between community college and four-year colleges by income. Therefore, free public college may not reduce gaps in the quality of colleges attended by students.

Welfare gains are concentrated among high ability students for all policies. Moreover, while the free public college option improves average student welfare the most, relaxing credit constraints is a cost effective policy to improve student welfare. Relative to free college, increasing borrowing limits provides 50 percent of the average welfare gains and more than 94 percent of the welfare gains for high ability students at a fraction of the policy cost. Accounting for pass-through of federal loans to tuition reduces average welfare gains by 20 percent and reduces low- and middle-income students' welfare gains by up to 30 percent. However, increasing loan limits are unique from other policies as the resulting welfare gains for high ability students are similar across the income distribution.

In addition to the policy contribution, this research adds to a growing literature on the presence and relevance of credit constraints in students' postsecondary education decisions in order to better understand enrollment gaps by family income. Specifically, I am able to use data from more recent student cohorts exposed to federal policy changes in 2007 and 2008 to quantify the role of credit constraints in postsecondary human capital investments. Previous studies that document the enrollment effects of reduced college costs mainly consider financial aid mechanisms that subsidize

[5] I use the terms "two-year", "less than four-year", and "community college" interchangeably.

tuition without a need for repayment, such as scholarships, grants, and education tax credits.[6] These forms of aid relax a student's and her family's budget constraints by explicitly lowering the price of attendance. Access to loans further relaxes the student's credit constraints. The economics literature has debated whether such credit constraints exist.[7] However, research on younger cohorts shows that credit constraints, such as federal loan limits, currently bind more often than in the 1980s (Lochner and Monge-Naranjo, 2011; Johnson, 2013; Hai and Heckman, 2017). Due to consistent tuition growth coupled with stable federal borrowing limits, more students face binding borrowing constraints, which result in persistent enrollment disparities by family income and wealth even after conditioning for student ability.

Furthermore, this paper is among few to consider several important margins of student response to loan policies beyond enrollment, including college choice, part-time labor during college, and annual decisions to continue enrollment or drop out. Although credit constraints are more prevalent among recent cohorts, analyses of relaxing these constraints, through expansionary student loan policies, show small positive enrollment responses (Johnson, 2013; Hai and Heckman, 2017).[8] Other studies highlight the need to address the intensive margins of enrollment as availability of loans and repayment policies have sizable effects on student behaviors during college that affect human capital accumulation. Black et al. (2020) find that increased student loan availability improves degree completion for credit constrained students, while Joensen and Mattana (2020) find that students in Sweden compensate for new repayment plans that make borrowing costlier by working more during college, which leads to adverse affects on human capital accumulation. Furthermore, experimental

[6]The reviews by Deming and Dynarski (2010) and Nguyen et al. (2019) highlight that this type of gift aid has beneficial effects, particularly for low-income populations: the federal Pell grant program, various state and private scholarships, and smaller scale experiments generally increase a student's likelihood of initial enrollment, year to year persistence, and degree completion.

[7]Studies of earlier cohorts found little evidence for the existence of credit constraints, concluding that factors such as college preparedness are the primary barriers to a college education (Keane and Wolpin, 2001; Carneiro and Heckman, 2002; Cameron and Taber, 2004).

[8]Programs in Chile that expanded availability of loans for students who clear a college admission threshold show large increases in enrollment and persistence, which significantly reduces the income gap in enrollment and postsecondary education attainment (Solis, 2017; Card and Solis, 2020).

evidence from a community college shows that improving a student's information about available loan options increases education attainment (Marx and Turner, 2019).[9]

I contribute to this literature by explicitly modeling the student's choice of college, while also considering annual persistence in enrollment and part-time labor during college. As my data include more information about the student's choice set than other analyses, such as applications and admissions, this dissertation is able to address the distribution of students across colleges resulting from changes to loan policies.[10] This margin of college choice is particularly relevant for student welfare; analysis of a loan expansion in 1992 showed larger effects on college choice than enrollment (Dynarski, 2003), while enrollment at high quality colleges offers a substantial earnings premium (Dillon and Smith, 2020).

For the remainder of the dissertation, I describe the federal financial aid environment in the U.S. and highlight relevant data trends in chapter 2. Chapter 3 discusses the model, chapter 4 outlines the empirical specification, and chapter 5 describes the estimation strategy. Lastly, chapter 6 discusses estimated parameters and model fit, chapter 7 evaluates current and hypothetical policies, and chapter 8 concludes.

[9]Studies considering the student's information set regarding loans rely on nudge interventions, and results from such experiments depend on the context, scale, and design of the treatment. Bird et al. (2019) provide a review of this literature and highlight the relevance of scale by finding no enrollment impacts of similar interventions at the state and federal levels.

[10]This research does not focus on the implications on loan repayment behavior. Ionescu (2009) and Ionescu and Simpson (2016) provide such an analysis of the expansion of federal loans and find a higher risk of default in the private market.

CHAPTER 2: DATA

2.1 U.S. Federal Financial Aid

To access federal financial aid, students must be citizens or eligible non-citizens, satisfy minimum college enrollment conditions, and complete the Free Application for Federal Student Aid (FAFSA). Two major avenues of federal aid, Pell grants and student loans, have both expanded over time. Between 2004 and 2013, the college entry dates of the two cohorts in my data, the proportion of all undergraduate students receiving Pell grants grew from 31 to 43 percent, the average grant provided increased from $2,477 to $3,634, and the total volume of grants increased from $13.2 to $31.5 billion. College students primarily borrow from the federal government through the Stafford loan program.[1] From 2004 to 2013, the proportion of all undergraduates who borrowed Stafford loans grew from 33.8% to 39.4%, the average annual amount they borrowed increased from $6,215 to $6,986, and the total volume of undergraduate Stafford loans increased from $36.3 to $56.1 billion.

Pell Grants Pell grants are targeted towards low-income households with a strict schedule that determines which students receive grants. After receiving the FAFSA, the office of Federal Student Aid uses a legally defined formula to calculate a student's expected family contribution EFC_{it} as a function of household finances and number of family members that may attend college. A full-time

[1] I abstract away from private student loans, which peaked in utilization in the 1980s and 1990s, for two reasons (Lochner and Monge-Naranjo, 2011). First, total nonfederal loan volume decreased from 10.8 to 3.9 percent of all undergraduate aid between 2004 and 2013 and are mostly utilized by for-profit college students (Consumer Financial Protection Bureau, 2012; Baum et al., 2019). I exclude students who attend for-profit colleges from my analysis. Second, my data does not have information on private loan utilization and loan terms or their determinants, such as assets and credit ratings. I also abstract away from Perkins subsidized loans, which constitute less than 1 percent of total aid volume and was discontinued in 2017.

enrolled student's Pell grant is

$$Pell_{ijt} = \max\left\{\min\{\tau_{ijt}, Z_t^{Pell}\} - EFC_{it}, 0\right\}. \tag{2.1}$$

Students with sufficiently low EFC_{it} are eligible for the Pell grant program, and furthermore, the amount of the grant is restricted by the difference between the student's cost of attendance τ_{ijt}, or a federally defined maximum amount Z_t^{Pell}, and EFC_{it}. Cost of attendance at college j includes tuition, fees, room, and board minus any scholarships or grants the student receives, and thus can be lower than the advertised sticker price.

Stafford Loans Loan terms include eligibility criteria, interest rates, borrowing limits, and repayment horizon. Stafford loans can be either subsidized or unsubsidized. Both loans have low interest rates varying annually between 3.4 and 6.8 percent from 2004 to 2013 that accrue from origination. However, the government fully subsidizes the interest accrued during enrollment for subsidized loans, making them more attractive to students.

A student can borrow subsidized loans only if her financial need N_{ijt}, defined as her cost of attendance net of expected family contribution and any received Pell grants, is positive.

$$N_{ijt} = \tau_{ijt} - EFC_{it} - Pell_{ijt} \tag{2.2}$$

Both subsidized and unsubsidized loans have an exogenous federal borrowing limit. Regardless of the federal limit, a student cannot borrow subsidized loans beyond her financial need and she cannot borrow unsubsidized loans beyond her cost of attendance. Therefore, a student can borrow an unsubsidized loan even if her financial need is zero; that is, she can use loans to cover the EFC. Table 2.1 shows that, while the federal borrowing limits differ by the student's year in college and dependence status, the limits have increased only in 2007 and 2008 over the past twenty-five years. As a result of this policy change, the real loan limit for dependent students at four-year institutions increased from 19 to 35 percent of advertised cost of attendance for public college in-state freshmen and from 9 to 16 percent for private college freshmen between 2006 and 2008

(Figure 2.1). Appendix A provides an example of a student's eligibility for each type of loan. Lastly, the standard repayment plan allows students ten years after finishing college to pay back their student debt.

Table 2.1: Annual Federal Stafford Loan Borrowing Limits (nominal USD)

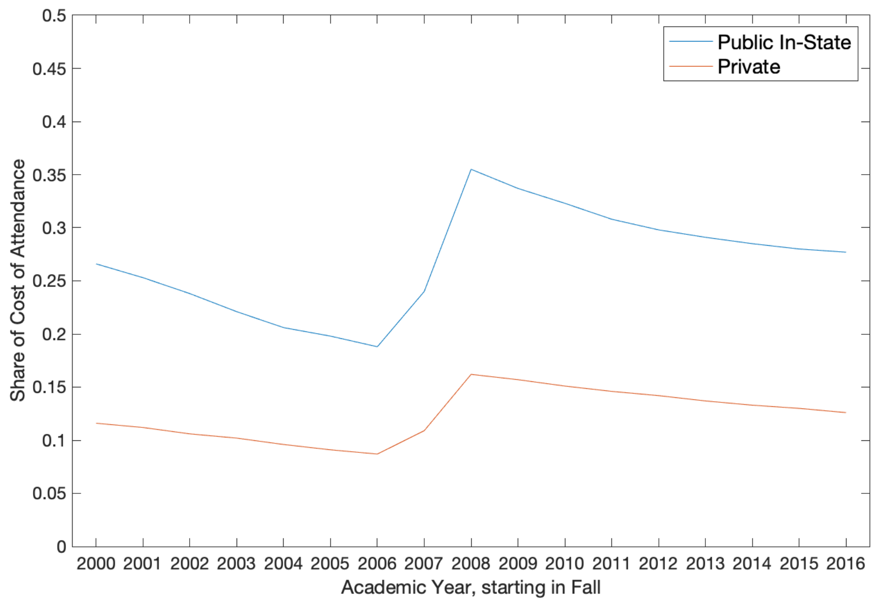
	Limit type	1994-2006	2007	2008-2019
Freshman	Subsidized	2625	3500	3500
	Total (subsidized + unsubsidized)	2625	3500	5500
	Total (independent students)	6625	7500	11500
Sophomore	Subsidized	3500	4500	4500
	Total	3500	4500	6500
	Total (independent students)	7500	8500	12500
Juniors & Seniors	Subsidized	5500	5500	5500
	Total	5500	5500	7500
	Total (independent students)	10500	10500	14500
College aggregate	Undergraduates	23000	23000	31000
	Independent undergraduates	46000	46000	57500

2.2 Data Sources

Two nationally representative panel surveys of high-school students from the National Center for Education Statistics (NCES) provide the most appropriate dataset for my research goals. The Education Longitudinal Survey (ELS) of 2002 follows 16,197 students from 2002, when they were in the 10th grade, to 2012. ELS supplements this cohort with a number of 12th grade students in 2004 who were added to replace students who left the sample before 2004. The High School Longitudinal Survey (HSLS) of 2009 is designed to be the successor to ELS, and follows 21,444 students from 2009, when they were in the 9th grade, to 2016.

NCES data include the necessary student characteristics (such as high-school transcripts, standardized test scores, and geographic indicators) and outcomes of interest to address my research questions: a student's college applications with admission and institutional aid, her decision to

Figure 2.1: Federal Loan Limit as Share of Advertised Cost of Attendance



NOTE: Total federal loan limit for a dependent college freshman at a four-year institution, as a share of the advertised cost of attendance.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), Fall 2000 – Fall 2016

attend college, her choice of college, her annual student loan borrowing, and, in some cases, her labor market earnings. Furthermore, ELS high-school students apply to college before the borrowing limit increases of 2007 and 2008, while HSLS students apply after. Data from cohorts exposed to these different loan environments provide policy variation necessary to estimate a causal effect. A typical student in the HSLS enters college in 2013 and can borrow up to 29 and 14 percent of advertised costs at four-year public in-state and private colleges, respectively, while the typical student in the ELS who enters college in 2004 can borrow a lower share of advertised costs, up to 21 and 10 percent (Figure 2.1).

NCES also provides administrative data from each student's Free Application for Federal Student Aid (FAFSA). I link my cohort data to annual college level data from the Integrated Postsecondary Education Data System (IPEDS). All college campuses that offer financial aid must provide annual information to IPEDS, including a rich set of characteristics, such as in- and out-of-state tuition, cost of attendance, and total applications and enrollment. As a result, I am able to use the student's expected family contribution from her FAFSA and cost of attendance from IPEDS to construct her financial need at each college she considers, which dictates her federal financial aid eligibility. Lastly, I use historical college rankings from USNews[2] to classify any campus as "elite" if it is a state flagship institution or has ever been ranked as a top 50 university or top 25 liberal arts college. The interactions of college control (public or private), level (two- or four-year), location (in- or out-of-state), and elite status constitute the college type in my empirical model.

2.3 Student Characteristics and Enrollment Behavior

I analyze a sample[3] of 7,960 students from the ELS who are eligible to enter college for the first time in the 2004-2005 academic year, and 10,550 students from the HSLS who are eligible to enter college for the first time in the 2013-2014 academic year.[4] Henceforth, I refer to the cohorts by their year of high school completion and potential college entry, as in the class of 2004 and the class of 2013. Due to data availability, I consider education decisions for the first three academic years after high school exit of each cohort. Appendix A further details the analysis sample, data availability, and variable construction.

Table 2.2 describes the characteristics of the estimation sample, revealing two demographically similar cohorts with a few key differences. The class of 2013 have higher academic achievement, as measured by a composite of high school grades and SAT scores, than the class of 2004. In the model, colleges use this measure of academic achievement as signals of student ability to determine admissions and institutional aid.[5] Students in 2013 are also more likely than their 2004

[2]Compiled by Andrew G. Reiter and publicly-available at andyreiter.com/datasets/.

[3]In accordance with the Institute of Education Sciences (IES) restricted-use data guidelines, I report all unweighted sample sizes rounded to the nearest ten.

[4]This reduced sample excludes students who transfer during college, attend graduate school immediately after college, apply to more than five schools, or have missing data.

[5]A student's academic signal is high if their SAT score is 1200 or above and if their high school GPA is 3.5 or greater. Students who have SAT scores below 1000 and high school GPA below 3.5 have a low signal,

counterparts to come from a high-income household, more likely to complete the FAFSA, and have fewer siblings. However, conditional on completing the FAFSA, expected family contributions (EFC) remain unchanged across cohorts. This lack of difference suggests that families eligible for federal aid have similar abilities to pay for their children's college education according to the federal government, despite different income levels and FAFSA completion rates. All of these observable characteristics impact the student's ability to receive aid from both federal and non-federal sources, and consequently determine their financial need that affects the amounts students can borrow.

The top panel of table 2.3 shows the types of institutions in which students enroll. The largest shift in college choice across cohorts occur at the lower end of the college quality spectrum; class of 2013 students are no more likely to attend elite colleges than their 2004 counterparts, but they are more likely to attend public four-year non-elite institutions rather than two-year colleges. Further examination of the students' consideration set of available colleges highlights two factors entering the student's college choice decision: price and non-monetary preferences. The bottom panels of table 2.3 show characteristics of the selective institutions attended by students in comparison to the other selective institutions that offered them admissions, as well as the cost of less than four-year institutions that I include in all students' consideration sets as an outside option.

The advertised cost of attendance at all colleges in the student's consideration set is higher for the class of 2013 than the class of 2004. Interestingly, while both cohorts choose a cheaper college relative to the rest of their consideration set, the advertised price difference is greater for the class of 2013. Furthermore, colleges not attended are similarly selective in comparison to those attended for both cohorts, but colleges not attended are slightly more generous than the ones attended for the class of 2013, offering greater amount of aid to more students. However, the higher levels of aid offered do not sufficiently offset the higher advertised cost of attendance, suggesting that financial constraints may bind in the student's college choice decision.

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and all other students have the middle signal. The class of 2013 has higher high school grades, likely due to greater grade inflation; however, SAT scores are standardized within cohorts.

Table 2.2: Student Characteristics for High School Classes of 2004 and 2013

	Class of 2004		Class of 2013	
	Mean	Standard Deviation	Mean	Standard Deviation
Academic achievement in high school				
HS GPA > 3.5	0.20	(0.40)	0.32***	(0.47)
SAT $\in [1000, 1200)$	0.23	(0.42)	0.25**	(0.43)
SAT ≥ 1200	0.12	(0.33)	0.13**	(0.34)
Academic Signal, middle	0.32	(0.47)	0.35***	(0.48)
Academic Signal, high	0.08	(0.27)	0.11***	(0.31)
Demographic characteristics				
Female	0.52	(0.50)	0.51	(0.50)
Black	0.12	(0.32)	0.09***	(0.29)
Hispanic	0.13	(0.33)	0.14***	(0.35)
Asian	0.09	(0.29)	0.08***	(0.27)
Other Race	0.06	(0.23)	0.10***	(0.29)
Household characteristics				
Completed FAFSA	0.54	(0.50)	0.62***	(0.48)
EFC ($1,000s)	12.521	(19.305)	12.334	(20.156)
Middle Income	0.41	(0.49)	0.32***	(0.47)
High Income	0.29	(0.45)	0.43***	(0.49)
Dependent Student	0.97	(0.17)	0.96***	(0.20)
One Sibling	0.32	(0.47)	0.33	(0.47)
Multiple Siblings	0.33	(0.47)	0.26***	(0.44)
Observations	7,960		10,550	

NOTE: Stars show statistically significant differences of means between the Class of 2004 and the Class of 2013. EFC is the expected family contribution as calculated by the FAFSA, and is only available if the student and/or her family completed the FAFSA. All monetary amounts are in thousands of 2016 US dollars. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), 2004, and High School Longitudinal Study of 2009 (HSLS:09), 2013.
*** $p < 0.001$, ** $p < 0.05$, * $p < 0.01$

Table 2.3: Characteristics of Institutions in Admissions Set

	Class of 2004		Class of 2013	
	Mean	Standard Deviation	Mean	Standard Deviation
Institution of enrollment				
Less than 4 years	0.33	(0.47)	0.26***	(0.44)
Public, non-elite	0.34	(0.48)	0.42***	(0.49)
Private, non-elite	0.17	(0.38)	0.17	(0.37)
Public, elite	0.12	(0.32)	0.13**	(0.34)
Private, elite	0.03	(0.18)	0.02***	(0.13)
In-state	0.83	(0.38)	0.84	(0.37)
Less than 4 year institution characteristics				
Cost of Attendance ($1,000s)	13.024	(2.624)	14.353***	(2.628)
Characteristics of selective colleges attended				
Cost of attendance ($1,000s)	22.007	(8.864)	25.009***	(9.707)
Admission rate	0.65	(0.13)	0.62***	(0.13)
Students receiving aid	0.66	(0.14)	0.71***	(0.13)
Average aid ($1,000s)	6.443	(4.358)	7.885***	(5.559)
Characteristics of selective colleges not attended				
Cost of attendance ($1,000s)	23.242	(7.914)	27.654***	(9.467)
Admission rate	0.65	(0.11)	0.62***	(0.12)
Students receiving aid	0.67	(0.14)	0.73***	(0.13)
Average aid ($1,000s)	6.476	(3.680)	8.592***	(5.360)
Observations	7,960		10,550	

NOTE: All four year colleges are selective. Selective colleges not attended include institutions where students received admissions, but chose not to attend. Elite colleges are either a state flagship institution or have ever been ranked as a top 50 university or top 25 liberal arts college. Cost of attendance is the advertised sticker price, including tuition, room, board, and fees. Students with aid is the share of enrolled students with any non-federal aid, and the average amount of aid is conditional on receiving aid. Stars show statistically significant differences of means between the Class of 2004 and the Class of 2013. The following characteristics of not attended selective institutions significantly differ from those of attended selective institutions: cost of attendance and students receiving aid for both cohorts, and average aid for the class of 2013 only. All monetary amounts are in thousands of 2016 US dollars. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.

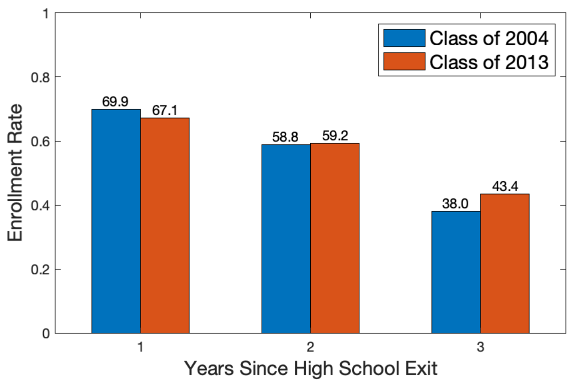
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), 2004, High School Longitudinal Study of 2009 (HSLS:09), 2013, and Integrated Postsecondary Education Data System (IPEDS), Fall 2004 and Fall 2013.

*** $p < 0.001$, ** $p < 0.05$, * $p < 0.01$

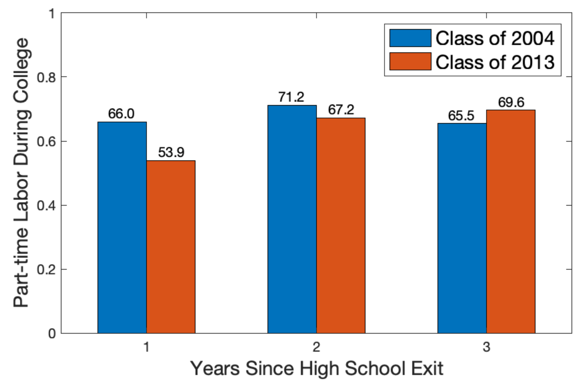
Beyond price, additional preferences for college type and location may drive student choices. For example, students are more likely to attend public institutions and more than 80 percent of students attend college in their home states. Therefore, the theoretical model accounts for the non-pecuniary benefits in enrollment and the college choice decision in addition to the presence of financial constraints.

Data trends beyond the initial college choice motivate additional features of the theoretical model. Figure 2.2 shows enrollment, part-time labor, and federal loan borrowing for each cohort in the first three years after exiting high school. Enrollment patterns are similar across cohorts, except that Class of 2013 students are more likely to persist into their third year. We see that Class of 2004 students borrow less frequently and lower amounts than Class of 2013 students, but the latter cohort's borrowers are less likely to take out the maximum amount of loans, as set by federal limits. This observation suggests that students who face higher borrowing limits are better able to borrow their desired amounts; similarly, the borrowing constraints bound a significant proportion of the 2004 class from accessing funds to finance college. We also see that loan amounts are increasing by the year of enrollment, which reflects the climbing borrowing limits by year of enrollment in college. The data suggest that borrowing constraints are relevant for a large group of students and highlights the need to explicitly model the student's optimal borrowing decisions in such a loan environment. Furthermore, 2013 students are less likely to work, especially early in their college careers, than their 2004 counterparts. Taken together with fewer constraints on borrowing, such behavior suggests a trade-off between work and borrowing as a means to finance college.

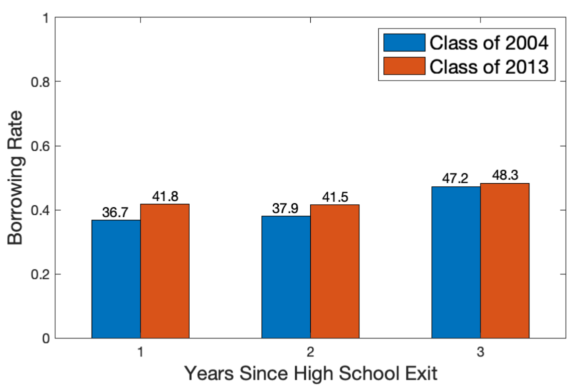
Figure 2.2: College Enrollment, Part-time Labor, and Borrowing



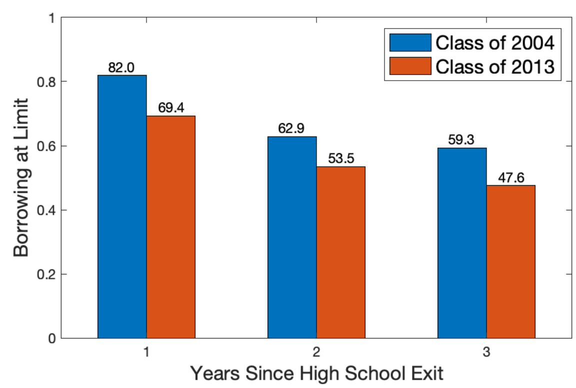
(a) Undergraduate Enrollment



(b) Part-time Labor, if enrolled



(c) Borrowing Rate, if enrolled



(d) Borrowing at Limit, if borrowed

NOTE: The sample includes only those eligible to enter college for the first time in the 2004-05 academic year or the 2013-14 academic year. Once a student exits college, she is not allowed to enroll again and is considered to be part of the labor force.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), 2004–2007, High School Longitudinal Study of 2009 (HSLS:09), 2013–2016.

CHAPTER 3: MODEL OF STUDENT DECISION-MAKING: APPLICATIONS, ENROLLMENT, AND BORROWING

A dynamic discrete choice model describes high school graduating students' decisions to apply to college, enroll on an annual basis, and finance their education. Let t denote the academic years after student i exits high school; she earns her high school diploma at the end of $t = 0$. She enters t with observed state variables Ω_{it} and ability μ_i that is known to herself, her family, and the colleges to which she applies but unobserved to the researcher.

Table 3.1: Information Set at Beginning of Period t, Ω_{it}

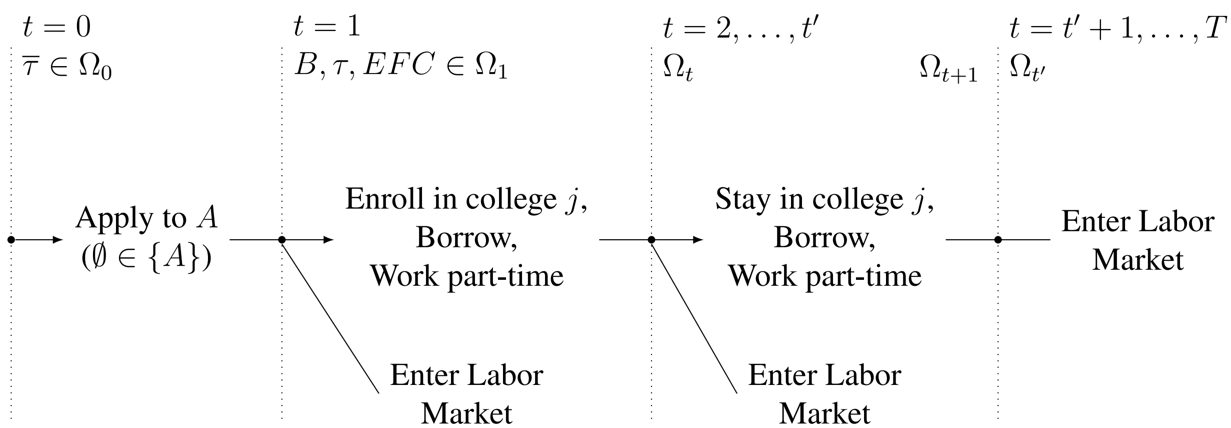
Observed characteristics	
Y_i	Family income
a_i	Student's high school academic signal
F_{it}	Household has completed annual FAFSA
X_{it}	Gender, race, number of siblings
First year after high school, $t = 1$	
B_i	Set of colleges that admit student i
τ_{ik1}	Cost of attendance at each college $k \in B_i$, net of aid
EFC_{i1}	Expected family contribution, determined by FAFSA
Subsequent years after enrolling at college j, $t > 1$	
S_{ijt}	Level of schooling and type of college attended entering t
$\mathbf{D_{it}}$	Borrowing history entering t
L_{it}	Ever worked part-time during college prior to t
N_{ijt}	Financial need for academic year t at college j
τ_{ijt}	Cost of attendance at college j, net of aid

The information available to the decision-maker Ω_{it} (i.e., the vector of variables describing the individual's state at the beginning of each period) includes exogenous observed heterogeneity and endogenous characteristics that evolve based on the student's decision history and stochastic shocks. Among the observed heterogeneity, the student's family income Y_i, academic signal a_i, and

FAFSA completion status F_{it} are key determinants of her decision making process. Endogenous state variables include the set B_i of colleges offering the student admission, cost of attendance net of institutional aid τ_{ijt}, expected family contribution EFC_{it}, financial need N_{ijt} as defined by (2.1), and decision histories associated with enrollment at college j. Table 3.1 defines each variable in Ω_{it} and establishes notation.

The timeline in figure 3.1 describes the sequence of the student's decisions. To reduce notation, I suppress the individual student subscript i. Entering each period t, she observes state variables Ω_t and ability μ.

Figure 3.1: Timeline of Student's Decisions after Final Year of High School $t = 0$



At the end of her last year in high school, $t = 0$, a student observes the posted cost of attendance $\overline{\tau}_{k1}$ at all colleges k for the following academic year, or the maximum any student will pay to attend college k. She applies to a set of colleges A, which may include no colleges. If she does not send any applications, she will have the option to enroll in a community college or enter the labor market and inelastically supply labor at the end of high school. Once in the labor market, she may not apply to or enroll in college again. Before $t = 1$, the student learns $\{B, \tau_1, EFC_1\} \in \Omega_1$. She simultaneously receives admission to a set of colleges $B \subseteq A$, corresponding individual cost of attendance net of institutional aid τ_{k1} at all admitting colleges $k \in B$, and her expected family contribution EFC_1, only if her family has completed the FAFSA.

In $t = 1$, the student evaluates her college alternatives and financing methods based on the lifetime value of welfare associated with each combination of options. She optimally chooses which college to attend and a method to finance her education. She is personally responsible to pay the price p_{k1} to enroll at college k, where p_{k1} factors in her parent's contributions in addition to the individual cost of attendance. She may forgo college enrollment and enter the labor market, or jointly enroll at a college $j \in B$, borrow via student loans, and work part-time during her first year.

The student spends the subsequent academic years $t = 2, \dots, t'$ in college. Prior to each t, her past observed choices and realized shocks update her state variables from Ω_{t-1} to Ω_t. Specifically, she learns her cost of attendance τ_{jt} and, if her family has completed the FAFSA, her financial need N_{jt} for the upcoming year t. In each t, the student may forgo enrollment (drop out)[1] to enter the labor market, or jointly decide to continue enrollment at college j, borrow, and work part-time. She may not transfer colleges after initial enrollment in $t = 1$.

The student exits college j at the end of t' by dropping out, graduating with an exogenous probability, or completing the maximum years of schooling, $\bar{t}$.[2] For $t = t' + 1, \dots, T$, the student inelastically supplies labor, earns a wage conditional on finding employment, and repays student debt.

3.1 Enrollment, Borrowing, and Part-time Labor Decision

The student spends academic years $t = 1, 2, \dots, t'$ in college. At the beginning of t, she evaluates enrollment (e_{jt}), borrowing (d_{jt}), and part-time work (l_{jt}) alternatives at each college $j \in B$ that offers her admission to maximize her expected discounted value of lifetime utility. The student's

[1] College dropout is not the focus of this paper, but an endogenous dropout decision allows for the associated option value of a student's decision to "try out" college, which Stange (2012) measures to be 14% of the total benefits of college enrollment for the average student.

[2] The theoretical model can accommodate an endogenous graduation probability that depends on the student's decision history and unobserved ability. However, missing variables in the fourth year of the student's college enrollment and beyond do not allow for identification of the parameters of such an endogenous graduation process. As a result, I estimate an exogenous graduation probability that depends on the college and year of enrollment, which I discuss further in chapter 5.

choice set at each college j includes all possible alternatives of (e_{jt}, d_{jt}, l_{jt}).

$$(e_{jt}, d_{jt}, l_{jt}) \in \underbrace{(0,0,0)}_{\text{not enroll}} \cup \underbrace{\{(1,d,l) : d \in \text{ supp}(d_{jt}), l \in \{0,1\}\}}_{\text{enroll at college } j \text{, borrow } d \text{, work part-time } l}.$$

Furthermore, in $t = 1$, her choice set is $\{(e_{jt}, d_{jt}, l_{jt})\}_{j \in B}$, which includes each enrollment, borrowing, and part-time labor alternative at all colleges j in her admission set B.

In each t, the student compares the expected lifetime value at time t of entering the labor market $\left(V_{jt}^{L}\right)$ with the expected lifetime values $\left\{V_{jt}^{dl}\right\}$ at time t of jointly enrolling at college j, borrowing d, and working l, that is $(e_{jt}, d_{jt}, l_{jt}) = (1, d, l)$. She may also directly enter the labor market without ever attending college $(j = 0)$:

$$\max_{\{e_{j1}, d_{j1}, l_{j1}\}_{j \in B}} \left\{V_{01}^{L}, \left\{V_{j1}^{dl}\right\}_{j \in B}\right\}.$$

For $t = 2, \ldots, t'$, the student compares the values of the labor market option to the values of the alternatives she faces at the college j that she chose in $t = 1$:

$$\max_{e_{jt}, d_{jt}, l_{jt}} \left\{V_{jt}^{L}, V_{jt}^{dl}\right\} \qquad \forall t = 2, \ldots, t'.$$

The j subscript on V_{jt}^{L} shows that the value of entering the labor market in $t > 1$ depends on the student's past enrollment in college j.

The budget constraint (3.1) reflects that the student annually consumes borrowed amounts d_{jt} and part-time labor income $\overline{W}$, while paying p_{jt}. The price of college p_{jt} depends on cost of attendance τ_{jt}, financial need N_{jt}, and household characteristics. That is,

$$c_{jt} = d_{jt} + l_{jt}\overline{W} - p_{jt}. \tag{3.1}$$

A borrowing constraint (3.2) sets an individual borrowing limit $\bar{d}_{jt}$ on the amount she may borrow, determined by her cost of attendance τ_{jt} net of any federal grants received $Pell_t$ or an exogenous federal borrowing limit $\bar{d}_t$.[3] Specifically,

$$0 \leq d_{jt} \leq \bar{d}_{jt} \equiv \min\left\{\tau_{jt} - Pell_{jt}, \bar{d}_t\right\}. \tag{3.2}$$

Value Functions The student solves her optimization problem by choosing the alternative at time t from $\{(e_{jt}, d_{jt}, l_{jt})\}_{j\in B}$ in $t = 1$ and $\{(e_{jt}, d_{jt}, l_{jt})\}$ in $t > 1$ that has the highest lifetime value. For each alternative that includes college enrollment at j, borrowing d, and part-time labor l, the lifetime value is V_{jt}^{dl}.

$$\begin{aligned} V_{jt}^{dl} &\equiv V_{jt}\left(1, d, l; \Omega_t, \varepsilon_{jt}^{dl}\right), \qquad \forall j, d, l \\ &= \begin{cases} u_{jt}^{dl} + \varepsilon_{jt}^{dl} + \beta E_t\left[\max\left\{V_{jt+1}^{L}, V_{jt+1}^{dl}\right\} | \left(1, d, l\right)\right] & 1 \leq t < \bar{t} \\ u_{jt}^{dl} + \varepsilon_{jt}^{dl} + \beta E_t\left[V_{jt+1}^{L} | \left(1, d, l\right)\right] & t = \bar{t} \end{cases} \end{aligned} \tag{3.3}$$

The lifetime value at t of the alternative $(e_{jt}, d_{jt}, l_{jt}) = (1, d, l)$ is a function of the student's state Ω_t entering t, contemporaneous payoffs u_{jt}^{dl}, idiosyncratic taste shocks ε_{jt}^{dl}, and expected future value conditional on the time t alternative $(e_{jt}, d_{jt}, l_{jt}) = (1, d, l)$. The contemporaneous payoffs sum the utility of consumption $u(c_{jt})$ and non-pecuniary preferences η_{jt}^{dl}, which depend on the alternative, college characteristics, student characteristics, and unobserved ability, to capture psychic costs and benefits such as disutility of labor or preferences to attend college in the student's home state. Per period utility is

$$u_{jt}^{dl} = u\left(\underbrace{d + l \cdot \overline{W} - p_{jt}}_{c_{jt}}\right) + \eta_{jt}^{dl}.$$

The expectation of future value, conditional on each alternative, depends on future stochastic shocks to wages, preferences, financial need, cost of attendance, and college graduation.

[3]Constraint (3.2) reflects unsubsidized loans, but can be modified for subsidized loans as $0 \leq d_{jt} \leq \min\left\{N_{jt}, \bar{d}_t\right\}$. I solve for the total amount she borrows, d_{jt}^*, assuming that she borrows via subsidized loans first as they accrue less interest than unsubsidized loans. If d_{jt}^* is above the subsidized limit, the student borrows using unsubsidized loans until she reaches $\min\left\{d_{jt}^*, \bar{d}_{jt}\right\}$.

The student's value, V_{jt}^{L}, of entering the labor market at time t with the enrollment history associated with college j reflects the indirect utility of her optimal consumption path from labor market entry to retirement at T. Specifically,

$$V_{jt}^{L} \equiv V_{t}^{L}\left(\Omega_{t}, \varepsilon_{t}^{L}\right) = u\left(c_{t}^{*}\right) + \varepsilon_{t}^{L} + \sum_{s=t+1}^{T} \beta^{s-t} u\left(c_{s}^{*}\right) \tag{3.4}$$

She optimally smooths consumption and divides the present value of her expected lifetime earnings net of loan repayments over her working life,[4] such that

$$c_{s}^{*} = \frac{1}{\sum_{s=t}^{T} \beta^{s-t}} \left(E\left[\sum_{s=t}^{T} \beta^{s-t} \pi_{js}^{E}\left(S_{jt}, L_{t}\right) W_{js}\left(S_{jt}\right) \right] - r\left(\mathbf{D_t}, \mathbf{R_t}, H\right) \right) \quad \forall s = t, \ldots, T.$$

Expected lifetime earnings account for the probability of employment π_{js}^{E} in any future year s, which varies by accumulated education S_{jt} and part-time work experience L_t, and future wages W_{js}, which include returns to schooling. The student's discounted lifetime payment r of accumulated student debt depends on a vector of her borrowing history $\mathbf{D_t} = (d_1, \ldots, d_t)$, interest rates $\mathbf{R_t} = (R_1, \ldots, R_t)$ associated with each year of a student's borrowing history, and repayment horizon H.

The value function captures trade-offs (between contemporaneous and future utility for each alternative in the student's choice set) that rationalize the student's enrollment, her choice of college, borrowing, and part-time labor during college that we observe in the data. College enrollment provides future wage returns, which determine V_{jt+1}^{L}, and current non-pecuniary benefits η_{jt}^{dl} while costing the student p_{jt} today. Employment accumulates human capital that is rewarded on the labor market and provides additional income $\overline{W}$ during college, yet may impose a current psychic cost as part of η_{jt}^{dl}. Borrowing relaxes the student's current budget constraint, which can help her attend a college that offers future wage premiums, but deducts loan repayment from future earnings that reduces the value of the labor market option V_{jt+1}^{L} and imposes a psychic cost.

[4] Risk-averse individuals optimally smooth consumption from graduation to retirement assuming lifetime earnings are perfectly insured after college and there exists a credit market with interest rate $(1-\beta)/\beta$. The lifetime budget constraint equates discounted lifetime consumption with discounted lifetime expected earnings net of repayment.

3.2 Student's Application Decision

Prior to $t = 1$, a student applies to a subset A of the colleges in her consideration set by maximizing the expected discounted value of future lifetime utility associated with each subset of colleges to which she may apply. The value of of applying to subset A is

$$V_A = u(c_0) - \psi_A + \varepsilon_A + \beta E\left[\max\left\{V_{01}^L, \{V_{j1}^{dl}\}_{j\in B}\right\}|B \subseteq A\right], \qquad \forall A.$$

She consumes c_0, pays application cost ψ_A, and receives a preference shock ε_A specific to each application set. At the time of applications, the student is uncertain about future admissions, institutional aid, and expected family contribution as determined by her family's filed FAFSA. These three stochastic processes will determine the student's available college choice set in $t = 1$: admissions decisions define the set of colleges she may attend, and aid and expected family contribution (EFC) determine the price of attendance and borrowing constraints she will face. Therefore, the expectation of her future value depends on the probability of these three stochastic processes and her optimal decisions in $t = 1$ conditional on the realization of admissions, institutional aid, and EFC.

Expected Family Contribution I do not explicitly model the FAFSA filing behavior, and instead assume that a student's family exogenously decides to file or not to file. After the student submits her college applications, she learns her EFC. The federal government determines a student's EFC based on the household's financial situation and the potential need to pay for additional children to attend college. Therefore, the distribution of EFC depends on observable heterogeneity, such as family income Y and number of siblings X.

$$P(EFC_1) = f(X_1, Y)$$

EFC does not depend on the colleges to which the student applies. Once determined, the student and all the colleges to which she applies simultaneously learn EFC_1.

College Admissions and Institutional Aid A student's probability of gaining admissions and institutional aid depends on the information the college observes about her. Admissions offices at colleges observe the student's academic signal, through high school transcripts and standardized exam scores, and unobserved ability, through written components and interviews that the researcher does not observe. Furthermore, the aid office at the college receives the student's EFC_1. While the institution as a whole observes both academic and financial characteristics of the student, I assume the admissions office does not use any financial information about the student, motivated by popular need blind admissions policies.

For a student applying to college j, her probability P_j of gaining admission, that is $j \in B$, depends on her academic signal a and unobserved ability μ,

$$P_j \equiv P\left(j \in B\right) = f_j\left(a, \mu\right).$$

The probability P_j^A of receiving aid at admitting college j, that is $\tau_{j1} < \overline{\tau}_{j1}$, also depends on her EFC.

$$P_j^A \equiv P\left(\tau_{j1} < \overline{\tau}_{j1} | j \in B, EFC_1\right) = f_j^A\left(EFC_1, a, \mu\right)$$

The j subscript highlights that colleges admit observationally similar students differently based on each institution's constraints and objective function. This admissions and aid policy can be derived from the theoretical model of colleges as the suppliers of higher education described in Appendix D, where the college has preferences over mean academic characteristics and ability of its student body while facing budget and capacity constraints.[5] Solution to a supply side model shows that a college weighs the marginal benefit of admitting the student, measured by the student's marginal contribution to average academic characteristics, student body ability, and tuition revenue, against the marginal cost of giving up a seat from its limited capacity. Therefore, the admissions

[5]Epple et al. (2006) and Fu (2014) provide an equilibrium analysis of the higher education market where college admissions and pricing depend on anticipated enrollment decisions of the institution's applicant pool.

office admits students with the same academic signal and ability equivalently as these students present the same trade-off for the college.

The aid office additionally considers if the aid offer will induce a student to attend in relation to the marginal cost of distributing limited funds for institutional aid. To forecast a student's enrollment, the aid office uses the available EFC to infer the final price a student would need to pay to enroll, as EFC provides information on the family's capacity to pay as well as the student's eligibility for federal aid. Furthermore, recall from (2.1) that a student's federal Pell grants are deterministic given her EFC and cost of attendance. The aid office offers students with the same academic signal, ability, and EFC equivalent amounts of aid. Conditional on admissions, aid, and EFC, the student can construct her financial need N_{j1}, as given by (2.2), for her first year of enrollment at college j.

CHAPTER 4: EMPIRICAL SPECIFICATION

While the theoretical model highlights the constraints and trade-offs that influence a student's application, enrollment, choice of college, borrowing, and part-time labor decisions, estimation of a tractable version of the model requires a few simplifying assumptions about the student's consideration set, preferences, price of college attendance, and evolution of state variables.

4.1 Student's Consideration Set

To solve and estimate the student's application decision and choice of college, I restrict the number of colleges a student may consider. I assume that a student applies to and enrolls in a college of type j, rather than an individual college. Each college type is an enrollment-weighted aggregate of the individual colleges and, from the student's perspective, all colleges that share a type are identical.[1] Beyond tractability, college competition within types rationalizes a symmetric equilibrium, in which colleges that share the same type have identical optimal admission and pricing decisions for observationally similar students.

I define college types by the control, level, and location of the institution. There are five colleges per state and two national private elite institutions. Specifically, each state has a community college, public non-elite college, two private non-elite colleges, and a public elite college. The consideration set of each individual student includes eleven colleges. In addition to the five in-state colleges, she can also consider six out-of-state colleges: one public non-elite college, two private non-elite

[1] Models of a student's application behavior utilize two approaches to reduce the dimension of the consideration set: a similar method of aggregated individual institutions (Fu, 2014) or randomly drawing a set of individual institutions (Arcidiacono, 2005).

colleges, one public elite college, and two private elite institutions.[2] I assume all students apply to the community college and can send out a maximum of four additional applications to the remaining ten colleges. Even with the reduced consideration set and maximum number of applications, a student can choose from a set of 168 unique application portfolios. While a maximum number of applications may appear restrictive, more than 90 percent of my sample send four or fewer applications to selective colleges.[3]

4.2 Preferences

I assume log utility of consumption, $u(c) = \log(c)$, and additive college-specific preferences for students enrolled at college j,

$$\eta_{jt}^{dl} = \eta_j + \eta_{d0}\mathbb{1}[d_{jt} > 0] + \eta_d d_{jt} + \eta_l l_{jt} + \eta_{dl} d_{jt} l_{jt} + \eta_X X_{jt} + \eta_\mu \mu,$$

where contemporaneous utility is $u(c_{jt}) + \eta_{jt}^{dl} + \varepsilon_{jt}^{dl}$. I normalize the utility of not enrolling in college to zero. Therefore, preference parameter η_j captures the utility of being at college type j, relative to entering the labor market. Non-linear psychic costs or benefits of borrowing affect the student's utility through the parameters η_{d0}, if she borrows anything, and η_d, specified to be quadratic in the amount borrowed.

The parameters η_l and η_{dl} measure the preference for working, both while the student does and does not borrow. Furthermore, I discretize the support of borrowing decisions to reduce the computation burden. Specifically, a student may choose a set number of fractions $\delta \in [0, 1]$ of her

[2] I allow for two private institutions of each type because private four-year institutions double public four-year institutions in number and to better fit observed application behavior. Depending on the college type, 20 to 30 percent of students who apply to any private institution also apply to a second institution of that type.

[3] Data for the class of 2013 only provides details on the first three applications. I impute additional applications for a small group of students in order to complete their consideration sets. Appendix A describes the imputation based on similarities in application profile, conditional on number of applications sent, between the two cohorts.

individual borrowing limit $\bar{d}_{jt}$ to borrow, such that

$$d_{jt} = \delta \bar{d}_{jt}.$$

Student-college characteristics X_{jt} include race, gender, accumulated years of schooling, and in-state status and η_X highlights preferences that can match heterogeneity in enrollment rates, such as a desire to stay close to home, differential drop out rates by a student's progress in college, and enrollment trends of demographic groups. Lastly, η_μ measures preferences that vary by the student's unobserved ability, which I allow to differ by the college's elite status to further capture sorting by ability of students to elite colleges.

Taste shocks for entering the labor market or continuing in college $\left(\varepsilon_t^L, \varepsilon_{jt}^{dl}\right)$ follow an Extreme Value Type I distribution. The resulting choice probabilities P_{jt}^L and P_{jt}^{dl} of choosing the labor market option or alternative $\left(e_{jt}^*, d_{jt}^*, l_{jt}^*\right) = (1, d, l)$ at college j, respectively, are

$$\begin{aligned} P_{jt}^L &\equiv P\left\{\left(e_{jt}^*, d_{jt}^*, l_{jt}^*\right) = (0,0,0)\right\} = \frac{\exp\left(V_{jt}^L\right)}{\exp\left(V_{jt}^L\right) + \sum_{d,l} \exp\left(V_{jt}^{dl}\right)} \\ P_{jt}^{dl} &\equiv P\left\{\left(e_{jt}^*, d_{jt}^*, l_{jt}^*\right) = (1,d,l)\right\} = \frac{\exp\left(V_{jt}^{dl}\right)}{\exp\left(V_{jt}^L\right) + \sum_{d,l} \exp\left(V_{jt}^{dl}\right)}. \end{aligned} \tag{4.1}$$

4.3 Price of College Attendance

In order to attend college j, a student herself needs to pay for any remaining cost of attendance that is not covered by institutional aid, family contributions FC_t, and federal Pell grants $Pell_t$. That is, the price of attending college j is

$$p_{jt} = \tau_{jt} - FC_t - Pell_{jt}.$$

A student who does not complete the FAFSA is ineligible to receive federal Pell grants. For a student who has completed the FAFSA, I can measure her financial need as the cost of attendance net of expected family contribution and additional Pell grants. Substituting the definition for financial need (2.2) into the price function, we see that

$$p_{jt} = (1 - F_t)(\tau_{jt} - FC_t) + F_t(N_{jt} + EFC_t - FC_t).$$

Because the data do not provide dollar values of family contributions, I assume that the family contribution depends on household income, the FAFSA completion status, and the student's unobserved ability. I parametrize the price function as a reduced form of the above theoretical equation:

$$p_{jt} = (1 - F_t)\tau_{jt} + F_t N_{jt} + \eta_1^p Y + \eta_2^p F_t Y + \eta_\mu^p \mu. \tag{4.2}$$

Parameters η_1^p and η_2^p capture differences in family contribution and expected family contribution by household income and FAFSA completion status, while η_μ^p allows family contribution to vary by the student's unobserved ability.

4.4 Stochastic Processes Relevant to Student Decisions

Labor Market A student who exits college in t' earns a wage in all periods $t = t' + 1, \ldots, T$, if she is employed. Her log wages are

$$\log W_t = \gamma_0 + \gamma_j S_{jt'} + \gamma_j^{CG} + \gamma_q + \gamma_X X_{t'} + \gamma_Z Z_{t'} + \gamma_\mu \mu + \gamma_{gt} + \varepsilon_t^W \tag{4.3}$$

Wages depend on human capital and characteristics that are fixed after the student leaves college at t'. The return γ_j to the years of schooling $S_{jt'}$ estimate the wage premiums for completing an additional year of college, while allowing the return to vary by the level of the institution (two- or four-year). The return γ_j^{CG} measures the wage premium of college graduation.[4] The return γ_q measures any premium associated with attending an elite institution. A vector $X_{t'}$ and ability

[4]As the primary purpose of this paper is to understand college choice, I abstract away from signaling effects. If policies result in large shifts to college enrollment, wages may adjust due to a change in the signal that a certain type of college provides to employers. Students may learn of changes to their college's signal after enrollment and are more likely to adjust dropout and borrowing behavior once these shocks are realized than they are to internalize such effects ex-ante in a way that would alter their college choice.

μ control for observed demographic characteristics and unobserved heterogeneity, respectively. Aggregate measures $Z_{t'}$ of a student's home state's labor market in the year she enters the labor market include share of labor force with college degrees and employment rates of those with and without college degrees. Wage growth γ_{gt} for $t > t'$ is concave in potential work experience $(t - t')$. Lastly, wage shocks in each period follow a normal distribution, $\varepsilon_t^W \sim N(0, \sigma_W^2)$.

The probability of employment π_{jt}^E depends on similar factors as wage determination, as well as an indicator for if the student ever worked during college, $L_{t'}$. Assuming employment shocks follow a standard Extreme Value Type I distribution, the log odds ratio for employment is

$$\log \frac{\pi_{jt}^E}{1 - \pi_{jt}^E} = \pi_0 + \pi_j S_{jt'} + \pi_j^{CG} + \pi_q + \pi_X X_{t'} + \pi_Z Z_{t'} + \pi_\mu \mu + \pi_{gt}. \tag{4.4}$$

During her time in the labor market, the student repays the loan principal and all accumulated interest with H equal annual payments. This specification closely matches the standard loan repayment plan.[5]

$$r\left(\mathbf{D}_{\mathbf{t}'}, \mathbf{R}_{\mathbf{t}'}, H\right) = \sum_{s=0}^{H-1} \beta^s \frac{1}{H} \sum_{t=1}^{t'} R_t^{t'-t+H} d_{jt}.$$

Initial Period Admissions, Aid, and Cost of Attendance Recall from section 3.2 that a college j offers admission based on a student's academic signal and ability and the aid office also considers EFC while constructing their aid offer. For a student applying to college j, I model the admissions probability P_j and aid probability, conditional on admissions, P_j^A with a logistic specification. I assume that conditional on unobserved ability μ, admissions and aid shocks are not correlated

[5]The standard repayment plan is the most popular option and students make fixed monthly payments. A different form of the function $r(\cdot)$ can handle alternate repayment plans or more general borrowing histories that include a combination of subsidized and unsubsidized loans. Another common repayment option is the income-based plan where students pay a portion of their income until the loan balance is repaid; under this plan, the loan horizon is heterogeneous: $H = H\left(\mathbf{D}_{\mathbf{t}'}, \mathbf{R}_{\mathbf{t}'}\right)$.

within and across universities.

$$P_j(\mu) = \frac{\exp(\alpha_j + \alpha_{aj}a + \alpha_{\mu j}\mu)}{1 + \exp(\alpha_j + \alpha_{aj}a + \alpha_{\mu j}\mu)}$$
$$P_j^A(\mu) = \frac{\exp\left(\alpha_j^A + \alpha_{aj}^A a + \alpha_{Ej}^A EFC + \alpha_{\mu j}^A \mu\right)}{1 + \exp\left(\alpha_j^A + \alpha_{aj}^A a + \alpha_{Ej}^A EFC + \alpha_{\mu j}^A \mu\right)}$$

A student who files the FAFSA also learns her expected family contribution, which I model to be a function of household income, number of siblings, and the student's cohort. Given realizations of admissions, aid, and EFC, the student can calculate her financial need, and consequently her price p_{j1} for the first year of enrollment at college j according to (4.2). Therefore, conditional on application set A, the joint distribution of receiving admissions at the set of colleges B, associated aid, and EFC is

$$P(B, \tau_{j1}, EFC_1|\mu) = f\left(\varepsilon^E\right) \cdot \prod_{j\in B} P_j \left(P_j^A\right)^{I_j} \left(1 - P_j^A\right)^{1-I_j} \prod_{k\in A\setminus B} (1 - P_k), \tag{4.5}$$

where I_j is an indicator for receiving aid at college j and $f\left(\varepsilon^E\right)$ is the density of EFC (specified in Appendix B). The student receives rejections from all colleges $k \in A \setminus B$.

Cost of Attendance During College For a FAFSA non-filing student in college in $t > 1$, her annual price p_{jt} is a function of stochastic cost of attendance τ_{jt} that depends on the posted tuition, institution characteristics, individual characteristics, unobserved ability, and an idiosyncratic shock $\varepsilon_{\tau t}$ characterized by the density $f(\varepsilon_{\tau t})$. For a FAFSA filing student in college in $t > 1$, her annual price p_{jt} can be written as a function of financial need N_{jt} as shown in (4.2). Therefore, conditional on knowing N_{jt}, the cost of attendance net aid τ_{jt} and expected family contribution EFC_t are irrelevant. Rather than separately modeling the stochastic processes for τ_{jt} and EFC_t, I model the stochastic process for N_{jt} alone, as N_{jt} also explicitly enters the student's borrowing constraint. As observed financial need is censored to be nonnegative, I model the stochastic process for the latent financial need N_{jt}^* to be a function of posted tuition, institution and individual characteristics, factors that determine EFC and Pell grants, unobserved ability, and idiosyncratic shock ε_{Nt} characterized by the density $f(\varepsilon_{Nt})$. Appendix B provides the full specification of the stochastic processes of both cost of attendance for FAFSA non-filers and financial need for FAFSA filers.

4.5 Application Cost

The cost ψ_A of applying to the set A of colleges depends on individual heterogeneity, the number of applications sent, and the types of colleges to which the student applied, where

$$\psi_A = \psi + \psi_Y Y + \psi_a a + \psi_j + \psi_k + \psi_\mu$$

This specification reflects that students may experience a fixed cost of sending any applications that vary by the student's household income Y, academic signal a, cohort, and unobserved ability μ. The variable component of the application cost depends on the type j of colleges in her application set and the number k of colleges, which enters as a quadratic to allow lower marginal costs of sending additional applications. Assuming that taste shocks ϵ_A for applying to set A follow an Extreme Value Type I distribution, the associated choice probabilities of each set A are

$$P_A \equiv P(A) = \frac{\exp(V_A)}{\sum_{A'} \exp(V_{A'})}. \tag{4.6}$$

CHAPTER 5: IDENTIFICATION

It is important to discuss how the estimated structural parameters are identified using the data discussed in chapter 2. Before doing so, I first describe a set of calibrated parameter values and their source (Table 5.1).

Table 5.1: Calibrated Parameters of the Structural Model

Parameter	Description	Value	Source and/or notes
β	Discount factor	0.95	Calibrated
$\overline{W}$	Annual part-time labor income	\$8,415	Median student-worker earnings: \$8.25/hour wage and 20 hours worked/week during the school year. Further assumption: 30 weeks worked per academic year and 35 hours per week over 12 weeks of summer.
$\underline{c}$	Consumption floor	\$2,800	Hai and Heckman (2017)
$\bar{t}$	Maximum years of schooling (4-year institutions)	4	
	Maximum years of schooling (community colleges)	2	
T	Retirement horizon (years from age 18)	50	
H	Debt repayment horizon (years after college exit)	10	Standard repayment plan

Due to data limitations, I am unable to jointly estimate graduation probabilities with the rest of the model. Specifically, FAFSA and part-time labor behavior are missing in the fourth and later years of college enrollment, which prevents me from observing the student's optimal decisions for those years, and consequently from modeling the selection into the fourth year. However, I use the class of 2004 to estimate graduation probabilities separately as a function of year of enrollment, type of college, and demographic characteristics.

5.1 Estimation Strategy

I estimate structural parameters of the model using maximum likelihood estimation (MLE). I assume that unobserved ability μ can be approximated by a support of M discrete types[1] with ϕ_m denoting the probability of type m. The unconditional log likelihood function is therefore

$$\tilde{\ell} = \log\left(\sum_{m}^{M} \phi_m \cdot \prod_i \left(L^A_{i|\mu_m} \cdot L^0_{i|\mu_m} \cdot L^j_{i|\mu_m} \cdot L^\tau_{i|\mu_m} \cdot L^N_{i|\mu_m} \cdot L^W_{i|\mu_m}\right)\right),$$

where each $L^{\cdot}_{i|\mu_m}$ represents the likelihood contribution of observed choices and stochastic processes for a student i, conditional on $\mu = \mu_m$. The six likelihood contributions, conditional on unobserved ability μ, are:

1. $L^W_{i|\mu}$ is the likelihood contribution of employment and observed wages for years $t = t' + 1, \ldots, T$ after college. Parameters Γ_W include wage coefficients γ and variance σ^2_w that characterize the density f^W of wages as specified in (4.3), and employment coefficients π that characterize the probability of employment $\pi^E_{jt}(\mu)$ conditional on unobserved ability (4.4). The indicator I^E_{it} signifies if i is employed at t.

$$L^W_{i|\mu} \equiv L^W_i\left(\Gamma_W|\mu\right) = \prod_{t=t'+1}^{T} \left(1 - \pi^E_{jt}(\mu)\right)^{1-I^E_{it}} \left(\pi^E_{jt}(\mu) f^W\left(\varepsilon^W_t|\mu\right)\right)^{I^E_{it}}$$

2. $L^N_{i|\mu}$ is the likelihood contribution of financial need N_{jt} for FAFSA filers after they enter college, for years $t = 2, \ldots, t'$. Parameters Γ_N include coefficients α^N and variance σ^2_N characterize the density f^N of financial need as specified in (B.1), and the indicator I^N_{it}

[1] Several studies validate this method of addressing unobserved heterogeneity (Heckman and Singer, 1984; Mroz and Guilkey, 1992; Mroz, 1999). In this version, I use two discrete types, that is $M = 2$.

signifies that $N_{jt} > 0$.

$$L^N_{i|\mu} \equiv L^N_i \left(\Gamma_N|\mu\right) = \prod_{t=2}^{t'} P\left(N^*_{jt} \leq 0|\mu\right)^{1-I^N_{it}} f^N\left(\varepsilon^N_t|N^*_{jt} > 0, \mu\right)^{I^N_{it}}$$

3. $L^\tau_{i|\mu}$ is the likelihood contribution of cost of attendance τ_{jt} for FAFSA non-filers after they enter college, for years $t = 2, \ldots, t'$. Parameters Γ_τ include coefficients α^τ and variance σ^2_τ that characterize the density f^τ of cost of attendance as specified in (B.2).

$$L^\tau_{i|\mu} \equiv L^\tau_i \left(\Gamma_\tau|\mu\right) = \prod_{t=2}^{t'} f\left(\varepsilon^\tau_t|\mu\right)$$

4. $L^j_{i|\mu}$ is the likelihood contribution of annual college decisions (e_{jt}, d_{jt}, l_{jt}) for $t = 1, \ldots, t'$, where choice probabilities P^L_{jt} and P^{dl}_{jt}, conditional on unobserved ability, are defined in (4.1). Parameters include estimated preference and price function parameters η, parameters of the stochastic processes for the labor market, financial need, and cost of attendance, and calibrated discount factor β.

$$L^j_{i|\mu} \equiv L^j_i \left(\eta, \Gamma_\tau, \Gamma_N, \Gamma_W|\mu\right) = \prod_{t=1}^{t'} \left\{ \mathbb{1}\left[\left(e^*_{jt}, d^*_{jt}, l^*_{jt}\right) = (0,0,0)\right] \cdot P^L_{jt}(\mu) \right.$$
$$\left. + \sum_{d,l} \mathbb{1}\left[\left(e^*_{jt}, d^*_{jt}, l^*_{jt}\right) = (1,d,l)\right] \cdot P^{dl}_{jt}(\mu) \right\}$$

5. $L^0_{i|\mu}$ is the log likelihood contribution of initial period admissions, aid, and EFC, given parameters $\Gamma_0 = \left\{\alpha, \alpha^A, \alpha^E, \sigma^2_E\right\}$ and the joint distribution of admissions, aid, and EFC described by (4.5).

$$L^0_{i|\mu} \equiv L^0_i \left(\Gamma_0|\mu\right) = P\left(B, \tau_{j1}, EFC_1|\mu\right)$$

6. Lastly, $L^A_{i|\mu}$ is the likelihood contribution of observed applications, which depend on the cost parameters ψ, preference parameters η, and parameters that determine the remaining stochastic processes $\{\Gamma_0, \Gamma_\tau, \Gamma_N, \Gamma_W\}$. The choice probabilities for applying to set J of

colleges conditional on unobserved ability is given by (4.6).

$$L^A_{i|\mu} \equiv L^A_i\left(\psi, \eta, \Gamma_0, \Gamma_\tau, \Gamma_N, \Gamma_W | \mu\right) = \sum_J \mathbb{1}\left[A^* = J\right] \cdot P_J\left(\mu\right)$$

I denote all the estimated parameters in the student model as $\Theta_S = \{\psi, \eta, \Gamma_0, \Gamma_\tau, \Gamma_N, \Gamma_W\}$. In the absence of unobserved ability μ, maximizing the log likelihood $\tilde{\ell}$ is equivalent to maximizing the above six likelihood contributions for the entire sample in sequence (i.e. independently). In that case, the likelihood contributions of wages, financial need, and cost of attendance are independent and one can obtain consistent estimates of $\{\Gamma_\tau, \Gamma_N, \Gamma_W\}$. Given these $\left\{\hat{\Gamma}_W, \hat{\Gamma}_N, \hat{\Gamma}_\tau\right\}$, I can then maximize the likelihood of annual college decisions to estimate $\hat{\eta}$. I can then maximize the likelihood of initial conditions to estimate $\hat{\Gamma}_0$. Lastly, given $\left\{\hat{\eta}, \hat{\Gamma}_0 \hat{\Gamma}_W, \hat{\Gamma}_N, \hat{\Gamma}_\tau\right\}$ I can maximize the likelihood contribution of application behavior to estimate $\hat{\psi}$.

However, one cannot sequentially estimate the log likelihood $\tilde{\ell}$ in the presence of unobserved ability as the error terms are correlated. Estimation becomes computationally costly because my model includes a large number of alternatives (especially college application sets) and a large state space. For similar such applications, Arcidiacono and Jones (2003) show that the expectations maximization (EM) algorithm with a sequential maximization step yields consistent estimates.[2] In applications similar to mine where agent decisions can be divided into stages with distinct parameters (such as costs of application, preferences for enrollment,and returns to education), this sequential procedure can offer large computation savings but is less efficient than full information maximum likelihood.

To implement the EM algorithm, I use a version of the log likelihood function that is equivalent to $\tilde{\ell}$ but restores additive separability of its contributions. Specifically, I estimate parameters

[2] Arcidiacono (2005) implements this estimation procedure in a model of college and major choice that has similar decision stages as my model.

(Θ_S, ϕ_m) to maximize ℓ, defined as

$$\ell = \sum_i \sum_m q_i^m \cdot \left(\ell^A_{i|\mu_m} + \ell^0_{i|\mu_m} + \ell^j_{i|\mu_m} + \ell^\tau_{i|\mu_m} + \ell^N_{i|\mu_m} + \ell^W_{i|\mu_m} \right), \tag{5.1}$$

where each $\ell_{i|\mu_m}$ represents the logs of each of the six likelihood contributions $L_{i|\mu_m}$ for a student i, and q_i^m is the probability of being type m, conditional on the observed data X_i. This conditional probability q_m is derived using Bayes' theorem to be

$$q_i^m \equiv P\left(\mu_i = \mu_m | X_i, \Theta_S, \phi\right) = \frac{\phi_m \cdot L^A_{i|\mu_m} \cdot L^0_{i|\mu_m} \cdot L^j_{i|\mu_m} \cdot L^\tau_{i|\mu_m} \cdot L^N_{i|\mu_m} \cdot L^W_{i|\mu_m}}{\sum_m \phi_m \cdot L^A_{i|\mu_m} \cdot L^0_{i|\mu_m} \cdot L^j_{i|\mu_m} \cdot L^\tau_{i|\mu_m} \cdot L^N_{i|\mu_m} \cdot L^W_{i|\mu_m}}. \tag{5.2}$$

The algorithm iterates the below steps until estimates for the distribution of unobserved types converge, resulting in consistent estimates $\left(\hat{\Theta}_S, \hat{\phi}_m\right)$:

1. Taking initial values of $\hat{\phi}_m$ and $\hat{q}_i^m$ as given, estimate $\hat{\Theta}_S$ as the solution to

$$\max_{\Theta_S} \sum_i \sum_{m=1}^M \hat{q}_i^m \cdot \left(\ell^A_{i|\mu_m} + \ell^0_{i|\mu_m} + \ell^j_{i|\mu_m} + \ell^\tau_{i|\mu_m} + \ell^N_{i|\mu_m} + \ell^W_{i|\mu_m} \right).$$

   Note that since q_i^m is taken as given, I can sequentially estimate each expected log likelihood contribution in (5.1).

2. Update $\hat{q}_i^m$ using the estimated $\hat{\Theta}_S$ as shown in (5.2), and update the unconditional type probabilities as $\hat{\phi}_m = \frac{1}{N} \sum \hat{q}_i^m$.

5.2 Identification of Structural Parameters

Identification of the structural parameters of the model relies on the distribution of unobserved ability and plausibly exogenous variation in prices and federal policies that impact a student's decision-making at each stage. As the student's endogenous state variables are comprised of her decision histories, it is important to control for selection along these decision margins to avoid biased estimates of key parameters. For example, a model without unobserved ability may predict that a student who borrows high amounts today would discontinue enrollment in future years because the marginal net returns to college completion are lower due to higher accumulated student debt. However, since a student of high ability expects greater future earnings on the labor market, she may choose to borrow more and accumulate greater debt. At the same time, she may have strong preferences for college enrollment; as a result, a model with unobserved ability would show that a student who borrows high amounts today would prefer to continue enrollment – the opposite implication from ignoring unobserved ability. Empirically, the model without unobserved ability would understate the psychic costs of borrowing if the data suggest borrowers persist longer in college.

My estimation method controls for selection due to unobserved ability at various stages, by jointly estimating students' choices, stochastic outcomes, and the distribution of unobserved ability. This joint estimation mitigates concerns over bias because the identifying assumption requires shocks to preferences and stochastic processes to be idiosyncratic and uncorrelated over time and with endogenous state variables, conditional on μ and not unconditionally. For models of college enrollment, it is important to properly identify the relative importance of the returns to education to other preferences for college enrollment in order to conduct accurate policy analysis. Students endogenously accumulate education and high ability individuals are more likely to enroll in college due to lower psychic costs than low ability individuals. Similarly, high ability individuals likely earn more than observationally similar low ability individuals. Estimating the model without unobserved ability would overstate both the returns to education and the psychic costs of enrollment: accumulated education would be positively correlated with unobserved components in the wage function and the resulting higher returns to education would imply students face higher psychic costs of enrollment to match observed enrollment rates.

Joint estimation recovers the distribution of unobserved ability by using information from several time periods for an individual. I assume students are of different types, or ability levels. In the data, clusters of students systematically deviate in their outcomes and behaviors from model predictions based on observed characteristics, such as high school achievement and household income. For example, a student with mediocre high school grades may get into an elite college, enroll, and eventually earn more than other graduates from elite institutions. The magnitude of these deviations from model predictions identify the relative importance of unobserved ability at each decision and outcome stage (such as preference for college and returns to education). The relative size of the student population that exhibits these deviations identifies the unconditional probability mass of each type.

In addition to selection, I exploit plausibly exogenous variation in prices and federal policies and control for confounding factors to reduce estimation bias. From a student's perspective, posted tuition rates, federal loan limits, interest rates, and Pell grant limits provide exogenous variation in the price a student will eventually pay to enroll today. Variation in prices across colleges and across time and variation in federal policies across time help identify a student's price elasticity of the demand for college. A possible concern over federal policy variation may be that the Great Recession coincided with changes to federal loan policies in 2007 and 2008; consequently, changes to labor market returns that determine college enrollment would confound the effects of relaxing credit constraints. However, I control for labor market conditions that affect the aggregate economy and the specific returns to college enrollment using unemployment rates, employment to population ratios for college graduates, and share of the labor market with college degrees. These labor market variables further strengthen identification of college preferences, even outside of the Great Recession, by shifting the value of the labor market option, which provides variation in the opportunity cost of college enrollment.

CHAPTER 6: RESULTS

This section discusses a subset of estimated parameters that measure the key economic mechanisms of the model, the distribution of unobserved heterogeneity, and the resulting goodness of fit. I discuss all remaining parameter estimates in Appendix C.

6.1 Non-Pecuniary Benefits of College Enrollment

Estimates of preference parameters, $\hat{\eta}$, include non-pecuniary preferences that vary by alternative, institutional heterogeneity, and individual characteristics. A student faces psychic costs of enrollment at any college, as shown by negative preference parameters in Table 6.1. Such a result is expected as future gains to a college education are high, yet a substantial number of students do not enroll in college. Similarly, there are psychic costs to borrowing any money to finance a college education; however, these costs decrease as the student borrows more. These non-linear preferences for borrowing manifest in the data as we observe that most students either do not borrow or borrow at the limit.

6.2 Application Cost

Table 6.2 shows parameter estimates $\hat{\psi}$, which include fixed and variable application costs. As expected, the fixed cost of applications are lower for students with higher academic signals and higher household incomes. The class of 2013 also faces lower application costs, signifying greater access to online and common applications.

The variable cost of application is greater for elite institutions than non-elite, and greater for out-of-state institutions than in-state. I rationalize these results as students needing to conduct more research or fill out more application components for elite or out-of-state institutions. While per

Table 6.1: Estimates of Preference Parameters: Non-Pecuniary Benefits of College Enrollment

Any Borrowing	-2.317
Amount Borrowed ($1,000s)	0.884
Amount Borrowed Squared ($1,000s)	-0.079
Part-time Labor	0.271
Amount Borrowed $\times$ Part-time Labor	-0.078
College Type	
Community college	-6.357
Public	-4.509
Private	-4.473
In-State	-0.074
Elite	-0.717
Individual Characteristics	
Female	-0.018
Black	-0.647
Hispanic	-0.223
Asian	0.507
Other Race	-0.359
Year in Community College $= 2$	4.737
Year in Four-Year College $= 2$	1.601
Year in Four-Year College > 2	1.834
Type 2	1.630
Type 2 at Elite Institution	-2.035
Distribution of UH	
P(Type 2)	0.382

NOTE: Future version will provide bootstrapped standard errors.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

application costs are high, there are reductions in marginal cost per application as students apply to more colleges, shown by the negative parameter on applications squared.

Table 6.2: Estimates of Application Cost Parameters

Fixed Cost	
Middle Income	0.069
High Income	−0.500
Middle Signal	0.647
High Signal	−1.704
Class of 2013	−3.369
Type 2	−0.201
Variable Cost	
In-state Public Non-elite	−1.511
Out-of-state Public Non-elite	0.398
In-state Private Non-elite	0.398
Out-of-state Private Non-elite	0.855
In-state Public Elite	0.647
Out-of-state Public Elite	1.916
Private Elite	1.932
Number of applications	3.283
Number of applications squared	−0.389

NOTE: Future version will provide bootstrapped standard errors.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

6.3 Labor Market Returns

Table 6.3 shows there are high returns to education on the labor market. Each additional year of enrollment results in a 4.3 percent and 5.9 percent wage increase for two-year and four-year college enrollees, respectively. Furthermore, college graduation and enrollment at an elite college show even larger wage gains of 21.6 percent and 18.7 percent. Employment probability also increases in education attainment; however, the effects are greatest for college graduates and those with some work experience during college. The labor market exclusion restrictions Z also seem to be salient and provide confidence in identifying the future labor market returns of college enrollment.

Table 6.3: Labor Market Returns

	Log Wages		Employment	
	OLS		Logistic	
	Coefficient	(S.E.)	Coefficient	(S.E.)
Years of Schooling	0.043	(0.007)	0.093	(0.028)
× Four Year	0.016	(0.011)	−0.045	(0.024)
College Graduate	0.216	(0.023)	0.507	(0.078)
Elite College	0.187	(0.023)	0.388	(0.071)
Ever Worked in College			0.526	(0.048)
Labor Force with College Degree	0.007	(0.001)	0.006	(0.003)
Employment Ratio, College Graduate			0.018	(0.008)
Employment Ratio, No College			0.027	(0.006)
Unemployment Rate			−0.070	(0.017)
Constant	1.906	(0.040)	−3.085	(0.671)
Type 2	0.270	(0.012)	2.910	(0.053)
σ_W	0.634	(0.005)		
Observations	12,800		30,810	

NOTE: Labor market conditions are measured at the state level. Employment ratio is the employment to population ratio in the state for those with college degrees and those without. Estimation includes controls that are not presented in this table: gender, race, and years of potential labor market experience. Standard errors are not adjusted, future version will provide bootstrapped standard errors. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

6.4 Admissions and Aid

Each institution type offers admission based on academic signal and unobserved type, while the aid office further considers the student's FAFSA completion and EFC. Table 6.4 shows coefficients on interaction terms between the institution type and student characteristics that are relevant to admission and aid outcomes. For example, at an in-state non-elite public college, a student with a high academic signal is more likely to gain admissions, represented by a positive coefficient or log odds ratio of 2.482, than a student with a low signal, represented by the constant. The patterns are intuitive as elite institutions are more selective than non-elite for all students.

Table 6.4: Admission and Aid Offer

	Coefficients (s.e.) for college type × student characteristics					
	Constant	Academic Signal		FAFSA	EFC	Type 2
		Middle	High			
Offered Admission						
In-state Public Non-elite	0.713	1.368	2.482			0.652
	(0.029)	(0.040)	(0.123)			(0.037)
Out-of-state Public Non-elite	0.532	1.285	1.785			1.033
	(0.070)	(0.091)	(0.185)			(0.085)
In-state Private Non-elite	0.737	1.464	2.362			1.073
	(0.055)	(0.076)	(0.184)			(0.069)
Out-of-state Private Non-elite	0.842	0.719	1.400			0.989
	(0.065)	(0.075)	(0.124)			(0.071)
In-state Public Elite	−0.193	0.978	2.057			0.667
	(0.067)	(0.071)	(0.092)			(0.058)
Out-of-state Public Elite	0.123	1.065	1.170			0.741
	(0.103)	(0.112)	(0.131)			(0.092)
Private Elite	−1.055	0.608	0.993			−0.063
	(0.191)	(0.200)	(0.193)			(0.073)
Observations	26,150					
Offered Aid						
In-state Public Non-elite	−1.388	0.189	1.305	0.896	−0.032	1.257
	(0.053)	(0.049)	(0.091)	(0.046)	(0.002)	(0.052)
Out-of-state Public Non-elite	−1.956	0.236	1.497	1.910	−0.026	1.204
	(0.116)	(0.107)	(0.198)	(0.099)	(0.003)	(0.115)
In-state Private Non-elite	−0.633	0.682	1.331	1.201	−0.008	0.827
	(0.089)	(0.084)	(0.141)	(0.079)	(0.002)	(0.090)
Out-of-state Private Non-elite	−1.616	0.437	1.515	2.332	−0.012	1.468
	(0.089)	(0.085)	(0.122)	(0.075)	(0.002)	(0.086)
In-state Public Elite	−1.105	0.062	0.459	0.966	−0.020	1.224
	(0.126)	(0.123)	(0.133)	(0.083)	(0.002)	(0.097)
Out-of-state Public Elite	−1.598	0.208	0.560	1.085	−0.014	0.812
	(0.228)	(0.219)	(0.248)	(0.146)	(0.003)	(0.168)
Private Elite	−4.749	2.751	3.353	2.534	−0.036	2.770
	(0.490)	(0.490)	(0.483)	(0.137)	(0.003)	(0.172)
Observations	9,680					

NOTE: Future version will provide bootstrapped standard errors. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

Similarly, these institutions offer more aid to students with high academic signals. Interestingly, FAFSA completion crowds in institutional aid, perhaps as an incentive mechanism for students to explore all avenues to fund college. The aid offer does decrease as EFC increases; estimates imply that a family with a $70,000 expected family contribution can expect similar probabilities of aid offers at private elite institutions as a family that does not complete the FAFSA.

6.5 Unobserved Heterogeneity

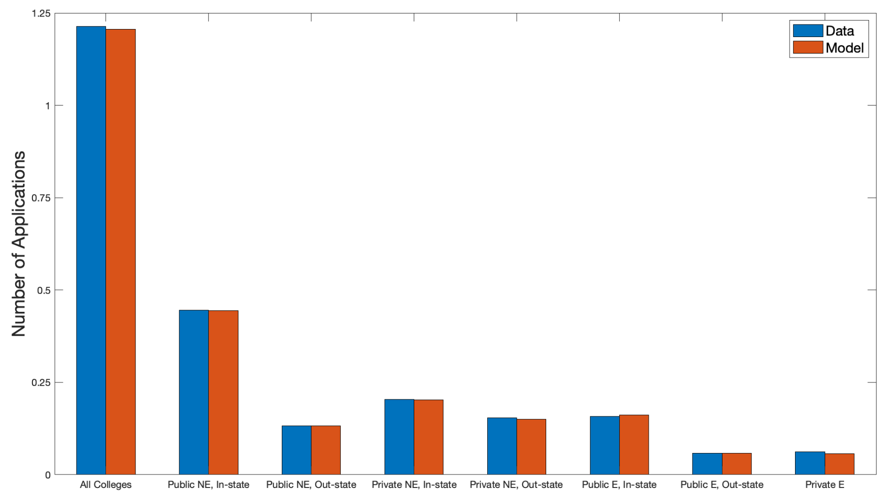
Parameter estimates suggest that the two unobserved types significantly impact various aspects of decision-making and likely measure student ability or motivation. For example, a type 2 student has stronger preferences for college enrollment (Table 6.1), finds applications to be less costly (Table 6.2), and is more likely to receive admissions and aid from all colleges (Table 6.4). Furthermore, a type 2 student also faces higher returns on the labor market as shown in Table 6.3 – she earns a wage premium that is greater than the returns from college graduation conditional on years of schooling and is more likely to find employment. Firms and colleges are better able to detect determinants of productivity unobserved by the researcher, such as ability or motivation; therefore, consistent gains on the labor market and admission process across the life-cycle enjoyed by a student identifies her unobserved type that also correlates with her preferences for college.

6.6 Model Fit

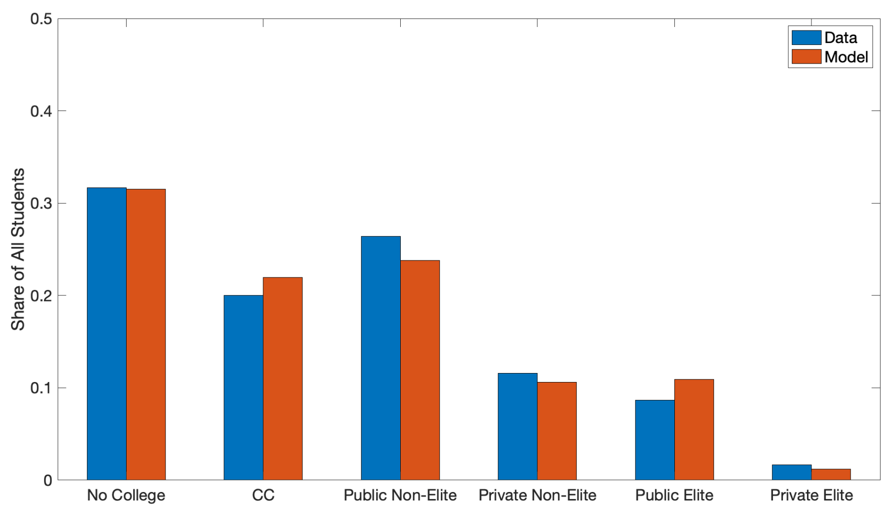
Figure 6.1 compares the model's ability to simulate student application and college choice behaviors against observed outcomes. The model fits application behaviors well on both the extensive margin of total number of applications and the intensive margin of applications sent to each type of school. I assume that application to a community college is arbitrary; that is, the student simply decides to enroll. Therefore, the figure shows the number of applications sent to four-year institutions. Once a student receives admission decisions, she may decide to not enroll in college, or choose a type of college to attend. The model fits the extensive margin of college enrollment quite well and generally matches the patterns of college choice. The model predicts that students attend public elite institutions more frequently than the data, while simulating lower enrollment at public non-elite institutions than the data.

Figure 6.2 shows a similar comparison of the model's prediction of annual student enrollment, borrowing, and part-time labor decisions to observed trends in the data. The model fits annual enrollment behavior well, suggesting the economic mechanisms present sufficiently capture students' college persistence. While the model does not perfectly fit students' part-time labor supply, it is able to capture the concavity in labor supply over the tenure in college. The model predicts the borrowing rate and prevalence of binding borrowing constraints well for most years, with the exception of over-predicting borrowing in the second year and under-predicting binding borrowing constraints in the first year.

Figure 6.1: Model Fit: Applications and College Choice



(a) Number of Applications to Selective Colleges

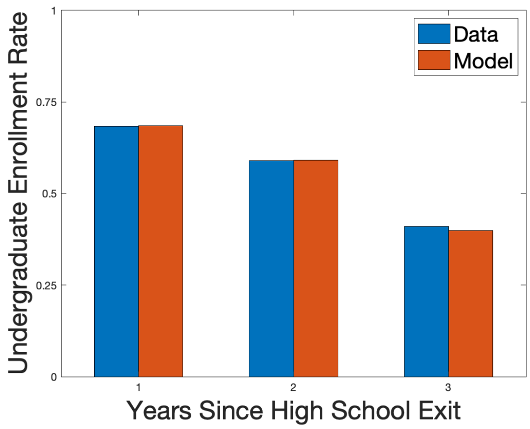


(b) Enrollment at Types of Colleges

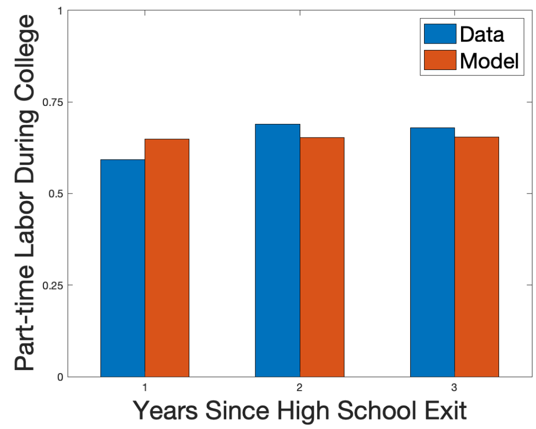
NOTE: The sample includes only those eligible to enter college for the first time in the 2004-05 academic year or the 2013-14 academic year. Bars marked as "Model" are simulated outcomes from the estimated model.

SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

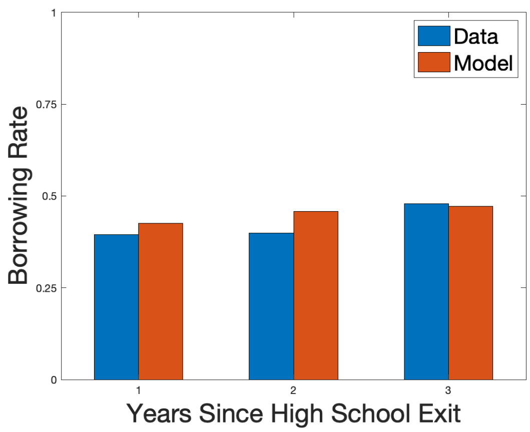
Figure 6.2: Model Fit: Annual Enrollment, Borrowing, and Part-time Labor



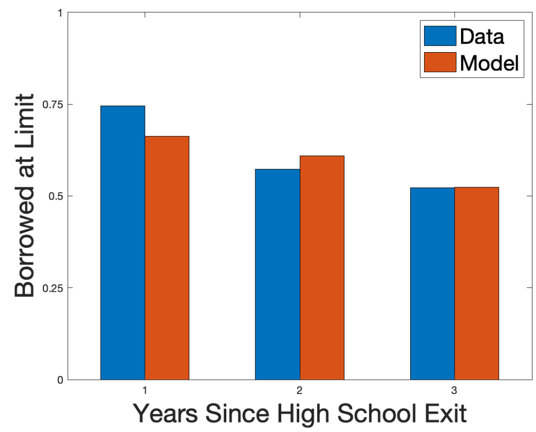
(a) Undergraduate Enrollment



(b) Part-time Labor, if enrolled



(c) Borrowing Rate, if enrolled



(d) Borrowing at Limit, if borrowed

NOTE: The sample includes only those eligible to enter college for the first time in the 2004-05 academic year or the 2013-14 academic year. Once a student exits college, she is not allowed to enroll again and is considered to be part of the labor force. Bars marked as "Model" are simulated outcomes from the estimated model.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

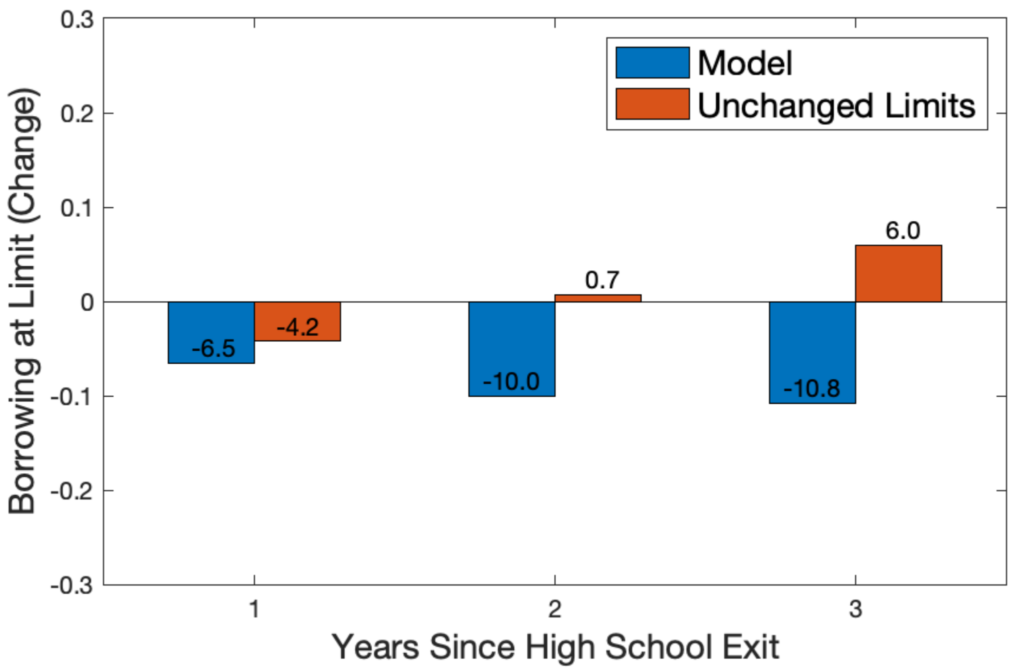
CHAPTER 7: POLICY ANALYSIS

Using the estimated structural parameters and re-solving the student's decision-making process, I simulate student outcomes under various policy environments, both current and hypothetical. First, I measure to what extent the increase of loan limits in 2007 and 2008 relaxed borrowing constraints. Second, I test three higher education subsidies: increased loan limits that relax credit constraints, additional Pell grants that target low-income households, and tuition-free public colleges. These subsidies represent policy levers that allow the federal government to relax a student's borrowing or budget constraint. Lastly, I discuss welfare implications of each policy and the effects of supply side responses in college pricing.

7.1 Loan Limits and Credit Constraints

For dependent students, the changes to federal loan policy in 2007 and 2008 increased loan limits by at most $2,000 per year (in nominal dollars). Counterfactual analysis shows that even this small increase in loan limits, relative to the annual cost of college attendance, substantially relaxed students' credit constraints. The model simulates student behaviors assuming two policy environments: observed loan limits (including changes in 2007 and 2008) and loan limits fixed at pre-2007 levels. As shown in figure 7.1, the model predicts that the share of borrowers at the limit for the class of 2013 is 6.5 to 10.8 percentage points (pp) lower than the share for the class of 2004. However, if the limits were unchanged from before 2007, we see that class of 2013 borrowers are more likely to be constrained: the share of borrowers at the limit for the class of 2013 is 4.2 pp lower than the class of 2004 at college entry, but up to 6 pp higher by the time students enter their third year. This difference suggests that evolving individual characteristics, costs of education, and labor market conditions led to greater demand for borrowing among students in the later cohort that would not have been met had loan limits not increased in 2007 and 2008.

Figure 7.1: Share of Borrowing Students at Limit: Class of 2013 relative to Class of 2004



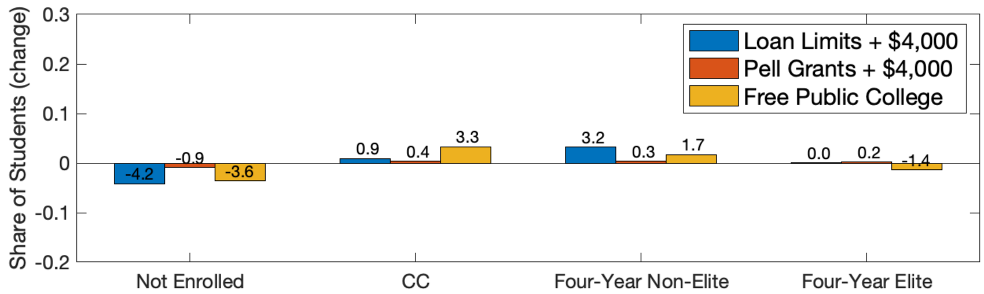
NOTE: Percentage point difference between the share of the class of 2013 borrowers at the limit and the share of the class of 2004 borrowers at the limit.

7.2 Policy Alternative 1: Relaxing Credit Constraints

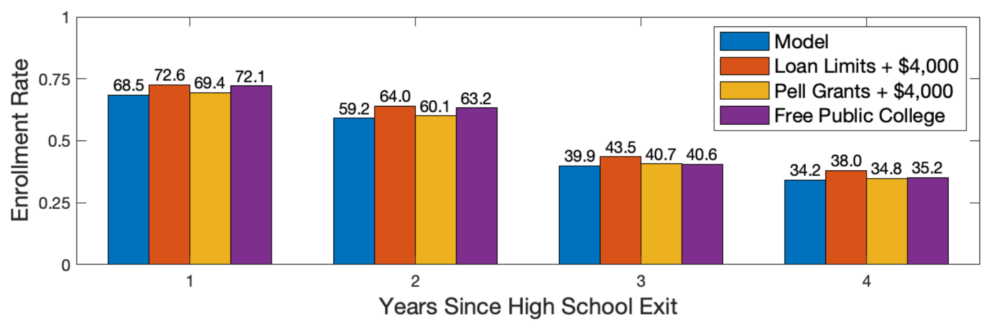
The Department of Education regulates the student loan market by primarily adjusting borrowing limits and interest rates. I consider a policy that increases each student's borrowing limit by $4,000. Such an increase in the loan limit is equivalent to the additional amount independent students are allowed to borrow. As a result, enrollment increases by 4.2 percentage points (pp), or by 6.1 percent in comparison to the current environment where 31.5 percent of students do not enroll in any college (Figure 7.2). The rise in borrowing limit primarily affects enrollment in four-year non-elite institutions, as 3.2 pp more students enroll at these colleges, an increase of 9.3 percent.

This increase in enrollment also translates to greater persistence in college, as seen by a 3.6 to 4.8 pp increase in enrollment rate in subsequent years of college.

Figure 7.2: Effects of Policies on Enrollment and Choice of College



(a) Enrollment and Choice of College at $t = 1$



(b) Annual Enrollment

NOTE: The baseline model predicts 31.5% of students are not enrolled, 21.9% enroll at community colleges, 34.4% enroll at four-year non-elite colleges, and 12.1% enroll at four-year elite colleges.

Columns labeled as (1) of Table 7.1 show which students drive the change in enrollment. The overall increase in enrollment ranges between 3.8 and 4.8 pp, with low- and middle-income students' enrollment increasing by 6.4 and 6.5 percent, respectively. Specifically, low-income type 2 students benefited the most with 7.3 percent higher enrollment. Relaxing credit constraints primarily increases four-year non-elite institution enrollment, by 7.1 to 11.5 percent, for all but the low-income type 1 students. For this group, two-year enrollment increases the most, by 8.5 percent. While there is some substitution away from elite institutions for high-income students, the magnitude is small with a decrease in enrollment by only 2 percent.

7.3 Policy Alternative 2: Targeted Subsidies

The federal government targets education subsidies through the Pell grant program. I test a change to the program that increases the maximum Pell grant award by $4,000. Recall from (2.1) that a student's Pell grant is determined as

$$Pell_{ijt} = \max\left\{\text{min}\left\{\tau_{ijt}, Z_t^{Pell}\right\} - EFC_{it}, 0\right\}.$$

Therefore, increasing Z_t^{Pell} would provide low-income students with higher levels of grants, while also providing small grants to those on the eligibility margin. While the overall effect on enrollment is small, low-income enrollment increases by 2.2 pp (column 2 in Table 7.1). Most of this increase in low-income student enrollment leads to higher community college enrollment, by 7.8 percent. The small change in Pell grants represent a larger share of the cost of attendance at a community college than at more expensive four-year colleges. While Pell grants are strictly need based, the findings suggest interesting correlations with student ability. Low-income type 2 students benefit the most as their overall enrollment increases by 7.6 percent and community college enrollment increase by 12.3 percent, likely because type 2 students have stronger preferences for college enrollment.

7.4 Policy Alternative 3: Free Tuition at Public Colleges

With the cost of college attendance increasing greatly, there exist several calls for free colleges. I evaluate a policy that makes it free for any student to attend a community college or a non-elite four-year institution within her state. The student still needs to apply and gain admissions to the non-elite four-year institution. Figure 7.2 shows a similar enrollment effect to increased loan limits, but students shift more toward community college. Column (3) in Table 7.1 shows heterogeneous take up of this policy by income and unobserved ability. Enrollment gains on the extensive margin are inversely related to household income, with low-income enrollment increasing by 10.2 percent and high-income enrollment increasing by 2.1 percent. However, low-income students primarily increase enrollment at community colleges, whereas high-income students shift enrollment towards four-year colleges. While free tuition to public colleges seems to reduce the college enrollment gap by income, the policy also induces sorting to different college types that may simultaneously increase the gap in the quality of colleges these students attend.

Table 7.1: Enrollment in Types of Colleges under Different Education Subsidies, by Income and Unobserved Type

	Overall				Type 1				Type 2			
	B	(1)	(2)	(3)	B	(1)	(2)	(3)	B	(1)	(2)	(3)
Low-Income												
No college	39.9	−3.8	−2.2	−6.1	37.0	−4.0	−0.7	−6.0	44.1	−4.1	−4.2	−6.3
Community College	24.3	2.0	1.9	6.2	25.9	2.2	1.4	6.0	22.2	0.7	2.7	5.0
Four-Year Non-Elite	26.9	1.9	−0.2	1.3	25.3	1.9	−1.2	1.9	30.0	2.9	1.1	1.4
Four-Year Elite	8.9	−0.1	0.5	−1.4	11.8	−0.2	0.5	−1.9	3.7	0.5	0.4	−0.1
Middle-Income												
No college	33.4	−4.3	−1.4	−3.7	31.2	−4.8	−1.5	−3.9	36.7	−4.5	−1.8	−3.9
Community College	23.5	1.1	0.4	3.3	25.1	1.0	−0.1	2.4	21.9	1.6	0.9	3.4
Four-Year Non-Elite	32.4	2.7	0.5	1.4	29.2	3.3	1.2	2.9	36.5	2.6	0.6	1.0
Four-Year Elite	10.7	0.5	0.5	−1.0	14.4	0.5	0.4	−1.5	4.9	0.3	0.2	−0.6
High-Income												
No college	23.6	−4.3	0.5	−1.6	22.6	−4.2	0.3	−2.7	25.8	−3.9	0.4	−0.3
Community College	18.6	0.0	−0.8	1.3	19.0	0.3	−0.8	2.4	18.0	−0.5	−0.9	−0.7
Four-Year Non-Elite	42.0	4.7	0.6	2.2	38.0	4.4	0.3	2.9	49.5	4.5	0.7	1.4
Four-Year Elite	15.8	−0.4	−0.2	−1.9	20.5	−0.4	0.1	−2.6	6.7	−0.1	−0.2	−0.4

NOTE: Policy (1) increases unsubsidized loan limits by $4,000, policy (2) increases the maximum Pell grant by $4,000, and policy (3) makes community college and in-state public non-elite institutions free to attend. The baseline columns (B) show share of all students of that group that do not enroll in college or enroll at various college types. Columns for policy simulations (1), (2), and (3) show the percentage point change from the baseline. An unobserved type 2 student has stronger preferences for college enrollment, is more likely to receive admissions and aid from all colleges, and enjoys higher labor market returns.

7.5 Welfare Implications

In addition to evaluating changes in enrollment and college choice under different policy scenarios, a consideration of the resulting welfare effects of each policy helps us understand exactly which students are better off and by how much. Specifically, I focus on welfare after the student leaves college – recall that in the model, once the student is on the labor market, she inelastically provides labor and smooths consumption over her working life. Furthermore, as consumption is a function of accumulated student debt in addition to wage gains, the welfare analysis accounts for the net gains to borrowing. I measure the welfare gain as the corresponding amount of annual transfer to the student that would result in the same lifetime utility gain or loss as the policy simulation. As shown in Table 7.2, welfare gains differ greatly by policy and student characteristics.

A free public college provides the greatest post-college welfare gain, equivalent to an annual $342 transfer for the average student. However, this policy is by far the most expensive among others I evaluate – depending on the year, the cost of the policy ranges from $15,030 to $18,598 per student. On the other hand, the cost of raising subsidized and unsubsidized loan limits are $746 per borrower, as measured by the subsidy rates of each loan type calculated by the Congressional Budget Office. For a significantly lower cost, relaxing subsidized loan limits provides 50 percent of the welfare gain as a free public college education to the average student.

Note that welfare gains from all policies are concentrated among higher ability (type 2) students. For example, type 2 students from low- and middle-income families enjoy 94 to 113 percent of the welfare gains they would have received from a full subsidy at public college. Furthermore, a unique result shows that relaxing loan limits are equally beneficial for high ability students from both low-income and high-income families. However, expanding access to loans does present the risk of inducing low ability students to enter college enrollment and consequently experience the lowest welfare gains of any policies due to accumulated student debt.

7.6 Effects of Supply Side Responses

College pricing may respond to financial aid programs, as hypothesized by former U.S. Secretary of Education William Bennett. Lucca et al. (2019) estimate that increasing the subsidized loan limit by a dollar passes through to a 56 to 76 cent increase in tuition, depending on the institution type. Increasing unsubsidized loan limits results in lower pass through of up to 22 cents per

Table 7.2: Post-college Welfare Gains: Select Policies ($/year)

	Increase Pell Grants		Free Public College		Relax Unsubsidized Loan Limit				Relax Subsidized Loan Limit			
					PE		GE		PE		GE	
Overall	71	(29)	342	(29)	142	(29)	135	(31)	171	(29)	137	(28)
Low-Income												
Overall	127	(58)	410	(57)	137	(64)	131	(55)	169	(61)	119	(61)
Type 1	48	(35)	227	(36)	25	(36)	24	(34)	44	(35)	26	(36)
Type 2	539	(175)	995	(187)	875	(194)	813	(185)	939	(171)	713	(196)
Middle-Income												
Overall	96	(46)	361	(48)	134	(42)	120	(45)	161	(49)	120	(46)
Type 1	38	(30)	202	(30)	15	(27)	10	(29)	35	(31)	21	(27)
Type 2	396	(162)	836	(166)	902	(160)	832	(153)	949	(155)	726	(170)
High-Income												
Overall	4	(54)	270	(53)	154	(54)	152	(55)	181	(53)	167	(55)
Type 1	−1	(33)	188	(31)	36	(33)	37	(33)	53	(34)	47	(32)
Type 2	44	(180)	329	(178)	932	(164)	899	(177)	979	(193)	907	(200)

NOTE: Welfare gains are measured as annual monetary transfers given to individuals in the labor market with equal marginal utility as the outcomes of each policy simulation. Pell grants increases the maximum grant awarded by $4,000. Relaxing unsubsidized loans lifts the unsubsidized limit by $4,000 and relaxing subsidized loans lifts the subsidized limit by $2,911 (a revenue neutral amount). Partial equilibrium analysis (PE) holds tuition fixed, while account for college pricing responses (GE) changes tuition by amounts estimated in Lucca et al. (2019). Standard errors provided in parentheses.

dollar. I use these estimates as given amounts of tuition pass-through for Stafford loans. Then, I evaluate increases in the limit for subsidized and unsubsidized loans assuming college tuition shifts simultaneously according to these pass-through amounts. This analysis provides a back-of-the-envelope pass through effect of financial aid on college choice. That is, I am able to provide an effect of relaxing credit constraints on student welfare while accounting for the equilibrium effects a federal policy may induce, rather than focusing on a partial equilibrium that is analogous to randomly extending the policy to a small subset of students.

As shown in the "GE" columns of Table 7.2, accounting for college pricing responses substantially reduces welfare gains from relaxing borrowing limits. Increasing subsidized limits show the largest effects, as they exhibit the highest amount of tuition pass-through – this pass-through of a $2,911 increase to subsidized loan limits reduces the average welfare gains from the limit increase by 20 percent. Furthermore, reductions of welfare gains are most pronounced for low- and middle-income students of all abilities, ranging from 26 to 30 percent. This heterogeneous pass-through effect by household income is likely due to lower sensitivity to tuition increases from high-income families.

CHAPTER 8: CONCLUSION

Although federal student loans are the largest form of undergraduate financial aid by volume, we know surprisingly little about the impact of an expansion in loans on a student's postsecondary human capital investments. This dissertation furthers our understanding of the different economic mechanisms presented by student loan policies and price reductions in a student's college enrollment behavior. Specifically, I develop a model of a student's decision-making with regard to college enrollment, choice of institution, borrowing, and part-time labor in the presence of borrowing constraints. I use data on two recent high-school graduating cohorts who straddle a rare increase in federal borrowing limits to estimate the structural parameters of the dynamic discrete choice model.

The empirical analysis shows that relaxing borrowing constraints increases overall enrollment and shifts enrollment towards four-year non-elite institutions. Additionally, higher loan limits lead to greater persistence as shown by higher levels of enrollment in the second and third years. Expanding targeted education subsidies through federal Pell grants lead to greater community college enrollment among low-income students. While free public college improves enrollment, sorting between community colleges and four-year colleges by income may not reduce existing gaps in the quality of colleges selected. Importantly, relaxing subsidized loan limits provides 50 percent of the average student's welfare gain from the free public college option at a significantly lower cost, and equally improves welfare for high ability students from all levels of household income.

Results from this research add to a growing consensus that credit constraints are more relevant to students' decision-making in recent years than in the 1980s. Due to infrequent changes to the loan environment, evaluation of federal policies has been difficult. However, this dissertation is among the first to use variation from the loan limit increases of 2007 and 2008 and nationally representative student level data to estimate the effect of relaxing borrowing constraints on students' postsecondary human capital investments.

As more recent studies find that loans play a role in human capital accumulation, promising future research could explore additional margins of human capital investments, such as major choice and degree completion. Furthermore, future research can focus on understanding endogenous decision-making of other agents in the market for education, such as institutions and governments. Accounting for colleges' pricing responses to increased availability of aid, measured by existing estimates, imply a reduction of average welfare gains by 20 percent and a reduction of low- and middle-income students' welfare gains by up to 30 percent. I explore such equilibrium effects of student loan policies in the presence of endogenous college admissions and pricing in Appendix D. Continued research in this area will offer insight on the effectiveness of policies at improving student outcomes without potentially increasing the already high costs of higher education.

APPENDIX A: DATA AVAILABILITY, VARIABLE CONSTRUCTION, AND SAMPLE SELECTION

A.1 Example of Federal Loan Eligibility

Consider the example of a dependent freshman student in 2008, whose college bill totals $10,000 after receiving scholarships and grants – her cost of attendance τ_{ijt}. The FAFSA determines here EFC to be $6,000. Since her financial need of $4,000 is greater than the federal limit on subsidized Stafford loans in 2008, she is able to borrow $3,500 of subsidized loans. Assuming she does, she can now borrow an additional $2,000 in unsubsidized loans, which is the remainder of the total borrowing limit of $5,500, because her remaining cost of attendance after scholarships, grants, and subsidized loans of $6,500 is still greater than the total borrowing limit. With a total of $5,500 borrowed, the student and her family owe the college $4,500. At this point, the family may pay that amount with a combination of out-of-pocket expense or through higher interest PLUS loans.[1] If her parents are denied a PLUS loan, the student is considered independent, and can borrow unsubsidized loans to finance the remaining $4,500 owed. Since she has borrowed up to her full $10,000 cost of attendance, she is not able to borrow up to the federal limit of $11,500. If her family is approved for a PLUS loan, but refuses to pay or take out the loan on her behalf, the student is still considered dependent and she will need to borrow from the private market at a higher interest rate by demonstrating her credit worthiness.

A.2 Sample Selection

The reduction in size from the survey sample to the analysis sample is primarily due to survey attrition and the availability of transcript data. I exclude those students who do not complete a high school credential. I classify a student as eligible to enter college for the first time in a specific

[1] Parents of students are eligible to borrow unsubsidized PLUS loans, which have higher interest rates (7–9%) and fees, and are limited by the COA less any other federal loans borrowed. While parents are contractually responsible for the repayment of the loan, students may often have informal agreements to repay these loans. Only 4.2% of students' parents borrow PLUS loans in 2004 (3.2% in 2013), borrowing an average of $12,810 ($16,052 in 2013).

academic year if she receives her high school credential in the prior academic year. Furthermore, I exclude students who directly enter graduate school a year after finishing undergraduate education and those that transfer colleges. In future versions of the model, I will reintroduce the transfer students by incorporating a reduced form transfer probability between community colleges and public institutions – the most commonly observed transfer behavior.

A.3 Data Availability in Select Years

While I have data for a longer horizon for the Class of 2004, I analyze enrollment, part-time labor, and borrowing behavior for the first three years. The administrative data on FAFSA is not reported in 2007 and 2008, which does not allow me to solve the model in the fourth and fifth years of college enrollment for the Class of 2004. Furthermore, part-time labor data is not available past the student's third year in college. One benefit of this restriction is that the Great Recession of 2008 does not directly affect my estimation because the first three years of enrollment (2004 to 2006) are unlikely to be altered by a future recession. While the Class of 2004 was undoubtedly affected in the labor market due to the recession, estimates of wage premiums rely on labor market data that covers the years 2004 to 2006, 2011, and 2012, which mitigate concerns over identification of the college wage premiums.

A.4 Individual Cost of Attendance

The student's cost of attendance τ_{jt} at college j in academic year t relies on the posted tuition $\bar{\tau}_{jt}$ and any institutional aid offered to the student. The data offers coarse level of detail regarding the amount of tuition that was covered by scholarships and aid at the student's enrolled institution, ranging from none to less than half, more than half (but not all), and all. During the application stage, the aid outcomes signify whether the student is offered aid, but not the amount. For these cases, I use the IPEDS data on average amount of aid offered by each institution, conditional on any aid offer. I consider all sources of nonfederal aid, including state and institutional, in construction the cost of attendance.

A.5 Class of 2013 Applications

Data on the class of 2013 only provides the first three student applications. However, I can also see the actual number of applications. Given this information, I compare class of 2013 students to class of 2004 students who also applied to the same number of schools. Conditional on the number of applications, the distribution of these applications across college types is remarkably similar. Therefore, I fill in the additional applications using a flexible logistic estimator that predicts the probability of applying to a specific type of college conditional on the total number of applications the student sends. I add two selective colleges in for those students whose three observed applications include a community college, and one selective college and one community college for those students whose observed applications do not include a community college. If a student has already applied for the same type of college as a newly imputed application, I assume she is admitted similarly. If a student has no observed applications to the same type of college as the newly imputed applications, I assume she is rejected.

APPENDIX B: COMPLETE EMPIRICAL SPECIFICATION

B.1 Expected Family Contribution in Initial Period

This specification of EFC follows from a legally defined formula that considers the household's finances, the potential for the household to pay for other children's college expenditures, and changes over time to the formula. Importantly, EFC is not a function of ability. Furthermore, after expected family contribution is calculated, it is bound below at zero. Therefore, I model the latent expected family contribution, assuming $\varepsilon^E \sim N(0, \sigma_E^2)$.

$$EFC_1^* = \alpha^E + \alpha_Y^E Y + \alpha_X^E X + \varepsilon^E$$
$$EFC_1 = \mathbb{1}\left[EFC_1^* > 0\right] \cdot EFC_1^*$$

B.2 Financial Need and Cost of Attendance

Recall that financial need is constructed as

$$N_{jt} = \tau_{jt} - EFC_t - Pell_t.$$

The stochastic process below of latent future financial need N_{jt}^* assumes that $\varepsilon_{Nt} \sim N(0, \sigma_N^2)$ and that observed financial need N_{jt} censors the latent variable to be nonnegative.

$$N_{jt}^* = \left(\alpha^N + \alpha_j^N + \alpha_{X1}^N X_{jt}\right) \overline{\tau}_{jt} + \alpha_{X2}^N X_t + \alpha_Z^N Z_t^{Pell} + \varepsilon_{Nt} \tag{B.1}$$
$$N_{jt} = \mathbb{1}\left[N_{jt}^* > 0\right] \cdot N_{jt}^*$$

This specification of financial need highlights that the student's cost of attendance τ_{jt} is a function of the posted sticker price $\overline{\tau}_{jt}$ and factors that determine the amount of aid she may receive from the institution. The terms α^N and α_j^N account for the average discount students receive at institution j, while α_{X1}^N captures discounts received by individual heterogeneity, including the amount of aid the student received in their first year of enrollment and the student's cohort. The vector X_t includes demographic characteristics and variables that influence expected family contribution, such as household income and the number of siblings. Lastly Z_t^{Pell} represent exogenously determined maximum Pell grant award amounts that vary annually.

Given this stochastic process, I assume that future financial need falls in discrete bin n if $N_{jt+1} \in [N_{n-1}, N_n)$, where $N_0 = 0$. This discretization simplifies calculation of the future expected value that enters the individual's value functions $\left\{V_{jt}^{dl}\right\}$:

$$
\begin{aligned}
E \max_{dlt+1} &\equiv E_t \left[\max\left\{V_{jt+1}^{L}, V_{jt+1}^{dl}\right\} \mid (1,d,l)\right] \\
&= \sum_n E_t \left[\max\left\{V_{jt+1}^{L}, V_{jt+1}^{dl}\right\} \mid (1,d,l), N_{jt+1}\right] \cdot P_N \left(N_{jt+1} \in [N_{n-1}, N_n)\right).
\end{aligned}
$$

The remaining expectation is taken over future preference shocks. Because I model these shocks as Type I Extreme Value, the expectation has a closed form.

For a FAFSA non-filing student in college in $t > 1$, her annual price p_{jt} is a function of stochastic cost of attendance τ_{jt}, which I model as

$$
\tau_{jt} = \left(\alpha^{\tau} + \alpha_j^{\tau} + \alpha_{X1}^{\tau} X_{jt}\right) \overline{\tau}_{jt} + \alpha_{X2}^{\tau} X_t + \varepsilon_{\tau t} \tag{B.2}
$$

This specification highlights that students receive various levels of price discounts from the sticker price, depending on the attended institution j and individual heterogeneity, including the amount of aid the student received aid in their first year of enrollment, the student's year in college, and the student's cohort. The vector X_t includes demographic characteristics. I assume that $\varepsilon_{\tau t} \sim N\left(0, \sigma_{\tau}^2\right)$.

Similar to financial need, I assume that future cost of attendance falls into discrete bin n if $\tau_{jt+1} \in [\tau_{n-1}, \tau_n)$, where $\tau_0 = 0$. For a student who does not file the FAFSA, her future expected value enters the her value functions $\left\{V_{jt}^{dl}\right\}$ as

$$\begin{aligned} E\max_{dlt+1} &\equiv E_t\left[\max\left\{V_{jt+1}^{L}, V_{jt+1}^{dl}\right\} \mid (1,d,l)\right] \\ &= \sum_n E_t\left[\max\left\{V_{jt+1}^{L}, V_{jt+1}^{dl}\right\} \mid (1,d,l)\,, \tau_{jt+1}\right] \cdot P_\tau\left(\tau_{jt+1} \in \left[\tau_{n-1}, \tau_n\right)\right). \end{aligned}$$

APPENDIX C: ADDITIONAL PARAMETER ESTIMATES

C.1 Price Function

The price function measures the amount the student herself is responsible to pay for college, using part-time labor income and borrowed funds. The price function parameters for FAFSA filers measure the price adjustment relative to their government stated financial need. That is a low-income student of type 1 is responsible to pay $16,020 less than her financial need, as shown in Table C.1. The parameters for middle- and high-income show additional price reductions for FAFSA filers by household income. A high-income student is responsible to pay $20,795 less than her financial need. All terms for FAFSA filers are negative, suggesting that the student is receiving help, that is, FAFSA filing parents are helping their students and the price students are responsible for is reducing.

The price function parameters for non-filers are relative to the cost of attendance. We see that the level of parental support varies greatly by income and unobserved ability. A high-income type 1 student is responsible for $11,564 less than her cost of attendance, while a low-income type 1 student is responsible for $5,469 more than her cost of attendance.

Table C.1: Price Function Parameters

Price ($1,000s)	FAFSA Filers	FAFSA Non-Filers
Low Income	−16.020	5.469
Middle Income	−18.143	−6.122
High Income	−20.795	−11.564
Type 2	7.001	7.251

NOTE: Future version will provide bootstrapped standard errors.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

C.2 Financial Need, Cost of Attendance, and Expected Family Contribution

A key component of the price function is financial need for FAFSA filers and cost of attendance for non-filers. Therefore, students must account for future shocks to both of these stochastic processes. Table C.2 shows parameter estimates for the stochastic processes of financial need and cost of attendance in years $t = 2, \ldots, t'$. The coefficients on posted tuition and interactions show expected patterns of institutional aid in future years. Specifically, a student who receives aid in her first year can expect to receive 83 to 96 percent of that aid in subsequent years. For FAFSA filers, the parameters also show that higher income families exhibit lower financial need, while families with multiple children face higher financial need.

Table C.3 shows the stochastic process for initial period expected family contribution. As expected, EFC increases with income and decreases with the presence of multiple siblings.

Table C.2: Financial Need and Cost of Attendance ($1,000s)

	Financial Need (FAFSA Filers)		Cost of Attendance (FAFSA Non-Filers)	
	Tobit		Tobit	
	Coefficient	(S.E.)	Coefficient	(S.E.)
Posted Tuition	1.031	(0.036)	0.982	(0.016)
× Aid Discount in $t = 1$	−0.835	(0.010)	−0.957	(0.004)
× In-state Public Non-elite	−0.116	(0.016)	−0.002	(0.006)
× Out-of-state Public Non-elite	−0.150	(0.023)	−0.003	(0.008)
× In-state Private Non-elite	−0.079	(0.023)	0.018	(0.009)
× Out-of-state Private Non-elite	−0.108	(0.024)	0.016	(0.009)
× In-state Public Elite	−0.147	(0.020)	−0.004	(0.007)
× Out-of-state Public Elite	−0.177	(0.026)	−0.013	(0.009)
× Private Elite	−0.222	(0.029)	0.002	(0.010)
Middle Income	−1.129	(0.176)	0.004	(0.009)
High Income	−7.341	(0.190)	−0.073	(0.052)
One Sibling	0.034	(0.051)		
Multiple Siblings	1.446	(0.152)		
Maximum Pell Grant	−0.003	(0.002)		
Constant	8.504	(7.589)	0.299	(0.248)
Type 2	−1.235	(0.138)	0.200	(0.047)
σ	8.033	(0.055)	1.862	(0.017)
Observations	12,000		6,530	

NOTE: Estimation includes controls that are not presented in this table: gender, race, and the student's cohort and year in college in levels and interactions with posted tuition. Future version will provide bootstrapped standard errors. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

Table C.3: Expected Family Contribution in $t = 1$ ($1,000s)

	Tobit	
	Coefficient	(S.E.)
Class of 2013	-4.708	(0.483)
Middle Income	12.382	(0.612)
High Income	31.232	(0.619)
One Sibling	0.340	(0.673)
Multiple Siblings	-4.460	(0.670)
Constant	-3.294	(0.727)
σ_E	21.805	(0.185)
Observations	$10,260$	

NOTE: Coefficients for the college type (rows) interacted with student characteristics (columns). Future version will provide bootstrapped standard errors. All unweighted sample sizes are rounded to nearest ten according to IES restricted-use data guidelines.
SOURCE: U.S. Department of Education, National Center for Education Statistics, Education Longitudinal Study of 2002 (ELS:2002), High School Longitudinal Study of 2009 (HSLS:09), and Integrated Postsecondary Education Data System (IPEDS).

APPENDIX D: EQUILIBRIUM EFFECTS OF STUDENT LOANS IN THE U.S. COLLEGE MARKET

As shown in section 7.6, accounting for college pricing responses to federal policies can reduce welfare gains for students. Failure to understand behavior on both sides of the higher education market may lead to ineffective and costly policies meant to improve student outcomes. Colleges may increase tuition in response to an expansion in student loans because they anticipate that students who wish to enroll are willing to pay a higher tuition by borrowing, or may tighten admission because they receive more applications. If a loan expansion does induce a rise in tuition, then the eventual cost to the student could change very little, resulting in a weaker improvement in student welfare than expected. Dubbed the Bennett hypothesis after former U.S. Secretary of Education William Bennett, the pass-through of financial aid to higher college tuition has mixed empirical support in the cases of grants, state scholarships, and tax credits. Specific to the context of student loans, Lucca et al. (2019) estimate that the most recent loan expansion, in the 2007-2008 and 2008-2009 academic years, results in tuition increases of up to 76 cents for every additional dollar available to students from increased loan limits. Therefore, analysis of large scale policies aimed at helping students afford college should further consider how a simultaneous response from colleges may mitigate improvements to student outcomes.

To capture the above mechanisms of the U.S. higher education market, I complement the previously described analysis of student behaviors with a model of college admissions, institutional aid, and tuition. Colleges compete with each other for students and form beliefs of student demand in order to construct a desirable student body while balancing revenue from tuition, state and federal governments, and private sources with educational and operational costs.

A combination of models that consider simultaneous student and college behaviors can be used to identify education subsidies that are most effective at increasing higher education accessibility and at moderating tuition growth. Implications of subsidies to students differ from that of subsidies to colleges. The subsidies that target the student relax her budget or borrowing constraint, and generally improve welfare for those with financial need.[1] However, if financial aid passes through to tuition, these policies may induce tuition growth and, consequently, harm all students. Subsidies shifting government dollars to institutions instead may relax colleges' budget constraints, which could reduce tuition or increase education investments that improve student outcomes, such as completion rates and college quality[2] (Deming and Walters, 2017). Lower tuition has the potential to benefit all students, whereas expanded financial aid may help a narrower set of students with financial need and potentially harm all students if such policies also induce tuition growth.

In the rest of this appendix, section D.1 reviews the relevant literature and section D.2 describes a model of college decisions. As estimation of this complicated equilibrium model is difficult in nature, results will be reported in subsequent papers conducted post-graduation. However, section D.3 discusses an estimation strategy for future empirical analysis.

D.1 Related Literature

This research contributes to a growing literature at the intersection of economics and higher education that considers two central mechanisms affecting a student and her familys ability to afford college: the students enrollment response to financial aid and college pricing behavior. While a majority of analyses in this area focus on one side of the market in partial equilibrium, assuming other market factors remain fixed, select recent work has used general equilibrium analysis to consider student and college behaviors simultaneously.

One explanation for the commonly observed muted enrollment response to increased availability of loans, in comparison to grants, could be the borrowing trade-off between enrollment at a more expensive, and possibly higher quality, college today with future repayment of debt. College pricing

[1]Examples of such policies include increasing federal borrowing limits or lowering interest rates, proposals to completely subsidize public colleges, and a trend among elite colleges to replace loans altogether with grants and institutional scholarships for students with financial need. On the other hand, as discussed in the U.S. federal budget proposal for 2020, an example of aid reduction for students is the elimination of subsidized student loans, in which the federal government subsidizes accrued interest during enrollment.

[2]Several studies use student investments as a measure of college quality and document the high labor market returns to college quality (Black and Smith, 2004, 2006; Long, 2008; Dillon and Smith, 2017, 2020).

responses to financial aid programs offers another explanation. Several attempts to understand this relationship by empirically testing the Bennett hypothesis have yielded mixed results that vary by the type of institution and the type of federal aid. Studies focused on the effect of Pell grants estimate that every additional dollar of aid passes through to a zero to 50 cents increase in tuition, depending on the institution's control (public or private) and the student's location (in-state or out-of-state).[3] Similarly, analysis of state grants and education tax credits find a response in college pricing, with slightly lower pass-through rates of 30 percent (Long, 2004a,b). The pass-through associated with student loans appears to be higher than that of grants as Lucca et al. (2019) and Cellini and Goldin (2014) both find support for the Bennett hypothesis, with the latter study estimating that federal aid-eligible for-profit institutions charge tuition that is roughly 78 percent higher than their non-eligible for-profit counterparts.

Gillen (2012) reconciles the different amounts of pass-through for grants and loans with a refined hypothesis that emphasizes two mechanisms central to my model. First, the type of aid – more precisely the size and segment of the student population affected by the aid – can determine the size of the tuition increase. Therefore, unsubsidized federal loans that are available to potentially any student would have a different effect than grant programs that target low-income students. Second, the institutions ability to set tuition varies greatly as some public colleges face state level tuition caps while other private colleges use institutional aid to freely price discriminate. Not considering these differences across institutions would lead to incorrect interpretation of the empirical role of federal aid on tuition.

The model presented in this appendix most closely relates to equilibrium analyses of financial aid in the market for higher education. Epple et al. (2006) estimate a model of private colleges and students with financial aid, while Epple et al. (2017) calibrate a similar model including both public and private colleges. Fu (2014) estimates a multi-stage model to include the application-admissions game between students and colleges, students enrollment decisions, and tuition setting

[3]See McPherson and Schapiro (1999); Singell and Stone (2003); Rizzo and Ehrenberg (2004). Most recently, Turner (2017) estimates that colleges capture 11 to 20 cents per dollar of Pell grant aid, primarily through institutional aid as a lever of price discrimination.

behavior of both public and private colleges. These studies highlight heterogeneity in market power demonstrated through more flexible responses by elite private colleges to policies that subsidize students.[4] However, each of these models considers financial to be grants and scholarships.

Therefore, I contribute to this literature by incorporating student loans in order to account for the borrowing trade-off and the different implications for tuition pass-through. Gordon and Hedlund (2017, 2018) also include the borrowing trade-off, but focus on explaining the rise in college tuition. I address a complementary research question that focuses on student welfare, to which higher tuition is one contributory factor. I also use student-level data to estimate a richer empirical specification of students application, enrollment, and borrowing decisions. Importantly, students in my model differ by unobserved ability that impacts several outcomes, including future earnings. This inclusion allows me to address identification concerns arising from ability bias and match nuances in the data, such as a realistic college admissions process that considers measures of student ability unobserved to researchers beyond test scores.

D.2 Model of College Decisions

A dynamic discrete choice model outlined in chapter 3 describes the decision-making process of consumers (potential students) in the higher education market – high school graduating students decide to apply to college, enroll on an annual basis, and determine a method to finance education. On the supply side of the higher education market, colleges make static annual decisions to set tuition, and admission and aid policies.

The universe of heterogeneous colleges K include k institutions, each of a type j. A college's type reflects its level (two-year vs. four-year), control (private vs. public), national rankings (elite or non-elite), and location relative to the student (in- or out-of-state). The type j determines the institution's objective function, constraints, and choice set. Specifically, I assume community colleges do not make any decisions – their tuition is constrained by state policies and admission is

[4] Additional equilibrium analysis of higher education has considered college major provision (Cook, 2020), distributional impacts of race-blind affirmative action policies (Kapor, 2020), and colleges' pricing behavior and resource allocation in response to information available through the FAFSA (Fillmore, 2020).

not selective. All public colleges' tuition is determined by state policies; however, these institutions decide admissions and aid policies to maximize their objective functions. Lastly, private colleges set tuition and decide admissions and aid policies.

D.2.1 Timing and Information Set

Relative to the student's decision-making timeline (Figure 3.1), colleges act at two stages – before students apply and before students enroll. Colleges also make decisions simultaneously with competing colleges. Therefore, colleges use available observed information and knowledge of students' and other institutions' decision rules to form expectations of other agents' behaviors. Conversely, a student does not know a college's optimal decision rules; rather, she forms reduced form expectations of the uncertainty of college admission and aid.

Before the end of the student's last year in high school, $t = 0$, all colleges simultaneously announce cost of attendance $\overline{\tau}_{k1}$ for the academic year $t = 1$. Recall this sticker price is the maximum any student will pay to attend college k. Once students make application decisions, a college's admissions office observes the student's high school academic achievement a_i and ability μ_i. Furthermore, the college's aid office also observes the student's expected family contribution EFC_i. The assumption that the admissions office does not view the student's EFC is motivated by need blind admissions policies. Based on this information, each college receiving a student's application jointly offers (i) admission and (ii) institutional aid that determines the student's individual cost of attendance τ_{ik1}.

Particularly important to the college's optimization problem are students' and peer institutions' decision rules. First, I assume that colleges know the student's optimal decisions: δ_{j0} maps the student's information set prior to applications at $t = 0$ to her optimal application decision for college j, while δ_{j1} maps her information set at $t = 1$, after admissions and aid decisions, to her optimal enrollment e^*_{j1} at college j in $t = 1$.

$$\delta_{j0} : (X, \mu, \Omega_0) \to \mathbb{1}\left[j \in A^*\right] \qquad \delta_{j1} : (X, \mu, \Omega_1) \to e^*_{j1}.$$

Between the application stage ($t = 0$) and the enrollment stage ($t = 1$), the student's information set Ω updates to include college admission and aid offers that determine her individual cost of attendance. Second, I assume a symmetric equilibrium where colleges of the same type share a common optimal decision rule. Therefore, heterogeneity in college characteristics and student demand drives heterogeneity in outcomes. As each stage of the college decision making process relies on expectations of their own future behavior and other colleges' actions, I describe the model in reverse chronological order.

D.2.2 College Objectives

A college of type j maximizes a function of average enrolled student ability θ_j and high-school achievement A_j, as well as net revenue R_j. Each college chooses an admissions rule ρ_{ij} and an individual student cost of attendance τ_{ij} for a student of type i.

$$\max_{\rho_{ij},\tau_{ij}} \nu_j(\theta_j, A_j) + \lambda_j R_j.$$

The average ability and high-school achievement of enrolled students and net revenue are defined as following. The term π_{ij} is the share of college j applicants that are of student type i, differentiated by their ability μ_i, high-school achievement a_i, and expected family contribution EFC_i. The college may also receive exogenous revenue Y_j per student from outside sources (government or private) and incur an exogenous cost C_j per student to represent operational and educational expenses.

$$\begin{aligned} \theta_j &= \sum_i \pi_{ij}\rho_{ij} E(\delta_{ij1}|\rho_{ij}, \rho_{im}, \tau_{ij}, \tau_{im})\mu_i \\ A_j &= \sum_i \pi_{ij}\rho_{ij} E(\delta_{ij1}|\rho_{ij}, \rho_{im}, \tau_{ij}, \tau_{im})a_i \\ R_j &= \sum_i \pi_{ij}\rho_{ij} \underbrace{E(\delta_{ij1}|\rho_{ij}, \rho_{im}, \tau_{ij}, \tau_{im})}_{P(i \text{ enrolls at } j)}(\tau_{ij} + Y_j - C_j) \end{aligned} \tag{D.1}$$

Note that student body characteristics depend crucially on which students enroll. Therefore, colleges form expectations over student enrollment decisions δ_{ij1}, conditional on their potential admissions and cost of attendance at other institutions m. While college j does not see student i's application or admissions profile, they do know the student application and enrollment decision rules δ_{ij0} and δ_{ij1}, and the decision rules of other college's acceptance (ρ_{im}) of and prices charged (τ_{im}) to student i. College j uses this information to calculate the probability of student i enrolling at their institution. The college faces an exogenous enrollment target k_j that effectively operates as a capacity constraint (D.2).

$$\sum_i \pi_{ij}\rho_{ij}E(\delta_{ij1}|\rho_{ij},\rho_{im},\tau_{ij},\tau_{im}) \leq k_j \tag{D.2}$$

Lastly, public college cost of attendance is bound by an exogenous in-state and out-of-state cost of attendance $\bar{\tau}_j$ set at the state level, such that

$$\tau_{ij} \leq \bar{\tau}_j \quad \forall \text{ Public institutions } j \tag{D.3}$$

I drop the conditioning variables $(\rho_{ij},\rho_{im},\tau_{ij},\tau_{im})$ to reduce notation; however, this information remains in college j's information set.

I assume that ν_j is concave and monotonically increasing in ability θ_j and academic achievement A_j of the campus' incoming class.[5] I interpret this objective function as a college's desire to maximize short-term and long-term payoffs. In the short-run, colleges may look to attract high-achieving students with good grades and test scores in order to boost their rankings, which are functions of these high-school academic measures. In the long-run, however, colleges may care more about a student's ability, which can be productive on the labor market and potentially lead to a future stream of donations. Furthermore, colleges operate as non-profit organizations. Therefore,

[5]Several studies consider ν_j to be the college's quality, which is improved by attracting high-ability students (Epple et al., 2006, 2017; Gordon and Hedlund, 2017, 2018). I do not assume that colleges look to maximize quality; rather, I use college type as an exogenous characteristic similar to Fu (2014), who assumes colleges maximize a weighted average of student ability and tuition revenues. The general functional assumptions and inputs, however, are consistent with the literature's various models of college objectives as static and monotonically increasing in student ability.

I assume that the institution reinvests the net revenue generated from undergraduate students in other divisions of the college, such as faculty and graduate student research in the short-run and campus renovations in the long-run. While I do not factor in the realization of future benefits to the college, the objective function captures the effect of current decision on expectations of future payoffs without the need to solve a dynamic college problem.

D.2.3 Admission Rule

Solving the college's problem yields the indifference condition below that the admissions office uses to set an admissions rule.

$$\underbrace{\frac{\nu_{j\theta}}{\lambda_j}\mu_i + \frac{\nu_{jA}}{\lambda_j}a_i + E(\tau_{ij}|\mu_i, a_i)}_{E(MB|\mu_i,a_i)} = \underbrace{\frac{\lambda_k}{\lambda_j} + C_j - Y_j}_{MC}$$

The indifference condition equates the expected marginal benefit with the marginal cost of admitting a student of type i. As the admissions office only observes student ability μ_i and academic achievement a_i, they must form expectations of the marginal benefit the student provides to the institution. Specifically, the student can improve the average ability and achievement and also generate revenue, which the admissions office must predict to account for scholarships form the aid office.[6] The marginal cost of admitting student i is the net expense $(C_j - Y_j)$ and the opportunity cost of giving up a capacity constrained seat, represented by the multiplier λ_k if the constraint binds. The admissions office then simply accepts students who have greater expected marginal benefits than marginal costs, randomly accepts students on the margin with probability ρ, and rejects all others:

$$\rho_{ij}^* = \mathbb{1}[E(MB|\mu_i, a_i) > MC] + \rho \cdot \mathbb{1}[E(MB|\mu_i, a_i) = MC]$$

Two factors allow elite schools to set tight admissions standards. First, elite schools applications will be composed of more students from the higher end of the ability and achievement distributions

[6]In this notation, $\nu_{j\theta} \equiv \frac{\partial \nu_j}{\partial \theta_j}$ and $\nu_{jA} \equiv \frac{\partial \nu_j}{\partial A_j}$.

and they may also receive more applications overall because of the wage premium shown in (4.3). Therefore, their capacity constraint is more likely to bind $(\lambda_k > 0)$. Furthermore, a student on the margin of an institution's binding capacity constraint will be penalized more at an elite institution than at a non-elite institution because the opportunity cost of admitting her is admitting an average student, who will be of higher ability and achievement at the elite institution. Second, as ν_j is concave in θ_j, the marginal benefit of a high ability student is diminishing in ability. Therefore, the elite school sets higher standards as it is less impressed by a high ability student than a non-elite school.

D.2.4 Individual Student Cost of Attendance

The aid office faces a similar indifference condition as it determines the price to charge each individual student. Slightly rearranged, the cost of attendance charged to student i satisfies

$$\tau_{ij}^* + \frac{E(\delta_{ij})}{\partial E(\delta_{ij})/\partial \tau_{ij}^*} = \frac{\lambda_k}{\lambda_j} + C_j - Y_j - \frac{\nu_{j\theta}}{\lambda_j}\mu_i - \frac{\nu_{jA}}{\lambda_j}a_i$$

Here, we notice multiple mechanisms that affect the student's cost of attendance and likelihood of receiving aid ($\tau_{ij}^* < \bar{\tau}_j$). First, cost of attendance is decreasing in student ability μ_i and achievement a_i, which is rationalizes colleges offering merit scholarships. Second, colleges with larger outside sources of revenue Y_j charge lower prices. Third, marginally admitted students, for whom the college's capacity constraint binds ($\lambda_k > 0$), are likely to face higher prices. Lastly, the student's likelihood of enrollment and price sensitivity play a critical role. As students are more likely to enroll in response to lower prices ($\partial E(\delta_{ij})/\partial \tau_{ij}^* < 0$), colleges will reduce prices if they think they can entice a desirable student to enroll. This further rationalizes need-based aid as students who have low expected family contributions are more likely to respond to a college's price reduction by enrolling.

As student enrollment decisions are a function of other college's optimal decisions $(\rho_{im}^*, \tau_{im}^*)$, college j's decision depend on college m's behavior. Similarly, college m's behavior is also a function of college j's behavior. These colleges do not observe each other's decisions as they act simultaneously, but they do know the decision rules as part of a symmetric equilibrium. Therefore $(\rho^*_{ik}, \tau^*_{ik})_{\forall k \in K}$ is a fixed point solution of colleges' optimization problem.

D.2.5 Advertised Cost of Attendance

Before period $t = 0$, all colleges simultaneously announce a cost of attendance $\bar{\tau}_j$ that serves as the maximum price. However, I assume that private and public colleges systematically differ in setting the sticker price.

Private colleges Private college j determines the sticker price $\bar{\tau}_j$ as the highest price they anticipate that their aid office will charge once applications are revealed. Therefore, the advertised cost of attendance is a function of the distribution of ability, achievement, and EFC that will determine future applications and the knowledge of competing colleges m's decision rules.

$$\bar{\tau}_j = E[\max \tau_{ij} | \delta_{j0}, F_\mu, F_a, F_{EFC}, \bar{\tau}_m]$$

Private colleges set prices for two broad reasons. First, they try to maximize net revenue and may raise the sticker price to cover declining outside funding Y_j or increasing costs C_j. Second, colleges try to predict the applications they receive in response to a specific cost of attendance, such that they can admit the highest ability students. Therefore, the student's application decision rule δ_{j0} plays a key role for each college's decision. Elite private colleges set higher prices as a screening tool. These colleges know that high ability students will attend, even at a higher cost, because of the wage premium. The availability of student loans allows colleges greater room to increase the sticker price, without the fear of reduced enrollment. These institutions may also compete against peer institutions that admit the same high ability students; this competition prevents a college from excessively increasing its price. The model then predicts that institutions of the same type should set similar cost of attendance, while across type cost of attendance differences should be larger.

Public colleges I assume that a state s's government mandates price caps or growth rates that constrain its public universities to set current cost of attendance based on past cost of attendance.[7] Therefore, I model their sticker price setting behavior as a function of lagged sticker price and growth rate:

$$\log \bar{\tau}_{jt} = \beta_1 \log \bar{\tau}_{jt-1} + g_{jst} + \epsilon_{jt}.$$

Here g_{jst} may be an explicitly stated price cap as compiled for some states in Deming and Walters (2017), or an implicit function of several university- and state-specific characteristics, such as tax revenue, political affiliation, or local economic conditions.

D.3 Estimation Strategy

Estimation of the structural parameters will follow a three-step procedure. The first step estimates the student model of application, enrollment, college choice, and student loan borrowing as detailed in chapter 5. Given these estimates, I will simulate multiple cohorts of high school seniors. Colleges then receive applications from these simulated cohorts based on the optimal student decision rules and determine admission and individual cost of attendance.

In the second step, I will estimate the college objective function parameters Θ_ν. Conditional on estimated student side parameters $\hat{\Theta}_S$, the college solves its admission and aid decisions and yields several model moments, including the probability of admission $\rho_j(\mu_i, a_i)$ and individual cost of attendance $\tau_j(EFC_i, \mu_i, a_i)$. I will use the generalized method of moments (GMM) to match these model moments to moments from the simulated population of student applications. The population counterpart to the model outputs would include admissions probabilities $\hat{P}_j(\mu, a)$ and the probability of receiving aid $\hat{P}_j^A(EFC, a, \mu)$, estimated in the student model and reported in chapter 6. One concern with such a model is the presence of multiple equilibria, but estimation of

[7] Deming and Walters (2017) document explicit state mandates. Rejection of this assumption implies that public universities set low prices (as observed in data) to increase student enrollment, in hopes of raising net revenue.

average rates of admission $\hat{P}_j$ and institutional aid $\hat{P}_j^A$ identifies the equilibrium in the data, rather than imposing an equilibrium selection rule.

In the third step, I will estimate the college tuition function and cost parameters by matching model tuition to observed tuition. Solution to the college problem provides the optimal advertised cost of attendance, $\bar{\tau}_j^*$. As in the previous step, I will use GMM to estimate optimal advertised cost of attendance and parameters of the college expenses to match observed data on advertised cost of attendance $\bar{\tau}_j$.

Identification of College Parameters Identification of college parameters Θ_ν relies on the following plausibly exogenous variation and assumptions. First, colleges take external funding Y_j as exogenous; examples include state and federal funding received by colleges. Second, Deming and Walters (2017) highlight the presence of price caps for public universities: some states set a percentage cap on public university tuition growth, such that it may not exceed a particular amount. Such data present exogenous policies that could identify public university tuition functions. Furthermore, these price caps and lagged public university tuitions could also identify these institutions' marginal effect on competing private universities of similar types.

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