Competition, Borrowing Constraints, and High School Achievement Gap

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Abstract

This paper studies how borrowing constraints interact with capacity limits at high-quality universities to affect students' sorting into selective universities and human capital accumulation during high school. When students compete for the limited seats in high-quality universities, borrowing constraints play an important role in shaping the strategic behaviors of high school students. I develop a model of high school students' effort and college-application choices, and estimate the model with the Education Longitudinal Study of 2002. I use geographic variations of the sticker prices for attending selective and nonselective universities as exogenous variations to identify students' responses to financial incentives. Borrowing constraints not only distort who attends selective universities, but also widen the achievement gap between rich and poor students in advance of college entrance, and lower pre-college human capital of high-ability students from *all*-income backgrounds. Provided by selective universities, need-based aid can close the achievement gap better than merit-based aid, while having a similar impact on the aggregate achievement level.

Keywords: College Education, Borrowing Constraints, High School Achievement Gap

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1 Introduction

To understand the source of persistent income inequality across generations, previous studies extensively investigate different monetary investment in human capital between rich and poor families.[1] Another important but relatively less investigated margin that contributes to human capital is the student's own effort. Because effort investment usually does not incur a direct monetary cost, boosting the effort levels of low-income students can be a cost-effective way to close the achievement gap between rich and poor students. In this paper, I focus on the incentive aspects of college-admission processes for high-quality universities that influence high school students' effort, and discuss how borrowing constraints interact with the capacity limit in high-quality selective universities to create an effort gap between rich and poor high school students.[2]

The following facts motivate this paper. First, regardless of family income levels, applicants to selective universities put substantially more effort into their study than non-applicants. For instance, for both rich and poor students, applicants to selective universities take four times more Advanced Placement/International Baccalaureate (AP/IB) classes than non-applicants during high school.[3] A similar pattern is found in weekly time spent on homework. I also find that applying to selective universities significantly increases high school students' academic choices and achievement by using the state variations in the sticker prices for attending selective and nonselective universities as instrumental variables for students' college-application decisions. The large difference in the effort choice between applicants and nonapplicants to selective universities can be related to the competitive admission process for the limited seats in selective universities. Because the admission probability depends on the student's *relative* academic performance, applicants to selective universities need to put in extra effort to remain competitive in the admission process.

Second, rich students are twice as likely as poor students to apply to selective universities (50% and 26%, respectively). The gap does not disappear even though I compare rich and poor students

[1] See Becker and Tomes [1986], Cameron and Heckman [2001], Restuccia and Urrutia [2004], Cameron and Taber [2004], Belley and Lochner [2007], Lochner and Monge-Naranjo [2011], and Abbott et al. [2019], among others.

[2] Selective universities refer to high-quality four-year colleges that have relatively low acceptance rates in the admission process. To define selective universities in the data, I use the NCES-Barron's Admissions Competitiveness Index Data Files 2004, which is constructed based on SAT scores, high school GPAs, the class rank of each college's incoming students, and the percentage of students accepted. I classify a college as selective if it belongs to the top two categories among the seven categories in the Barron's college competitive index. According to this classification, selective universities account for about 16% of four-year enrollment.

[3] In this paper, I refer to students from the top and bottom quintile of the family income distribution as rich (high-income) and poor (low-income) students, respectively. Similarly, I refer to students from the top and bottom quintile of the 10th grade standardized math-score distribution as high- and low-ability students.

with high ability. The high cost of attending selective universities can potentially explain different application rates by family income. For instance, even if I account for generous grants from selective universities, the net cost of attending selective universities is 136% higher than that of attending nonselective universities. Also, I find the share of Pell Grant recipients, a proxy for low-income students, in selective universities decreases as the gap in the sticker price for attending selective and nonselective universities increases in that state. Because low-income students are less likely to attend selective universities if the relative cost for selective universities is more expensive in that state, borrowing constraints can potentially explain heterogeneous college-application behaviors between rich and poor students.

When borrowing constraints discourage low-income students from applying to selective universities, a financial aid policy that relaxes borrowing constraints can induce higher effort by low-income students by changing their college-application behaviors. However, the impact of a financial policy is not limited to low-income students. Having more high-ability low-income applicants to selective universities changes the relative ranking of all other applicants in the college-admission process. By changing the admission probability of each applicant to selective universities, financial aid can affect effort investment, the college application, and academic achievement of students from all income backgrounds. The impact of financial aid policy thus depends on the strategic interaction between high school students.

To examine the impacts of borrowing constraints in the presence of the competitive college-admission process, I develop a model of high school students' learning, college application, and admission processes, and investigate how students' effort choice and college-application behavior are determined in equilibrium. In the model, students start high school with different ability, family income, and an unobservable characteristic. Attending selective universities provides pecuniary and nonpecuniary benefits. However, attending selective universities is much more expensive than attending nonselective universities. The admissions process for the limited seats in selective universities is highly competitive and depends on students' academic achievement. Students decide their effort choices during high school and whether to apply to selective universities. After the admission result for selective universities is realized, the student takes out student loans to finance the net cost of college education. A fixed borrowing constraint during college can limit the student's borrowing capacity. The admission probability is determined in an equilibrium such that given the admission-cutoff value in the high school achievement score, the number of attendees is equal to the number of seats in selective universities. I estimate the model with the Educational Longitudinal

Study of 2002 based on the method of simulated moments. The geographic variations of the sticker prices for attending selective and nonselective universities are important exogenous variations in identifying students' responses to financial incentives.

Based on the estimated model, I quantify to what extent borrowing constraints magnify the achievement gap when students compete for limited seats in high-quality universities. First, I find that borrowing constraints significantly distort students' sorting into selective universities, and such distortion results in a substantial loss in pre-college human capital, especially among low-income high-ability students. Without borrowing constraints, the gap in the SAT score between rich and poor students decreases by 16 points (17%), and the gap in the annual income between rich and poor students decreases by \$671 (8%). Second, by distorting the incentives of high school students, borrowing constraints lower the average human capital of the population, which implies a \$387 reduction in the average annual income of all four-year-college graduates.

As a policy experiment, I compare the impact of need- and merit-based aid from selective universities. First, if selective universities provide \$2,600 more in annual grants for students from the bottom quintile of the income distribution, which covers the median difference between Pell Grants and the estimated college cost, the achievement gap, as measured by the SAT score, decreases by 16.3% (15 points) and in their annual income after college graduation by 6.6% (\$576). Second, additional need-based aid increases the effort level and labor income of high-ability students from *all* income backgrounds. For example, 27% of students from the top quintile of the family income distribution would have higher incomes. For those high-income students, competitive pressure counteracts diminishing returns to effort. Finally, keeping the budget spending the same, increasing need-based aid is better than increasing merit-based aid at closing the achievement gap if it is provided by selective universities, whereas increasing either has a similar impact on the aggregate achievement level. The negative impact of borrowing constraints on pre-college human capital is greatest for low-income high-ability students. By targeting those low-income high-ability students, need-based aid from selective universities can effectively relax the borrowing constraints and boost the effort level of students with greater academic potential without borrowing constraints. Because the effort increase from those low-income high-ability students is large, need-based aid from selective universities can induce aggregate achievement as high as that induced by merit-based aid.

Finally, I evaluate the respective roles of tuition, grants, and the borrowing limits in explaining observed trends in students' sorting into selective universities and high school achievement. The model can explain a moderate increase in the share of low-income students in high-quality universities (Kinsler and Pavan [2011] and Chetty et al. [2017]). I add to the literature by showing the trends in tuition, grants, and borrowing limits not only affect the share of low-income students in high-quality universities, but also affect high school students' academic achievement. Without the rapid increase in grant amounts from selective universities, the overall high school achievement as well as the academic quality of attendees of selective universities in recent years would have been substantially lower than the data, due to the large increase in tuition for both selective and nonselective universities.

This paper adds to the literature on educational credit constraints. First, it evaluates how borrowing constraints in college financing change high school students' efforts and human capital accumulation. This focus is different from most previous studies that look at the impact of borrowing constraints on the college enrollment decision, taking the pre-college human capital as given (e.g., Cameron and Heckman [1998], Cameron and Heckman [2001], Cameron and Taber [2004], Lochner and Monge-Naranjo [2011], Hai and Heckman [2017]). An exception is Restuccia and Urrutia [2004], who evaluate the relative importance of early and college education in intergenerational mobility. By accounting for endogenous human capital formation before college, Restuccia and Urrutia [2004] also show progressive college subsidies can reduce earning disparity between rich and poor students by increasing early investment by poor families. The difference in this paper is that I show strategic interactions between high school students through the college-admission process can magnify the negative impact of borrowing constraints on pre-college human capital accumulation. Second, this paper studies how borrowing constraints affect the quality of college education. As an increasing number of papers document a positive correlation between family income and the quality of colleges (Kinsler and Pavan [2011], Chetty et al. [2017], Arcidiacono et al. [2019]), understanding how borrowing constraints affect students' sorting patterns across different types of colleges can have important policy implications, such as how financial aid policy should be designed across different types of colleges.

This paper also relates to studies that evaluate financial aid policies (e.g.,Akyol and Athreya [2005], Avery et al. [2006], Garriga and Keightley [2007], Dynarski [2010], Abbott et al. [2019]). This paper complements previous studies by comparing need- and merit-based aid from a broader set of high-quality universities. In particular, this paper re-evaluates the incentive aspects of need-based aid, which is an important departure from most previous studies, which focus on merit-based aid when discussing incentives. For example, abstracting from a heterogeneous quality of colleges, Akyol and Athreya [2005], Garriga and Keightley [2007], and Abbott et al. [2019] find that need-based aid can have an adverse-selection problem that encourages college enrollment by less able low-income students. However, this paper shows that in focusing on students at the margin of attending high-quality universities, need-based aid can result in better student sorting into high-quality universities than merit-based aid, which, in turn, can close the achievement gap more effectively, while having an aggregate achievement level similar to that of merit-based aid.

The paper is organized as follows. I describe the data and motivating facts in section 2. I explain the model and high school students' choices in section 3. I discuss characterization of the model in section 4. Section 5 discusses how I conduct quantitative analysis. Section 6 discusses the results. Section 7 concludes.

2 Motivating Facts

In this section, I first describe data sets and document facts about the achievement gap between rich and poor students and its relationship with the college-application process and tuition for selective and nonselective universities.

2.1 Data

I use the ELS 2002 as the main data set. The ELS 2002 is a nationally representative sample of US high school students, following the sample up to eight years after high school graduation. It includes information on the students' academic achievement scores, school characteristics, family background, college attendance, and the hourly wage at age 26-27. I also use a restricted data set that includes information on all institutions the student applied to, was admitted to, and attended. I focus on students who attend a four-year college.[4] To supplement the ELS 2002, I use the following data sets: (i) the NCES-Barron's Admissions Competitiveness Index 2004 and (ii) the IPEDS 2004.

The NCES-Barron's Admission Competitiveness Index 2004 is used to define college selectivity. It covers all four-year colleges across the US and provides an admission-competitiveness index for each university. I define selective universities as universities in the top two out of seven categories of the Barrons' index 2004. The reason is that the hourly wage and the SAT scores of students change most drastically when the Barron's college-selectivity index changes from the second highest to the

[4]The original sample size of the ELS 2002 is about 15,000 10th graders in 2002. I dropped students who do not attend four-year colleges and observations with missing variables. Because the wage is collected just a few years after college graduation, I drop from the sample students who enter a doctoral program. The final sample consists of 4,520 individuals.

Table 1: Characteristics of Rich and Poor High School Students

Variables	All	Low-income	High-income	t-statistics
Family income	80,053	21,783	162,670	177.21
	(52,048)	(8,929)	(21,773)	
Math score in 10th grade	51.27	40.88	58.54	14.10
	(27.96)	(27.71)	(26.97)	
SAT score	1,058	971	1,133	19.29
	(188)	(187)	(180)	
Hourly wage (age 26-27)	18.87	17.17	20.51	6.92
	(10.01)	(10.01)	(10.89)	
Number of observations	4,520	850	1,080	

Note. The table shows summary statistics of all students, students from the top (high-income/rich) and bottom quintiles (low-income/poor) of the family income distribution of the sample. All monetary values are normalized to 2004 USD by using the CPI. t-statistics are for the t-test on whether the difference in the means of the low- and high-income students is 0. Data are from the ELS 2002.

third highest. According to this classification, 16% of all four-year-college students attend selective universities.[5]

The IPEDS 2004 is used to get information on the sticker price to attend selective and nonselective universities. The IPEDS issues a yearly survey to all post-secondary institutions in the US that participate in the federal student financial aid programs. The survey includes data on basic characteristics of institutions, institutional prices, and admissions. The sticker price of each university is calculated as the sum of tuition, fees, and the cost for books and supplies for the university.

2.2 Facts about High School Students' Effort Choices and College Applications

Table 1 shows characteristics of rich and poor high school students. The achievement gap between rich and poor students exists from the early years of high school. For example, high-income students enter the 10th grade with 43% (0.63 standard deviations) higher standardized math scores than low-income students.[6] This gap seems to persist beyond the early years of high school: Looking at the sum of verbal and math SAT scores shows rich students achieve 0.86-standard-deviations-higher SAT scores at the end of high school than poor students, and their hourly wage during the early years

[5] In Appendix B, I discuss the robustness of the main findings by changing the definition of selective universities.

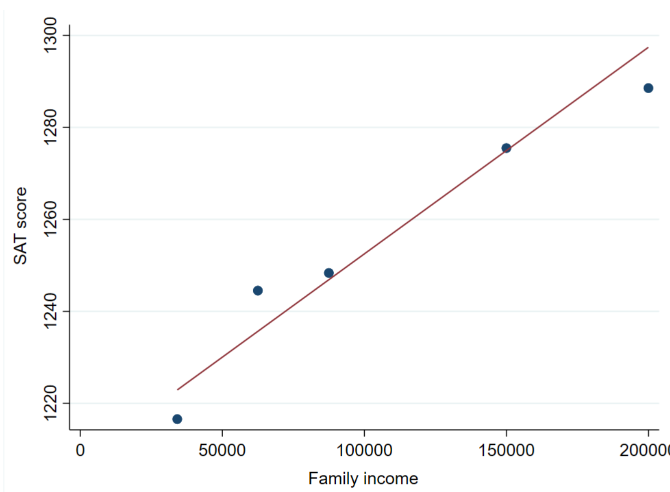
[6] The math score in 10th grade is a percentile of the standardized math scores among 10th graders in the sample. The standardized test score in 10th grade is the earliest available achievement score in the ELS 2002.

of labor market (at age 26-27) is 3.34 USD higher than that of the poor students. In the following discussion, I demonstrate that the earlier achievement gap between rich and poor students cannot fully explain the achievement gap when they graduate from high school, and students' academic choices during high school can also play an important role in determining students' outcomes during high school and after.

Fact 1. The achievement gap between rich and poor students widens during high school conditional on the initial academic preparation level.

If I look at the trajectories of students' academic achievement during high school, the achievement gap between rich and poor students widens during high school conditional on their earlier academic achievement. Figure 1 shows a binned scatter plot on the relationship between family income and the sum of verbal and math SAT scores of students who are in the top quintile of the math score distribution in 10th grade. Although the students have similar initial math-scores in the 10th grade, at the end of high school, high-income students score substantially higher on the SAT than low-income students.

Figure 1: Family Income and SAT Score among High-Ability Students



Note. The graph shows a binned scatter plot showing the relationship between family income and the sum of verbal and math SAT scores of students who are in the top quintile of the math-score-distribution in the 10th grade. The data are from the ELS 2002.

Fact 2. High school students' academic choices are strongly correlated with whether they apply to selective universities, and the application rate to selective universities increases by family income.

Panel A of Table 2 shows an applicant to selective universities (a student who applies to at least one selective university during the college-application process) achieves a 0.68-standard-deviations (128 points)-higher SAT score than a student who does not, focusing on students from the lowest quintile of the family income distribution. The corresponding number for students from the highest quintile of the family income distribution is 0.94 standard deviations (176 points).[7] Panels B and C in Table 2 compare (1) the number of AP/IB classes students took and (2) weekly hours spent on homework between the applicants and non-applicants to selective universities conditional on family income. Regardless of family income levels, applicants to selective universities take four times more AP/IB classes (two more units of AP/IB classes) than non-applicants. A similar pattern emerges in weekly time spent on homework. This finding suggests applicants to a selective university put in significantly more effort during high school than non-applicants, and achieve a higher SAT score at the end of high school.

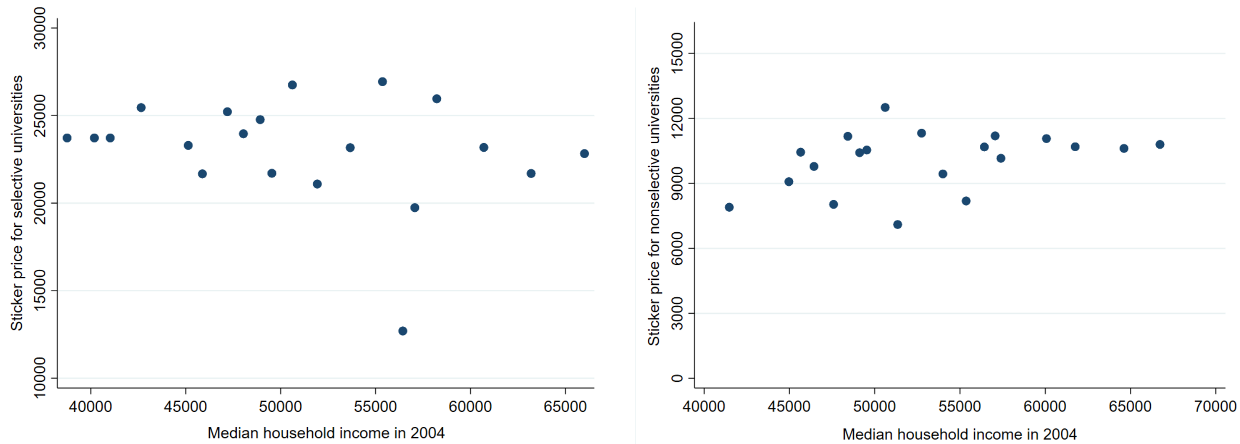
Table 2: College-Application and Academic Choices of High School Students

Variables	Income	Applicants to selective univ.	Non-applicants to selective univ.	t-statistics
(A) SAT score	Low	1,066	938	9.12
		(185)	(175)	
	High	1,219	1043	18.46
		(159)	(154)	
(B) AP/IB classes	Low	2.26	0.44	11.03
		(3.07)	(1.67)	
	High	2.47	0.57	12.42
		(3.08)	(1.75)	
(C) Homework	Low	13.29	11.50	2.37
		(9.60)	(9.31)	
	High	14.29	11.63	5.02
		(8.85)	(8.13)	

Note. The table shows the SAT score, the number of AP/IB classes students took during high school, and weekly hours spent on homework, conditional on whether the student applied to selective universities. Low-(high-)income students refer to students from the bottom (top) quintile of the family income distribution. Data are from the ELS 2002.

[7] The standard deviation of the SAT score of all students in the sample is 188 points (Table 1).

Figure 2: Correlation between Sticker Price for Attending Selective/Nonselective Universities and 2004 Median Household Income across States



Note. The graph shows a binned scatter plot showing the relationship between sticker prices for attending selective (left) and nonselective (right) universities and the median household income in 2004 across states.

However, findings in Table 2 do not necessarily imply changing students' college-application behavior can affect high school students' academic choices and achievement. An unobservable characteristic such as motivation or family background factor (i.e. information) could explain different academic choices, application behaviors, and achievement scores. To check whether the correlations in Table 2 are solely driven by different unobservable characteristics between applicants and non-applicants, I use variations in the sticker prices for attending selective and nonselective universities across states as instrumental variables (IVs) for whether a student applies to selective universities. The underlying assumption is that the location of residence of high school students is independent of students' unobservable characteristics that affect students' college application and high school choice simultaneously. This assumption, for instance, implies students with high motivation/better family background select themselves into states with a low (high) sticker price for selective (nonselective) universities. Compared to the parents' job market opportunity or the housing market condition, the sticker price of universities may not be a primary concern when the parents choose the location of residence. To further investigate the validity of the IVs, I use the state average median household income in 2004 as a proxy measure for the state average unobservable characteristic that is associated with students' family income. In Figure 2, I show that no clear correlation exists between the sticker price for attending selective universities and the median household income in 2004 across states.

Panel B of Table 2 shows the first-stage estimates in the IV regression. The state-specific sticker prices for attending selective and nonselective universities significantly predict whether a student applies to selective universities, after controlling for the math score in 10th grade and family income. Panel A shows the OLS estimates and the second stage estimates of the IV regression. In column (1) of Table 3, I run an OLS regression of the SAT score on a dummy variable that takes a value of 1 if the student applies to at least one selective university, the standardized math score in 10th grade, and family income. Column (2) shows the regression results with the IV. In both OLS and IV regressions, whether the student applies to selective universities has a significantly positive correlation with the SAT score. The coefficient of students' application decision on the SAT score is smaller in the IV regression than in the OLS, consistent with the idea that not accounting for selection bias would overstate the impact of the college-application decision on the high school achievement. Similarly, the number of AP/IB classes a student takes also has a significantly positive

Table 3: College Application and High School Students' Choices and Achievement

	Panel A: OLS and IV estimates			
	(1)	(2)	(3)	(4)
VARIABLES	SAT score	SAT score	AP/IB	AP/IB
	OLS	IV	OLS	IV
Apply to selective univ.	94.19	53.56	1.425	0.800
	(4.260)	(20.43)	(0.0733)	(0.351)
Math score in 10th grade	3.919	4.087	0.0179	0.0204
	(0.0725)	(0.110)	(0.00125)	(0.00189)
Family income	0.000403	0.000462	2.02e-07	1.12e-06
	(3.83e-05)	(4.85e-05)	(6.59e-07)	(8.33e-07)
Constant	795.3	796.1	-0.308	-0.295
	(4.653)	(4.716)	(0.0801)	(0.0810)
Observations	4,520	4,520	4,520	4,520
R-squared	0.523	0.513	0.153	0.140
	Panel B: 2SLS first stage estimates			
Sticker price for selective univ.		-9.11e-06		
		(1.40e-06)		
Sticker price for nonselective univ.		4.63e-05		
		(3.25e-06)		
R^2		0.1390		
F-statistic		104.743		

Note. Panel A shows the estimates from the OLS and the IV regression. Column (1) shows the OLS regression of the SAT score on whether the student applies to selective universities, the standardized math score in 10th grade, and family income. Column (2) shows the IV regression of the SAT score by using the state-specific sticker prices for selective and nonselective universities as IVs for a student's college-application decision. Columns (3) and (4) show the OLS and IV regression of the number of AP/IB classes a student takes on the same control variables. First-stage estimates in Panel B include the control variables that are indicated in the corresponding columns of Panel A. F-statistic is Cragg-Donald Wald F statistic. Standard errors are in parentheses. Data are from the ELS 2002.

Table 4: Application Rate to Selective Universities by Family Income

	Variables	All	Low-income	High-income	t-statistics
(A)	Application rate to selective univ.	0.35	0.26	0.50	11.47
	(all students)	(0.48)	(0.44)	(0.50)	
(B)	Application rate to selective univ.	0.56	0.44	0.69	5.74
	(high-ability students)	(0.50)	(0.50)	(0.46)	
(C)	Attendance rate for selective univ.	0.16	0.08	0.28	11.58
	(all students)	(0.37)	(0.27)	(0.45)	
	Number of Observations	4,520	850	1,080	

Note. The table shows the application and attendance rate for selective universities as measured by the share of students who apply to and attend selective universities. (A) is the application rate of all students to selective universities, and (B) is the application rate to selective universities among students in the top quintile of the initial-math-score distribution in the 10th grade. (C) is the attendance rate for selective universities. Standard deviations are in parentheses. Data are from the ELS 2002.

correlation with the college application decision after controlling selection bias by using the IVs.

Given that the decision to apply to a selective university is important to understand high school students' achievement, I compare the number of applicants to selective universities between high- and low-income students. The results are shown in row A of Table 4. The application rate of high-income students to a selective university is almost twice as high as the application rate of low-income students (50% and 26%, respectively). In row B of Table 4, I show application rates to selective universities among high-ability students who are from the top quintile of the initial-math-score distribution (69% for high-income students and 44% for low-income students). First, the application rate is significantly higher for high-ability students. Second, even after controlling for students' ability, the application rate to selective universities is substantially higher for students from high-income backgrounds. As a result, the attendance rate for a selective university is much higher for the high-income group (28%) than for the low-income group (8%).

2.3 Facts about College Application, Admission, and Direct Cost

Why do applicants and non-applicants to selective universities make different academic choices during high school? Why are poor students less likely to apply to selective universities than comparable rich students? To answer these questions, I focus on two key features of selective universities: the competitive admissions process and the expensive cost.

Table 5: Annual Direct Cost for Selective and Nonselective Universities

	Variables		(1) Selective Univ.	(2) Nonselective Univ.
(A)	Sticker price	Mean	22,750	9,650
			(4,910)	(2,110)
		Median	23,720	9,660
(B)	Net cost	Mean	15,970	6,770
			(7,330)	(4,750)
		Median	17,480	5,930

Note: The table shows the annual direct cost of attending selective and nonselective universities in 2004 USD. (A) is the average sticker price of attending selective and nonselective universities as measured by the sum of tuition, fees, and costs for books and supplies for in-state students in the sample. (B) is the net cost of attending selective and nonselective universities as measured by the sum of tuition, fees, and cost for books and supplies for in-state students net of grants. Data are from the ELS 2002 and the IPEDS 2004. Standard deviations are in parentheses.

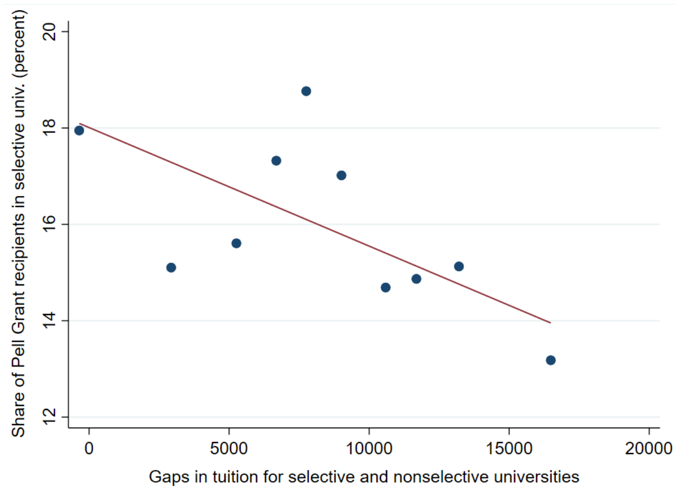
Fact 3. Admission into selective universities is competitive, and the direct cost for attending selective universities is higher than that of attending nonselective universities after accounting for grants.

First, admission into selective universities is competitive. In my sample, 35% of four-year-college students apply to at least one selective university, and only 16% of four-year-college students attend selective universities. The low acceptance rate in selective universities is related to the capacity limit in those high-quality universities. High school students' academic performance is an important determinant of the admission probability into selective universities. According to the IPEDS 2004, the 75th percentile of the SAT math score of students at selective universities is 700 out of 800, which is 1.80-standard-deviations higher than that of nonselective universities (580).

Second, the monetary cost of attending selective universities is substantially higher than that of attending nonselective universities.[8] Table 5 shows the annual cost of attending selective and nonselective universities. The average sticker price (row A) as measured by the sum of in-state tuition, fees, and costs for books and supplies for attending selective universities (22,750 USD) is more than twice as high as that of nonselective universities (9,650 USD). Even if I account for generous grants

[8] To get the sticker price for selective and nonselective universities, I first use the IPEDS 2004 to get the institution-level tuition, fees, and costs for books and supplies. Then I match college-specific cost data from the IPEDS 2004 with student-specific college data observed in the ELS sample. The average sticker price for attending selective (nonselecitive) universities is the mean value of the sticker price of students who attend selective (nonselective) universities in the ELS sample. To get the net cost of attending selective and nonselective universities, accounting for grants, I use the individual-level grant data from the ELS 2002 and subtracting it from the sticker price of the attending college. The net cost of attending selective (nonselective) universities is the mean value of the net cost of students who attend selective (nonselective) universities.

Figure 3: Cost Gap by College Selectivity and Share of Pell Grant Recipients in Selective Univ.



Note. The top graph shows a binned scatter plot of the relationship between the state average cost difference between selective and nonselective universities and the share of Pell Grant recipients in selective universities across states. Based on the institution-year-specific data on sticker prices (as measured by the sum of tuition, fees, and the costs for books and supplies), I get the average sticker price of selective and nonselective universities for each state and year, and calculate the difference between two types of colleges. All monetary values are normalized to 2004 USD by using the CPI. To calculate the share of Pell Grant recipients in selective universities for each state and year, I use the institution-year-specific data on the proportion of Pell Grant recipients, and then calculate the mean value for selective universities for each state and year. Selective universities are defined as colleges in the top two categories of Barron's index in 2004. The data are from IPEDS 2001-2016.

from selective universities, the net cost (row B) of attending selective universities is 136% higher than that of attending nonselective universities (15,970 USD and 6,770 USD, respectively).

Fact 4. The share of Pell Grants recipients in selective universities decreases as the gap in the sticker prices for attending selective and nonselective universities increases.

Figure 3 is a binned scatter plot that describes the relationship between the gap in the sticker prices for selective and nonselective universities and the percentage share of Pell Grant recipients in selective universities. The plot is based on 830 state-year observations calculated from the IPEDS 2001-2016.[9] Because most federal Pell Grant are awarded to low-income students, the share of Pell Grant recipients in selective universities can be considered a proxy for the share of low-income students in high-quality universities.

As the gap in the sticker price of selective and nonselective universities increases by $15,000, the share of low-income students in selective universities decreases by about 4%. A similar pattern is found if I use the sticker price for selective universities instead of the gap in the sticker prices

[9] See the note of Figure 3 for the details of the data construction.

between selective and nonselective universities. Thus, the relative monetary cost for attending selective and nonselective universities can play a role in explaining Fact 2, the different college-application behaviors between rich and poor students.

2.4 Discussion

Because the admission probability depends on the student's relative academic performance, applicants to selective universities need to put in extra effort to remain competitive in the admission process. Therefore, the competitive college-admission process for selective universities can explain why applicants to selective universities make different academic choices from non-applicants.

On the other hand, given the high cost for attending selective universities, borrowing constraints can be an important reason behind heterogeneous college-application behaviors between rich and poor students. When borrowing constraints discourage low-income students from applying to selective universities, a financial aid policy that relaxes borrowing constraints can induce higher effort by low-income students by changing their college-application behaviors. However, the impact of financial aid policy is not limited to low-income students. Having more high-ability low-income applicants to selective universities changes the relative ranking of all other applicants in the college-admission process. By changing the admission probability of each applicant to selective universities, financial aid can affect effort investment, the college-application behavior, and academic achievement of students from all income backgrounds. The impact of financial aid policy thus depends on the strategic interaction between high school students driven by the competitive college-admission process. Therefore, understanding the respective roles of borrowing constraints and the competitive college-admission process by accounting for the equilibrium effect can be important to design financial aid policy.

3 The Model

To examine the impacts of borrowing constraints on strategic behaviors of high school students and to quantify the role of borrowing constraints in explaining the achievement gap between rich and poor students, I develop a model of high school students' learning, the college application, and admission processes.

3.1 Environment

Consider a high school student who lives for three periods $t = 0, 1, 2$, where $t = 0$ is the high school period, $t = 1$ is the college period, and $t = 2$ is the working period. The student accumulates human capital during high school ($t = 0$) and college ($t = 1$), and consumes during the college period ($t = 1$) and the working period ($t = 2$). At the beginning of period 0, the individual is characterized by $Z_0 = (h_0, m_p, \theta)$, where $h_0 \in \mathbb{R}_+$ is the initial stock of human capital at the beginning of high school, $m_p \in \mathbb{R}_+$ is family income, and $\theta \in \mathbb{R}_+$ is an unobservable characteristic. θ captures family background factors such as information and network that can affect college-admission processes and labor earnings after college graduation. θ follows a log-normal distribution $ln(\theta) \sim N(\mu_\theta, \sigma_\theta^2)$, where $\mu_\theta = \lambda \cdot m_p$.[10] The financial assets available to the student at the beginning of the college period is $W = W_p + W_s$, where $W_p = \phi_1 m_p + \phi_2 h_0 + \phi_0$ is parental transfer and W_s is income from self-financing by working during college.[11] All individuals prepare for and attend a four-year college.[12] Two types of colleges exist: selective and nonselective. The quality of education provided by selective universities is higher than that of nonselective universities. Anyone can attend nonselective universities, whereas the admission process for selective universities can be competitive because of a capacity limit in selective universities.

During the high school period, the individual first chooses how much effort to put into human capital accumulation ($x \in \mathbb{R}_+$), and then decides whether to apply to selective universities ($I_a \in \{0, 1\}$). The effort choice x affects the level of human capital at the end of high school ($h_1 \in \mathbb{R}_+$). At the beginning of the college period, a student chooses consumption ($c_1 \in \mathbb{R}_+$) and student loan ($L \in \mathbb{R}$), which also determines consumption during the working period ($c_2 \in \mathbb{R}_+$).

3.1.1 Preference

The utility from consumption is $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$. Other than consumption, the individual obtains utility from three additional components: the nonpecuniary benefit of attending selective universities ($u_{sel} \in \mathbb{R}$), the utility cost of exerting effort during high school ($K \in \mathbb{R}_+$), and the utility cost of

[10]Thus, the mean of θ changes by family income, but depending on the realization of the i.i.d. random component in θ, students with different family income might also have similar θ.

[11]Similar to Keane and Wolpin [2001], Johnson [2013], and Hai and Heckman [2017], I allow parental transfer to vary by characteristics of parents and children, and also incorporate labor earnings during college as a source of financial resources during college.

[12]The mechanism in this paper mostly affects students at the margin of applying to/attending selective universities, who tend to have higher academic achievement than those who are at the margin of attending non-selective universities. For this reason, I do not model students' decision on whether to attend a four-year college.

applying to selective universities $\zeta \in \mathbb{R}$. β is the time-discount factor.

The nonpecuniary benefit of attending selective universities is

$$u_{sel} = \psi_0 + \psi_1 h_1 + \psi_2 \theta + \epsilon_\psi.$$

ψ_0 captures the overall consumption value of attending selective universities, which may include utility from consuming high-quality facilities. $\psi_1 h_1$ captures the heterogeneous utility gain of attending selective universities by the academic-preparation level, which may include disutility from mismatch (Arcidiacono [2005], Arcidiacono et al. [2014]). u_{sel} can vary by the unobservable characteristic ($\psi_2\theta$). An i.i.d. random component $\epsilon_\psi \sim N(0, \sigma_\psi^2)$ that captures individual-specific tastes for high-quality universities also affects u_{sel}. ϵ_ψ is realized at the end of high school before students make a college-application decision.

During the high school period, two types of utility costs are associated with students' choices. First, exerting effort during high school incurs utility cost $K(x)$:

$$K(x) = \kappa \cdot e^x.$$

Second, preparing a college-application portfolio for selective universities and participating in the competitive-admission process may incur a nontrivial utility cost. Let ζ be the utility cost associated with applying to selective universities, which is homogeneous for everyone.

3.1.2 Human Capital Production Function

Human capital accumulation during high school depends on students' ability (h_0) and effort choice (x). The human capital of a high school graduate is $h_1 \in \mathbb{R}$:

$$h_1 = \gamma_0 {h_0}^{\alpha_1} x^{\alpha_2},$$

where γ_0 is a constant and α_j ($j = 1, 2$) determines the marginal productivity of (h_0, x). This implies that conditional on h_0, all heterogeneity in h_1 is explained by different effort choices of students during high school x.[13]

[13] Although θ does not directly increase h_1, it can change h_1 through its impacts on students' effort choice x. I do not allow θ to directly affect h_1, because without a proper effort measure (x) in the data, I cannot separately identify how θ and x affect h_1. I do not use one particular academic choice variable in the data, such as the number of AP/IB classes a student takes, as an effort measure in the model estimation, because doing so may impose nontrivial

Human capital accumulation during college depends on human capital at the end of high school h_1, the unobservable characteristic θ, and the type of college the student attends. Let $I_s \in \{1, 0\}$ be the indicator for whether the student attends a selective university or not. Let $h_2 \in \mathbb{R}_+$ be the human capital after the college period. Then,

$$h_2 = \begin{cases} \gamma_1 \theta h_1^{\alpha_3}, & \text{if } I_s = 0 \\ \gamma_1 \theta h_1^{\alpha_3} e^{\alpha_4}, & \text{if } I_s = 1, \end{cases} \tag{1}$$

where γ_1 is a constant, α_3 determines the marginal productivity of high school achievement (h_1) on human capital accumulation during college (h_2), and α_4 captures the percentage increase in human capital during college when attending a high-quality university. Other than high school achievement and college selectivity, the unobservable characteristic θ also affects h_2.[14] Therefore, the wage difference between two students who have the same high school achievement (h_1) but attend different types of colleges can be explained by the wage premium from attending selective universities (α_4) and different unobsevable characteristic θ. After the college graduation, all individuals become full time workers and work $\overline{H}$ hours per year.[15] Denote m_j to be post-schooling labor income when the individual attends a college of type $j \in \{s, n\}$. Then $m_n = \gamma_1 \theta h_1^{\alpha_3} \overline{H}$ and $m_s = \gamma_1 \theta h_1^{\alpha_3} e^{\alpha_4} \overline{H}$. Everyone graduates from a college. Also, there is no uncertainty in labor income, which is equivalent to having a full insurance against labor income shock after college.[16]

3.1.3 College Admission and Monetary Cost

Selective universities have a limited capacity, and hence the admission process for attending selective universities can be competitive. Nonselective universities do not have a capacity limit; thus, students can always attend nonselective universities. If the student is not accepted by a selective university,

restrictions on what effort means during high school. Alternatively, I can use multiple effort measures such as the number of AP/IB classes a student takes, time spent on homework, and time spent on extracurricular activities in the estimation to account for various types of efforts during high school, while allowing θ to directly affect h_1. Doing so does not change the main findings of the paper significantly, but does add too many parameters to the model, and the estimation results are much less precise.

[14] Thus, the wage premium from attending selective universities in absolute terms differs by students' college preparedness (h_1) and the unobservable characteristic (θ).

[15] Although dropping out is not explicitly incorporated in the model, θ can explain a low wage rate of college dropouts, whereas heterogeneous nonpecuniary benefits of attending selective universities can partially account for different returns to attending selective universities between graduates and dropouts from selective universities.

[16] This assumption is similar to Lochner and Monge-Naranjo [2011]. As discussed in Ionescu [2009], assuming full insurance might understate the negative impact of borrowing constraints on pre-college human capital accumulation of low-income students. I find the quantitative results of this paper remain similar when I introduced college-dropout risk and a labor income shock in the previous version of this paper.

she attend a nonselective university. Let $s(h_1, \theta, \epsilon_s)$ be the admission criteria for selective universities that are pre-determined and commonly known to everyone:

$$s = \pi_1 h_1 + \pi_2 \theta + \epsilon_s. \tag{2}$$

s depends on high school test score h_1, the unobservable characteristic θ, and an i.i.d. random shock in the admission process, $\epsilon_s \sim N(0, \sigma_s^2)$. s depends on θ because students from high-income families might be better at preparing nonacademic factors such as extracurricular activities, essays, alumni connections, or athletic merit.[17] No private information exists regarding θ.[18] Three random components in the model, ϵ_ψ, ϵ_θ, and ϵ_s, are independent.

Let s^* be the admission-cutoff value in the admission criteria above which selective universities accept the applicant. Given the admission criteria and the cutoff value s^*, the probability of an individual with (h_1, θ) being admitted to a selective university is

$$p = Prob(s > s^*) = \Phi(\pi_1 h_1 + \pi_2 \theta - s^*).$$

for the applicant to selective universities and 0 for the student who does not apply to selective universities.

On the other hand, attending a college incurs a monetary cost that depends on college selectivity. Let t_j be the sticker price to attend college of type $j \in \{s, n\}$. Let g_j be grants from college of type j and let $\tau_j = \max\{0, t_j - g_j\}$ be the net cost of attending a college of type $j \in \{s, n\}$.

3.1.4 Capital Market

The individual faces borrowing constraints during the college period. After the college period, the individual has access to the complete capital market. Loan amounts have a fixed borrowing limit that students can take out during college $\overline{L}$ (Abbott et al. [2019]).[19] The student repays the loans

[17] Arcidiacono et al. [2019] document that admission to Harvard university significantly depends on family background factors.

[18] This assumption is different from Fu [2014] who explicitly models private information and uncertainty facing students and colleges in the college-admission process. However, because I do not model college's admission decision criteria, financial aid policies, and who they want to accept, allowing asymmetric information regarding θ between students and colleges would not significantly change the main finding of this paper as long as the noise in the signal is independent of ϵ_s.

[19] Hai and Heckman [2017] carefully discusses different specifications used in the literature to model educational borrowing constraints. This paper focuses on the impact of borrowing constraints on the quality of college and high school achievement, and those margins are significantly different from previous studies that focus on the college enrollment decision. Because the literature has widely adopted a fixed borrowing constraint to study educational

after the college period at the risk-free interest rate r:

$$L \leq \overline{L}.$$

3.1.5 Equilibrium

Let $F(h_0, m_p, \theta)$ be the joint distribution of the initial characteristics of individuals. Let (x^i, I_a^i) be the effort and college-application choice of an individual $i = 1, \cdots, N$, where N is the total number of individuals. Let s^i be the score of an individual i according to the admission criteria for selective universities (s). Let N_s be the number of seats available in selective universities.

Given $F(h_0, m_p, \theta)$, human capital production function $h_1(\cdot)$ and $h_2(\cdot)$, the admission criteria $s(\cdot)$, and (t_s, t_n, g_s, g_n), an equilibrium is $\{x^i, I_a^i\}_{i=1}^N$ and s^* that maximize the utility of each individual, and satisfies

$$N_s = \sum_{i=1}^{N} I(s^i \geq s^*), \tag{3}$$

where $I(\cdot)$ is the indicator function of having a value of 1 if $s^i \geq s^*$. The above condition implies the number of seats available in selective universities is equal to the number of attendees in selective universities with the equilibrium admission-cutoff value s^*.

4 Characterization

In this section, I discuss how the competitive college-admission process and borrowing constraints affect high school students' choices, and discuss how such impacts differ by students' initial asset W. In doing so, I discuss an individual's problem by backward induction.

In section 4.1, I first show why borrowing constraints are more likely to bind if the student attends a selective university, and how the utility loss associated with borrowing constraints differs by initial asset W. Next, I explain how the returns to attending a selective university relative to attending a nonselective university change by family income, and show why borrowing constraints make selective universities relatively more attractive to high-income students.

In section 4.2, I explain heterogeneous impacts of borrowing constraints on students' application behaviors by W, and discuss how borrowing constraints change effort choices of high school students.

borrowing constraints, I choose a fixed borrowing constraints as a benchmark specification.

4.1 Student's Problem during College

After the realization of the college-admission result (I_s), the individual knows which type of college to attend ($j \in \{s, n\}$), and hence the associated net monetary cost (τ_j) and post-schooling labor income (m_j). At the beginning of the college period, the student who attends a college of type $j \in \{s, n\}$ solves the following problem:

$$\max_{c_1, c_2, L} u(c_1) + \beta u(c_2) + u_{sel} I_s \quad \text{subject to}$$

$$c_1 + \tau_j \leq W + L$$

$$c_2 + (1+r)L \leq m_j(h_1, \theta)$$

$$L \leq \overline{L}$$

$$c_1, c_2 \geq 0.$$

Without borrowing constraints ($\overline{L} = \infty$), the optimal amount of loans the student takes out is $L_j^* = \frac{\beta}{1+\beta} m_j(h_1, \theta) - \frac{\beta}{1+\beta}(W - \tau_j)$ for $j \in \{s, n\}$. Thus, the borrowing constraint for attending a college of type $j \in \{s, n\}$ binds if and only if

$$\overline{L} < \frac{\beta}{1+\beta}\big[m_j(h_1, \theta) + \tau_j - W\big]. \tag{4}$$

The borrowing constraint is more likely to bind if labor income after the schooling period ($m_j(h_1, \theta)$) is higher, the initial asset (W) is lower, and the net cost of attending college of type $j \in \{s, n\}$ (τ_j) is greater. Because attending high-quality universities increases labor income ($m_s(h_1, \theta) > m_n(h_1, \theta)$), whereas the net cost of attending high-quality universities is usually more expensive than that of attending nonselective universities ($\tau_s > \tau_n$), the borrowing constraint is more likely to bind if the student attends selective universities.

To clarify, let $v_c^j(h_1, \theta, W)$ be the value from consumption in period 1 of the student with (h_1, θ, W) who attends a college of type $j \in \{s, n\}$. To explain the main channel through which borrowing constraints affect the value of the college student, I focus on the value from consumption $v_c^j(h_1, \theta, W)$, which does not include the nonpecuniary benefit from attending selective universities (u_{sel}). For $j \in \{s, n\}$, let $v_c^{*j}(h_1, \theta, W)$ be the value from consumption without borrowing constraints:

$$v_c^{*j}(h_1,\theta,W) = (1+\beta)u\Big(\frac{1}{1+\beta}\Big[W-\tau_j+\beta m_j(h_1,\theta)\Big]\Big). \tag{5}$$

Let $\hat{v}_c^j(h_1,\theta,W)$ be the value from consumption if the borrowing constraints bind:

$$\hat{v}_c^j(h_1,\theta,W) = u(W+\overline{L}-\tau_j)+\beta u(m_j(h_1,\theta)-(1+r)\overline{L}). \tag{6}$$

Proposition 1 below describes how the utility loss associated with the binding borrowing constraints changes by the college selectivity and students' initial assets W. For a given h_1, let $\Delta v_c{}^j(h_1,\theta,W) = v_c^{*j}(h_1,\theta,W) - \hat{v}_c^j(h_1,\theta,W)$ be the decrease in the value from consumption when borrowing constraints bind and the student attends a college of type $j \in \{s,n\}$.

Proposition 1. *For a given (h_1,θ,W), (i) $\Delta v_c{}^s(h_1,\theta,W) > \Delta v_c{}^n(h_1,\theta,W)$ if $\tau_s \geq \tau_n$, and (ii) $\Delta v_c{}^j(h_1,\theta,W)$ decreases by W for $j \in \{s,n\}$.*

All proofs are shown in Appendix A. Part (i) of the Proposition 1 implies borrowing constraints incur greater utility cost from consumption if the student attends a selective university. Because attending a selective university increases post-schooling income ($m_s(h_1,\theta) > m_n(h_1,\theta)$) but decreases consumption during college if $\tau_s > \tau_n$, the extent of distortion in the intertemporal consumption smoothing is greater if the student attends a selective university. Part (ii) of the Proposition 1 implies that, conditional on attending a college of type $j \in \{s,n\}$, borrowing constraints incur greater utility cost from consumption if the student has less asset W. The reason is that the impact of borrowing constraints on the intertemporal consumption smoothing is greater if the student has fewer resources to finance consumption during college.

In Proposition 2, I discuss how the pecuniary benefit of attending selective universities defined by ($v_c^s(h_1,\theta,W) - v_c^n(h_1,\theta,W)$) changes by W and borrowing constraints. The borrowing constraints do not bind for attending either a selective or nonselective university if equation (7) holds. The borrowing constraints bind only if the student attends a selective university if equation (8) holds:

$$\overline{L} \geq max\{\frac{\beta}{1+\beta}\big[m_s(h_1,\theta)+\tau_s-W\big], \quad \frac{\beta}{1+\beta}\big[m_n(h_1,\theta)+\tau_n-W\big]\} \tag{7}$$

$$\frac{\beta}{1+\beta}\big[m_n(h_1,\theta)+\tau_n-W\big] \leq \overline{L} < \frac{\beta}{1+\beta}\big[m_s(h_1,\theta)+\tau_s-W\big]. \tag{8}$$

Proposition 2. *(i) Suppose equation* (7) *holds. Then,* $v_c^s(h_1, \theta, W) - v_c^n(h_1, \theta, W)$ *decreases by* W *if* $\beta(m_s(h_1, \theta) - m_n(h_1, \theta)) > \tau_s - \tau_n$. *(ii) Suppose equation* (8) *holds. Then,* $v_c^s(h_1, \theta, W) - v_c^n(h_1, \theta, W)$ *increases by* W *if* $W < \overline{W}(h_1, \theta) = m_n(h_1, \theta) + \frac{1}{\beta}(\tau_s - \tau_n) + \beta\tau_s - (1+\beta)\overline{L}$.

Proposition 2 implies the pecuniary benefit of attending selective universities is greater for students with low initial assets W without borrowing constraints, but the reverse can hold if borrowing constraints exist. Because of the diminishing marginal return from consumption, without borrowing constraints, the utility gain associated with higher income from attending selective universities decreases by W (Part (i)).

If borrowing constraints bind for attending selective universities but not for attending nonselective universities, the pecuniary benefit of attending selective universities can increase by W as long as $W < \overline{W}(h_1, \theta)$. Because the loss in utility from consumption driven by borrowing constraints is greater for students who have fewer resources during college (Proposition 1), borrowing constraints have disproportionately greater negative impacts on $v_c^s(h_1, \theta, W)$ of the poor.[20]

In sum, Proposition 2 implies heterogeneous incentives exist for attending selective universities by family income, and borrowing constraints can make attending selective universities more attractive to high-income students. The extent to which borrowing constraints create heterogeneous incentives by family income depends on the extent of borrowing constraints ($\overline{L}$) and the monetary cost of attending selective and nonselective universities (τ_s, τ_n).

4.2 Student's Problem during High School

In this section, I discuss how borrowing constraints affect high school students' college-application and effort choices. During high school, the student first decides how much effort to put into her study (x), and then decides whether to apply to selective universities (I_a). The individual does not consume during high school but needs to pay effort cost $K(x)$. Based on backward induction, I first discuss the student's college application decision conditional on h_1, then discuss how heterogeneous application decisions lead to different effort choices and human capital accumulation during high school. Let $Z_1 = (h_1, \theta, W, \epsilon_\psi)$ be the vector of state variables at the end of high school. Let $V_{na}(Z_1)$ be the value of a student with $Z_1 = (h_1, \theta, W, \epsilon_\psi)$ if the student does not apply to selective

[20] If $W > \overline{W}(h_1, \theta)$, the income effect dominates and the pecuniary benefit of attending selective universities starts to decrease as W increases.

universities:

$$V_{na}(Z_1) = \beta v_c^n(h_1, \theta, W).$$

Let $V_a(Z_1)$ be the value at the end of high school if the student applies to selective universities:

$$V_a(Z_1) = p[\beta v_c^s(h_1, \theta, W) + \beta u_{sel}(h_1, \theta, \epsilon_\psi)] + (1-p)\beta v_c^n(h_1, \theta, W) - \zeta.$$

For a given Z_1, the student applies to selective universities iff $V_a(Z_1) \geq V_{na}(Z_1)$, which is equivalent to

$$v_c^s(h_1, \theta, W) - v_c^n(h_1, \theta, W) \geq \frac{\zeta}{\beta \cdot p} - u_{sel}(h_1, \theta, \epsilon_\psi) \tag{9}$$

The right-hand side of equation (9) does not depend on W, because p and u_{sel} do not change by W conditional on (h_1, θ). From Proposition 2, I can characterize the student's application decision according to the student's initial asset W.

Proposition 3. *(i) Suppose equation* (7) *holds and* $\beta(m_s(h_1, \theta) - m_n(h_1, \theta)) > \tau_s - \tau_n$. *Then, for each* (h_1, θ), *a unique cutoff value* $W^*_{(h_1,\theta)}$ *exists such that* $I_a = 1$ *if* $W < W^*_{(h_1,\theta)}$ *and* $I_a = 0$ *if* $W > W^*_{(h_1,\theta)}$. *(ii) Suppose equation* (8) *holds and* $W < \overline{W}(h_1, \theta)$. *Then, for each* (h_1, θ), *a unique cutoff value* $W^{bc}_{(h_1,\theta)}$ *exists such that* $I_a = 0$ *if* $W < W^{bc}_{(h_1,\theta)}$ *and* $I_a = 1$ *if* $W > W^{bc}_{(h_1,\theta)}$. *(iii)* $W^*_{(h_1,\theta)}$ *decreases by* $(\tau_s - \tau_n)$, *whereas* $W^{bc}_{(h_1,\theta)}$ *increases by* $(\tau_s - \tau_n)$.

Part (i) of Proposition 3 implies that without borrowing constraints, rich students are less likely to apply to selective universities than poor students with the same (h_1, θ), due to the wealth effect. In this case, W cannot explain the positive correlation between family income and application rate for selective universities observed in the data. Without borrowing constraints, a positive correlation between W and θ can instead account for the observed correlation between family income and the application rate to selective universities. Part (ii) of Proposition 3 implies that if borrowing constraints bind for attending selective universities and $W < \overline{W}(h_1, \theta)$, rich students are more likely to apply to selective universities than poor students with the same characteristic (h_1, θ). Thus, binding borrowing constraints for attending selective universities can generate greater positive correlation between family income and the application rate to selective universities. Part (iii) of Proposition 3 implies that if borrowing constraints do not bind, the application rates of high-income students to selective universities increase as $(\tau_s - \tau_n)$ increases. If borrowing constraints bind, the application rates of low-income students to selective universities decrease, which, in turn, widens the gap in the application rates between rich and poor student. In both cases, a larger gap in the cost for attending selective and nonselective universities increases the relative application rates of high-income students to low-income students to selective universities.

Next, the effort choice x depends on the application decision at the end of high school. Let $v_{na}(Z_0)$ be the value of a student of initial characteristic Z_0 at the beginning of high school if the student does not apply to selective universities:

$$v_{na}(Z_0) = \max_x \beta E_{\epsilon_\psi}\Big[V_{na}\big(h_1(Z_0,x),\theta,W,\epsilon_\psi\big)\Big] - K(x).$$

Let $v_a(Z)$ be the value of a student with the initial characteristic Z if the student applies to selective universities:

$$v_a(Z_0) = \max_x E_{\epsilon_\psi}\Big[V_a\big(h_1(Z_0,x),\theta,W,\epsilon_\psi\big)\Big] - K(x) - \zeta.$$

Because the marginal cost of effort $K'(x) = \kappa e^x$ is common to everyone, the heterogeneity in students' effort choice is determined by different marginal returns from effort across students. To illustrate how students' effort choice is associated with application decision, define $\Delta_{MR}(Z,x)$ to be the difference in the marginal benefit of effort between applying and not applying to selective universities conditional on (Z,x):

$$\Delta_{MR}(Z,x) = \underbrace{p\big[\frac{\partial v_c^s}{\partial x} - \frac{\partial v_c^n}{\partial x} + \frac{\partial u_{sel}}{\partial x}\big]}_{(1)} + \underbrace{\frac{\partial p}{\partial x}\big[v_c^s + u_{sel} - v_c^n\big]}_{(2)}. \tag{10}$$

If the admission probability does not depend on x, Part (2) of equation (10) is 0. However, if the admission probability increases by effort level ($\frac{\partial p}{\partial x} > 0$), it provides additional incentive for the applicants to put in extra effort to increase the admission probability. This additional incentive increases as $(v_c^s + u_{sel} - v_c^n)$ increases. Thus, the competitive admission process can boost the effort levels of students who strongly prefer to attend selective universities. As discussed in Proposition 3, low-income students are less likely to apply to selective universities than comparable high-income students when borrowing constraints exist. Such a difference in the application decision for high-quality universities can widen the achievement gap between rich and poor students during high school, because students' incentive substantially depends on whether they apply to selective universities.

4.3 Discussion

First, the prediction in Proposition 3 is consistent with Fact 4 in section 2, which shows a greater difference in costs for attending selective and nonselective universities is associated with a larger gap in the application rates for selective universities between rich and poor students.

Second, the implication of equation (10) is consistent with Fact 2, which shows a strong correlation between students' college-application behavior and their academic choices during high school.

5 Quantitative Framework

5.1 A Life-Cycle Model

In the quantitative analysis, I extend the working period into a lifetime. Individuals live for $t = 0, \cdots, T$. The individual attends a high school in $t = 0$ and attends a college during $t = 1, \cdots, S$. The individual works full time during $t = S+1, \cdots, R-1$, and retires during $t = R, \cdots, T$. Similar to Lochner and Monge-Naranjo [2011], I assume $S = 4$, $R = 65$, and $T = 80$. The individual consumes during the college, working, and retirement periods, $t = 1, \cdots, T$. No uncertainty exists regarding the labor market outcome, and the growth rate of the wage per year is ν during the working period. I assume $1 + r = \frac{1}{\beta}$.

The present value of the lifetime income is $\Phi \cdot m_j$, where $\Phi = \beta^S \left(\frac{1-[\beta(1+\nu)]^{R-S-1}}{1-\beta} \right)$ and m_j is annual income at the beginning of the working period ($t = S + 1$) after graduating from a college of type $j \in \{s, n\}$.

The individual faces borrowing constraints during the college periods but has access to the complete capital market after the college period. At the beginning of the schooling period $t = 1$, students can take out student loans up to $\overline{L}$. I focus on the borrowing limit on the amount of student loans that can be accumulated during the college period $\overline{L}$.

Without borrowing constraints, the problem of a college student whose human capital at the end of high school is h_1 and whose initial wealth is W can be written as

$$\max \sum_{t=1}^{T} \beta^{t-1} u(c_t) + I_s u_{sel} \quad \text{subject to}$$

$$\Omega_1 c_1 + \tau_j \leq W + \Phi m_j(h_1, \theta),$$

where $\Omega_1 = \frac{1-\beta^T}{1-\beta}$. Then, the value from consumption of attending a college of type j in period 1 without borrowing constraints is

$$v_c^{*j}(h_1, \theta, W) = \Omega_1 u\Big[\frac{\Phi m_j(h_1, \theta) + W - \tau_j}{\Omega_1}\Big].$$

When the individual faces binding borrowing constraints,

$$\hat{v}_c^j(h_1, \theta, W) = \Omega_3 u\Big(\frac{W - \tau_j + \overline{L}}{\Omega_3}\Big) + \beta^S \Omega_4 u\Big(\frac{(1+r)^S \Phi m_j(h_1, \theta) - (1+r)^S \overline{L}}{\Omega_4}\Big),$$

where $\Omega_3 = \frac{1-\beta^S}{1-\beta}$ and $\Omega_4 = \big(\frac{1-\beta^{T-S}}{1-\beta}\big)$. Students' problem during high school is identical to the model discussed in the previous section.

5.2 Pre-determined Parameters

Panel A of Table 6 shows pre-determined parameters. The interest rate (r) is set to 0.05, an historical value of the risk-free interest rate. The utility parameter σ is set to 2 so that the intertemporal elasticity of substitution is 0.5, which is within the empirically supported value (Browning et al., 1999). To estimate the initial asset $W = W_p + W_s$, where $W_p = \phi_1 m_p + \phi_2 h_0 + \phi_0$ is parental transfer and W_s is income from self-financing by working during college, I use the National Longitudinal Study of Youth 1997 (NLSY 97). First, I calculate the total amount of parental transfer for college education, and then run an OLS regression of parental transfer on family income and a cognitiv-ability measure (the AFQT score). Because the AFQT score in the NLSY 97 is different from the standardized math score in 10th grade in the ELS 2002 ,which is used as a measure for h_0, I use the percentile score of the AFQT in the regression. For the self-financing, I set $W_s = 16,000$ based on the average labor income of four-year-college attendees during the first four years of college education calculated from the NLSY 97.[21]

[21] From the NLSY 97, I find that students in four-year colleges work, on average, about 800 hours per year during their studies. The wage rates during the college period, however, do not vary significantly by students' ability or

Table 6: Pre-determined Parameters

Panel A: Calibrated Parameters

Parameter	Description	Value
S	Age starting college	19
P	Age starting working	23
R	Age at retirement	65
T	Age at the last period	80
r	Interest rate	0.05
σ	Utility parameter	2
$\overline{L}$	Fixed borrowing constraint	46,000
$\overline{H}$	Annual working hours	2,000
ν	Growth rate of the wage	0.03
W_s	Self-financing during college	16,000

Panel B: First-Stage Estimation

Dependent var.	Independent var.	Parameter	Estimates	Standard Error
parental transfer	constant	ϕ_0	-6,486	(1,767)
	family income	ϕ_1	0.173	(0.0164)
	ability (h_0)	ϕ_2	197.0	(24.07)
g_n	constant	δ_{n0}	-2,313	(702.6)
	m_p	δ_{n1}	-0.00343	(0.00215)
	h_1	δ_{n2}	2.755	(0.570)
	t_n	δ_{n3}	0.423	(0.0457)
g_s	constant	δ_{s0}	324.8	(1,379)
	m_p	δ_{s1}	-0.0941	(0.00568)
	t_s	δ_{s2}	0.317	(0.0552)

Note: The table summarizes the calibrated parameters (Panel A) and the first-stage estimation for the parental transfer and grants (Panel B).

The fixed borrowing limit $\overline{L}$ is set to be \$46,000. In 2004, the cumulative borrowing limits for federal loans to dependent undergraduate students were \$23,000. Given the lack of data for private loans, I assume the limit for the private and the government loan is the same, similar to Abbott et al. [2019]), which implies $\overline{L} = \$46,000$.

Grants from selective (g_s) and nonselective (g_n) universities are also estimated in the first stage. The grants from selective and nonselective universities are estimated from two data sources. First, the ELS 2002 collects information on the fraction of the total cost of attending a college that is covered by grants. Second, the IPEDS 2004 has information on tuition and fees for each institution.

family income. For this reason, I use the average labor earnings for W_s.

By matching two data sets, I regress the amount of grants based on equations (11) and (12):

$$g_n = \delta_{n0} + \delta_{n1} m_p + \delta_{n2} h_1 + \delta_{n3} t_n, \tag{11}$$

$$g_s = \delta_{s0} + \delta_{s1} m_p + \delta_{n3} t_s. \tag{12}$$

I assume grants from selective universities (g_s) are need based, and thus depend only on family income (m_p), whereas grants from nonselective universities (g_n) have both need- and merit-based aid, and thus depend on both family income (m_p) and high school human capital (h_1).[22] t_s and t_n are the state average sticker price for attending selective and nonselective universities.[23] The OLS estimates show selective universities have more need-based aid than nonselective universities (δ_{n1}=-0.0034 and δ_{s1}=-0.094). On the other hand, the student's high school achievement score ($\delta_{n2} = 2.755$) is a significant factor determining the amount of grants from nonselective universities.

5.3 Identification

Seven structural components exist $\{\hat{\theta}, \hat{\alpha}_{h_1}, \hat{\alpha}_{h_2} \hat{\pi}, \hat{\psi}, \kappa, \zeta\}$, where $\hat{\theta} = (\lambda, \sigma_\theta)$ is the vector of parameters that determines the distribution of the unobservable characteristic θ, $\alpha_{h_1} = (\alpha_1, \alpha_2, \gamma_0)$ is the vector of parameters that determines human capital accumulation during high school, $\alpha_{h_2} = (\alpha_3, \alpha_4, \gamma_1)$ is the vector of parameters that determines hourly wage after college graduation, $\hat{\pi} = (\pi_1, \pi_2, s^*)$ is the vector of parameters that determines the admission criteria for selective universities, $\hat{\psi} = (\psi_0, \psi_1, \psi_2, \sigma_\psi)$ is the vector of parameters that determines the nonpecuniary benefit of attending selective universities, κ is the parameter that determines the marginal cost of effort, and ζ is the utility cost of applying to selective universities.

Because W increases by m_p, borrowing constraints do not bind if m_p is large enough. Thus, conditional on high school achievement and college selectivity (h_1, I_a), the wage distribution of high-income students can identify the distribution of unobservable characteristics $\hat{\theta}$. In particular, the correlation between wage and family income among high-income students identifies λ, whereas the variance of the wage rates identifies σ_θ. Once $\hat{\theta}$ is identified, parameters that determine the wage structure (α_3, α_4) can be identified from the correlation between (h_1, I_a) with the wage rate h_2 conditional on m_p. Similarly, for a given $\hat{\theta}$, (π_1, π_2) can be identified from the correlation between

[22] In the ELS 2002, I find selective universities mostly award grants based on financial need, whereas less selective universities also provide merit-based aid.

[23] If the state does not have selective universities, I use national average for t_s.

(h_1, m_p) and whether the student attends selective universities I_a. The constant terms γ_1 and s^* can be identified from the mean of h_2 and I_a.

Once $\hat{\theta}$, $\hat{\alpha}_{h_2}$, and $\hat{\pi}$ are identified, the pecuniary benefit of attending selective universities is known conditional on high school achievement, family income, and net costs for selective and nonselective euniversities. However, students' application decision regarding selective universities cannot be fully rationalized by the pecuniary benefit. Thus, for a given application cost ζ, the parameters associated with the nonpecuniary benefit of attending selective universities ($\hat{\psi}$) are identified from the application rate for selective universities. Specifically, ψ_0 is identified from the application rate for selective universities of the sample population, whereas ψ_1 (ψ_2) is identified from the application rate conditional on the high school test score (family income). σ_ψ is identified from the variation in the application behaviors among students with the same characteristics.

Next, I can identify the utility cost of applying to selective universities ζ, because ζ changes the application behavior of students regardless of the admission probability, whereas the extent to which $\hat{\psi}$ affects the student's application behavior depends on the admission probability. For instance, consider students who have the highest high school test scores. The admission probability into selective universities for those students is approximately 1. Thus, I can pin down ζ that matches the average application rate of students whose admission probability into selective universities is 1.

The remaining parameters are $\hat{\alpha}_{h_1} = (\alpha_1, \alpha_2, \gamma_0)$ and κ. Suppose the effort choice x is not observable in the data.[24] Then separately identifying α_2 (the marginal productivity of x in human capital accumulation during high school) and κ (the marginal utility cost of effort) without additional variation in the data is difficult. To address this issue, I use the geographic variations in the cost of attending selective and nonselective universities as an exogenous source that changes students' effort choice x. As shown in Proposition 3, the relative costs for attending selective and nonselective universities ($\tau_s - \tau_n$) can generate variations in the effort choice x conditional on the student's observable characteristic (h_0, m_p). Thus, for a given $\hat{\alpha}_{h_1} = (\alpha_1, \alpha_2, \gamma_0)$, different SAT scores among students with the same (h_0, m_p) who live in different states (which have different $(\tau_s - \tau_n)$) can identify κ. Finally, for a given γ_0, the variance in the high school achievement score (h_1) within a state (which has the same $(\tau_s - \tau_n)$) identifies α_2. The constant term γ_0 is identified from the population mean of h_1, and α_1 can be identified from the correlation between the SAT score (h_1) and the 10th grade math score (h_0) conditional on m_p and $(\tau_s - \tau_n)$.

[24] See section 3.1.2. for the discussion on why I do not use a particular academic choice variable in the data as an effort measure in the estimation.

5.4 Estimation

Table 7: Moment Conditions

Description	Moment Conditions
Mean of outcome variables	$\frac{1}{N}\sum h_1$
	$\frac{1}{N}\sum I_a$
	$\frac{1}{N}\sum I_s$
	$\frac{1}{N}\sum h_2$
Ability × outcome variables	$\frac{1}{N}\sum(h_1 \cdot h_0)$
	$\frac{1}{N}\sum(I_a \cdot h_0)$
	$\frac{1}{N}\sum(I_s \cdot h_0)$
	$\frac{1}{N}\sum(h_2 \cdot h_0)$
Family income × outcome variables	$\frac{1}{N}\sum(h_1 \cdot m_p)$
	$\frac{1}{N}\sum(I_a \cdot m_p)$
	$\frac{1}{N}\sum(I_s \cdot m_p)$
	$\frac{1}{N}\sum(h_2 \cdot m_p)$
Sticker price for NU × outcome variables	$\frac{1}{N}\sum(h_1 \cdot t_n)$
	$\frac{1}{N}\sum I_a \cdot t_n)$
	$\frac{1}{N}\sum(I_s \cdot t_n)$
	$\frac{1}{N}\sum(h_2 \cdot t_n)$
Sticker price for SU × outcome variables	$\frac{1}{N}\sum(h_1 \cdot t_s)$
	$\frac{1}{N}\sum I_a \cdot t_s)$
	$\frac{1}{N}\sum(I_s \cdot t_s)$
	$\frac{1}{N}\sum(h_2 \cdot t_s)$
Application/Attendance rate to SU × variables	$\frac{1}{n}\sum(h_1 \cdot I_a)$
	$\frac{1}{n}\sum(h_1 \cdot I_s)$
	$\frac{1}{n}\sum(h_2 \cdot I_a)$
	$\frac{1}{n}\sum(h_2 \cdot I_s)$
	$\frac{1}{N}\sum(I_s \cdot I_a)$
Dummy F5Q × outcome variables	$\frac{1}{N}\sum(h_1 \cdot I_{F5Q})$
	$\frac{1}{N}\sum I_a \cdot I_{F5Q})$
	$\frac{1}{N}\sum(I_s \cdot I_{F5Q})$
	$\frac{1}{N}\sum(h_2 \cdot I_{F5Q})$
Square of wage rates	$\frac{1}{N}\sum(h_2^2)$

Note: The table shows the moment conditions for the methods of simulated moments estimation. SU (NU) refers to selective (nonselective) universities. I_{F5Q} refers to a dummy variable for students from the top quintile of the family income distribution.

The 11 parameters are estimated based on the methods of simulated moments. I have 30 target moments listed in Table 7. The selection of the moments is based on the identification argument. The simulated model generates four outcome variables: high school achievement score (h_1), whether the student applies to selective universities (I_a), whether the student attends a selective university (I_s), and the wage rate after college graduation (h_2). First, I match the mean value of four outcome variables of the model to the data. I also match the interaction between those outcome variables with the student's ability, family income, and the state-specific sticker price for attending selective and nonselective universities, which adds 16 moment conditions. I add five moment conditions based on the correlation between I_a and I_s, high school achievement (h_1), and the wage (h_2). I add four moment conditions based on the average outcomes of students from the top quintile of the family income distribution, which is based on the identification argument that borrowing constraints are not likely to bind for the richest students. Finally, I add the square of the wage to identify the standard error of the unobservable characteristic.

6 Results

6.1 Estimates

Figure 4 shows how the model simulation fits the data. The model fits family income and ability gradients of high school achievement and application/attendance rate to selective universities reasonably well.

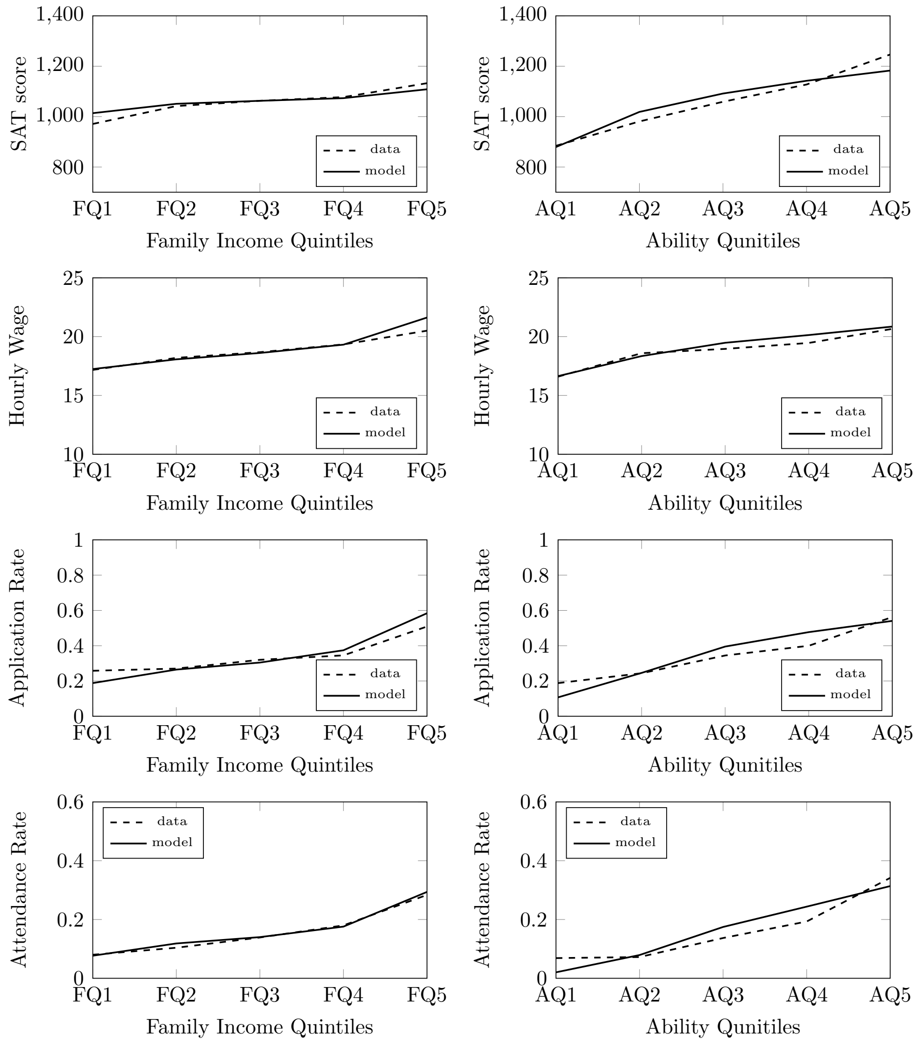
Table 8 shows the estimation results from the method of simulated moments. Regarding human capital accumulation during high school, both initial academic achievement h_0 ($\alpha_1 = 0.118$) and effort ($\alpha_2 = 0.041$) are significant determinants of high school achievement. Thus, not only the earlier academic preparation level but also students' effort during high school affects students' human capital accumulation during high school.

The unobservable characteristic θ significantly increases by family income. The mean of the distribution of log of θ (μ_θ) increases by 0.011 as family income increases by 10,000 USD (ϕ_1=1.1e-06). Because σ_θ is estimated at 2.2e-06, an increase in family income by 10,000 USD corresponds to a 0.5-standard-deviations higher value in ϵ_θ. Thus, family income largely accounts for variations in the unobservable characteristic across students.

The probability of admission to selective universities significantly depends on high school achievement ($\pi_1 = 0.0047$) and unobservable characteristics ($\pi_2 = 1.535$). Although a student's high school achievement explains most of the variations in the college-admission result, an unobservable characteristic associated with family background also explains significant part of the college-admission process in the US., which is consistent with Arcidiacono et al. [2019].

The wage significantly depends on high school achievement ($\alpha_3 = 0.532$), college selectivity ($\alpha_4 = 0.109$), and unobservable characteristic θ. The result suggests that after controlling for unobservable characteristics θ, attending selective universities still increases the wage rate by 10.9%. This estimate is much greater than Dale and Krueger [2002] and Arcidiacono [2005], who find

Figure 4: Model Fit



Note: The graph shows model predictions with respect to family income and ability quintiles.

insignificant estimates for the returns to the quality of college on labor earnings after controlling for unobservable characteristics, and is smaller than Hoekstra [2009], who finds a 20% wage premium for white men if they attend a state flagship university. Two important differences are worth noting to understand the different findings across studies. First, whereas Dale and Krueger [2002] and Arcidiacono [2005] use the average SAT score of attendees in each university, which is continuous, as a measure for the quality of college, this paper and Hoekstra [2009] use a discrete measure for the quality of college, focusing on a specific margin that leads to sufficiently different characteristics between the high-type and the low-type colleges in the data. Thus, different measures for the quality of college can partially explain the different estimation results.[25] Second, the sample in

[25]The estimation in the formal approach (Dale and Krueger [2002], Arcidiacono [2005]) is based on the assumption

Table 8: Parameter Estimates

Parameter	Estimate	Standard Error
α_1	0.118	(0.017)
α_2	0.041	(0.022)
γ_0	6.642	(0.081)
α_3	0.532	(0.006)
α_4	0.109	(0.053)
γ_1	-0.902	(0.011)
s^*	5.825	(0.526)
π_1	0.0047	(0.0006)
π_2	1.535	(0.553)
κ	2.534e-04	(6.41e-05)
ψ_0	6.536e-04	(2.089e-04)
ψ_1	2.651e-07	(1.925e-07)
ψ_2	1.774e-04	(6.384e-03)
σ_ψ	9.599e-04	(6.504e-04)
ζ	7.474e-05	(3.730e-05)
λ	1.1e-06	(4.74e-07)
σ_θ	2.2e-06	(6.80e-07)

Note: The table shows the estimates from the methods of simulated moment estimation.

Dale and Krueger [2002] and Arcidiacono [2005] enter colleges in the 1970s, whereas the sample in this paper enters colleges in 2002.[26] Thus, the cohort difference might be also relevant to explaining the difference in the estimate.

Finally, the nonpecuniary benefit of attending selective universities is significantly positive (ψ_0=6.536e-04), but application also incurs a nontrivial utility cost (ζ=7.474e-05).

6.2 Borrowing Constraints and Equilibrium

In this section, I quantify the impact of borrowing constraints by comparing the equilibrium outcomes of the baseline simulation with those from the counterfactual simulation without borrowing constraints.

Table 9 summarizes the results. First, Panel A of Table 9 shows borrowing constraints lower the average SAT score by 21 points, from 1,085 to 1064, which implies a \$387 reduction in the average annual income. Second, the gap in the application rate for selective universities between students from the top and bottom quintile of the family income distribution (the rich and poor students, respectively) decreases by 19.7 percentage point (50% of the baseline gap) without borrowing

that the marginal effect of the average SAT score of peers on individuals' earning outcomes is constant regardless of the level of SAT score, whereas the estimation result in this paper depends on the definition of the quality of college. In Appendix, I discuss the robustness of the findings by changing the definition of selective universities.

[26] Hoekstra [2009] uses the sample who enter colleges during 1986 and 1989.

Table 9: Impact of Borrowing Constraints

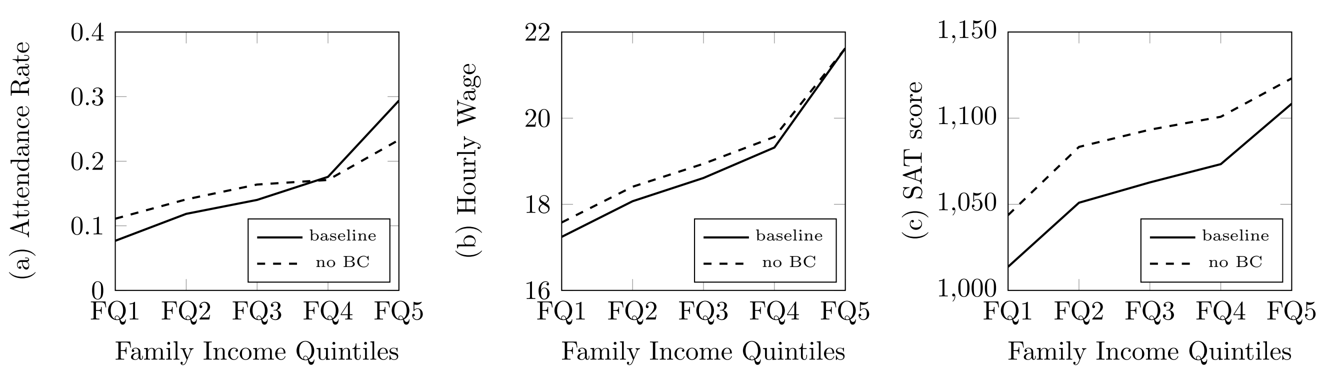
Panel A: Average Outcomes			
	SAT score	Income	
Baseline	1,064	38,153	
Without borrowing constraints	1,085	38,540	
Panel B: Gap between Rich and Poor Students			
	Baseline	Without BC	Difference (%)
Δ SAT score	95	79	16 (17%)
Δ Income	8,762	8,090	671 (8%)
Δ Effort	0.095	0.066	0.029 (30%)
Δ Application	0.396	0.199	0.197 (50%)
Δ Attendance	0.217	0.122	0.095 (44%)

Note: The table summarizes the impacts of borrowing constraints on average level of SAT and annual income (Panel A) and the gap between rich and poor students in various outcomes (Panel B). Rich and poor students refer to students from the top (the bottom) qunitile of the family income distribution. Δ refers to the difference between rich and poor students.

constraints. Third, without borrowing constraints, the effort gap between rich and poor students decreases by 30%, which, in turn, reduces the gap in the SAT score between rich and poor students by 17%, from 95 points in the baseline model to 79 points. Accordingly, the gap in annual income between rich and poor students would decrease by $671 (8%).

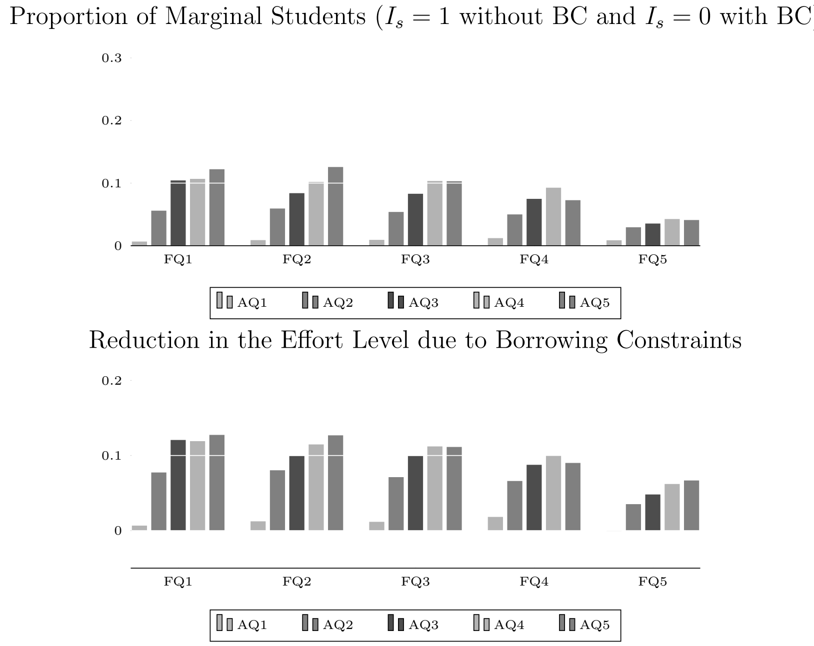
Figure 5 shows how high school achievement, hourly wage, and attendance rate into selective universities change once I relax borrowing constraints. First, relaxing borrowing constraints reduces the positive correlation between family income and the attendance rates for selective universities (Figure 4 (a)). In particular, the number of high-income students who can attend selective univer-

Figure 5: Counterfactual: No Borrowing Constraints



Note: The graph shows model predictions with respect to family income and ability quintiles.

Figure 6: Impacts of Borrowing Constraints on College Selectivity/Choices of High School Students



Note: The top panel of the graph shows the proportion of students who change their application decision due to borrowing constraints (BC), that is, the proportion of students who choose $I_a = 0$ in the baseline simulation but choose $I_a = 1$ in the counterfactual simulation without borrowing constraints. The bottom panel shows the difference in students' effort level between the baseline simulation and the counterfactual simulation without borrowing constraints.

sities decreases substantially once I relax borrowing constraints. However, it does not decrease the average wage of high-income students (Figure 4(b)). Although high-income students are not directly affected by borrowing constraints, relaxing borrowing constraints can boost their effort level due to the elevated competition in the college-admission process. Because high-income students have higher achievement score without borrowing constraints (Figure 4(c)), they can compensate for the wage loss associated with lower attendance rates into selective universities. In sum, borrowing constraints not only widen the achievement gap between rich and poor students, but can also reduce the overall achievement level at all income levels.

Figure 6 further shows the heterogeneous effects of borrowing constraints on high school students' attendance rate to selective universities and their effort levels by family income and ability. The top panel shows the proportion of marginal students who attend nonselective universities in the baseline model, but would attend selective universities without borrowing constraints. The number of those marginal students decreases by family income and increases by ability.[27] The bottom panel

[27] If I do not allow different parental transfer by student's ability, the proportion of the marginal students discussed in Figure 6 change more drastically according to family income and ability. Thus, not accounting for the heterogeneous

in Figure 6 shows a reduction in the effort level due to borrowing constraints. Most students reduce effort due to borrowing constraints. The negative impact of borrowing constraints on students' effort choice increases by students' ability and decreases by family income.

6.3 Counterfactual Policy Experiments

In this section, I compare two types of financial aid policies from selective universities: need-based grants and merit-based grants. By focusing on financial aid from selective universities, I can examine the incentive aspect of need-based aid if students compete for admission.

To evaluate the effect, I simulate a counterfactual economy in which selective universities increase grants to students from the lowest quintile of the family income distribution by \$2,600 per year. This amount is from the 2018-2019 Pell Grant payment schedule, the difference between the estimated cost of attendance and the Pell Grant awarded to students whose expected family contribution belongs to the median across all eligible students. For merit-based aid, I increase the amount of grants for each SAT score awarded to selective-university attendees by \$20 per an additional point, while keeping the total budget spending the same as in the need-based-aid case. I adjust the admission-cutoff value to keep the number of selective-university attendees the same as in the baseline simulation.

Table 10 summarizes the results. In the first column of Panel A, I find that increasing need-based aid by \$2,600 per year reduces the gap between students from the top and bottom quintile of the family income distribution (the rich and poor students, respectively) in their average SAT score by 16.3% (15 points) and in their annual income after college graduation by 6.6% (\$576). As shown in the first column of Panel B, the average achievement score and wage rate remain almost the same as in the baseline model (\$38,153 in the baseline and \$38,266 with additional need-based aid).

The first column of Panel B shows the proportion of students whose income increases once selective universities increase need-based aid. I find 64% of low-income students would have higher incomes, whereas 27% of students from the top quintile of the family income distribution would have higher incomes. For high-income students, borrowing constraints are less likely to be binding. The fact that need-based aid can increase high-income students' income shows strategic interaction between high school students.

parental transfer by student ability would overstate the impact of borrowing constraints on students' sorting into high-quality colleges and their effort choices during high school.

Table 10: Counterfactual Policy Experiment: Need- vs. Merit-based Aid from Selective Univ.

Panel A: Changes in the Gap between Rich and Poor Students	(1) Need-based	(2) Merit-based
Change in annual income gap	-$576	-$136
	(-6.6%)	(-1.5%)
Change in SAT score gap	-15	-1
	(-16.3%)	(-1.2%)
Change in effort gap	-0.039	0.008
	(-40.6%)	(+8.9%)
Change in application rate gap	-0.17	-0.05
	(-43.9%)	(-13.4%)
Change in attendance rate gap	-0.07	-0.03
	(-31.9%)	(-12.4%)
Panel B: Proportion of Students with a Higher Income after the Policy		
Lowest income quintile	64%	28%
Highest income quintile	27%	67%
Panel C: Average Outcomes		
Average wage rate	38,266	38,297
Average SAT score	1,067	1,068

Note. The table summarizes the counterfactual policy experiments on need- and merit-based from selective universities. For need-based aid, I simulate a counterfactual economy in which selective universities increase grants to students from the lowest quintile of the family income distribution by $2,600 per year. For merit-based aid, I increase the amount of grants for each SAT score awarded to selective-university attendees by $20 per an additional point, while keeping the total budget spending the same as in the need-based-aid case. I adjust the admission-cutoff value to keep the number of selective-university attendees the same as in the baseline simulation.

Increasing merit-based aid from selective universities has a much smaller impact on the achievement gap between rich and poor students. In the second column of Panel A, I show additional merit-based aid reduces the achievement gap by 1.2% and the gap in the annual income by 1.5% ($136). Merit-based aid also affects the strategic interaction among students such that not only would 28% of low-income students earn higher income, but 67% of high-income students would also earn more once merit-based aid from selective universities is increased (Panel B).

Interestingly, need-based aid and merit-based aid have similar impacts on the aggregate achievement level if the aid comes from selective universities (Panel C). By targeting those low-income high-ability students, need-based aid from selective universities can effectively relax the borrowing constraints and boost the effort level of students with greater academic potential without borrowing constraints. Because the effort increase from those low-income high-ability students is large, need-based aid from selective universities can induce aggregate achievement as high as that induced by merit-based aid.

6.4 Trends in Tuition, Grants, and High School Achievement

Figure 7 shows how tuition and grants of selective and nonselective universities changed during 2004 and 2014. Tuition is measured by annual tuition and fees, and costs for books and supplies of all four-year institutions in IPES 2004-2014. Selective universities are defined as colleges in the top two categories of Barron's index in 2004. Grants is the sum of average federal grants and institutional grants. I use the CPI index to adjust the inflation rate. Along with an overall tuition increase, the average sticker price of attending selective universities becomes relatively more expensive than attending nonselective universities. The gap in tuition between selective and nonselective universities increased by 38% from $8,580 to $11,830. However, grants also increased more in selective universities. The gap in grants from selective and nonselective universities doubled from $3,790 to $7.850.[28] In this section, I discuss respective roles of changes in tuition, grants, and borrowing limits in explaining students' sorting into high-quality universities.

The bottom panel of Figure 7 shows the share of low-income students and the SAT score in selective and nonselective universities. First, consistent with previous studies (Kinsler and Pavan [2011] and Chetty et al. [2017], the share of low-income students, as measured by the proportion of students who receive federal Pell Grants, in selective universities increased slightly (3%) over time. The share of low-income students increased much more in nonselective universities, reflecting the expansion of college education. Second, the SAT score in selective universities increased by 29 points (0.25 standard deviation), whereas it decreased by 16 points (0.14 standard deviation) in nonselective universities between 2004 and 2014.[29] Because the model abstracts from the college enrollment decision, which is an important margin when discussing the characteristics of students in nonselective universities, I focus on students' characteristics in selective universities in the following discussion.[30]

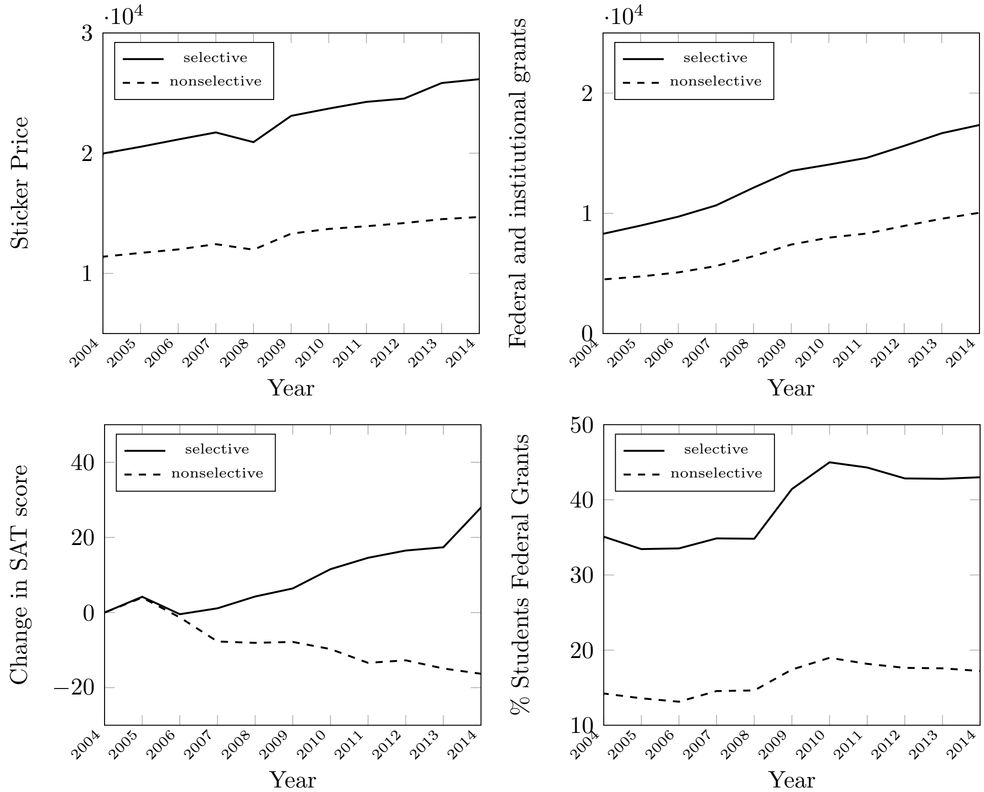
Row A of Table 11 documents changes in the SAT score of all four-year college students, the SAT score of students in selective universities, and the proportion of low-income students in selective

[28]To construct comparable data for tuition and grants during 2004-2014, I get the average values across all four-year institutions observed in the IPEDS. This is slightly different from the tuition measure used in the main analysis (sections 2 and 5). Grants are the sum of federal and institutional grants per student. I use the average grants amount and the proportion of students who receive grants to calculate the per-student value. Tuition for selective universities increased by 35% from $19,970 to $26,970, whereas tuition for nonselective universities increased by 33% from $11,390 to $15,140. Grants increased from $4,500 to $10,450 in nonselective universities, whereas it increased from $8,290 to $18,300 in selective universities.

[29]Data are from IPED 2004-2014. To get the SAT score for each institution, I first get the mean value of the 25th and 75th percentile of the SAT score for math and verbal subject, and then I add the math and verbal SAT score.

[30]For instance, without accounting for the increase in four-year college students who have relatively low SAT scores, the model cannot explain the large decrease in the average SAT score between 2004 and 2014 (Table 11).

Figure 7: Trends in Tuition, Grants, and Student Sorting



Note: The graph shows the trend in the sticker price, average grants (federal and institutional), the SAT score, and the percentage share of attendees who receive federal Pell grants for selective and nonselective universities during 2004 and 2014. Data are from the IPEDS 2004-2014.

universities as measured by the share of students who receive federal Pell Grants.[31] I consider the following counterfactual experiments. First, to evaluate the impacts of increasing tuition over time, I use the 2014 data for the average tuition for selective and nonselective universities, while keeping all other parameters as in the baseline simulation that uses the 2004 data (row A). Second, to account for the increase in the borrowing limits for the government student loans in 2008, I additionally increase the borrowing limit $\overline{L}$ by \$16,000 (row B).[32] Third, I use the 2014 data tuition, borrowing limits, and grants (row C).[33]

If I only change the tuition level as in the 2014 data, the aggregate SAT score reduces by 28 points (Column (1), row A) and the SAT score among selective-university attendees reduces by 7.8 points

[31]Due to the lack of data in 2014 on family income of selective-university attendees, I use the share of Pell Grant recipients in the IPEDS 2014 as a proxy for the share of low-income students.

[32]The loan limits for the government student loans increased from \$23,000 to \$31,000 in 2008. Keeping the assumption the same on borrowing limit for government and private loans, I raise $\overline{L}$ to \$62,000.

[33]Because I do not have information on how grants are allocated across students outside of my sample from ELS 2002, I keep the estimates for grants g_n, g_s as in the baseline model and scale the amount by a constant for all individuals to match the average level.

Table 11: Counterfactual Experiments: Trend on Tuition, Grants, and SAT Score

	SAT score		% Low-income students in selective Univ.
	All	Selective univ.	
	(1)	(2)	(3)
(A) Changes in the Data	-16	29	3
(B) Tuition	-28.0	-107.8	0.4
(C) Tuition + $\overline{L}$	-14.6	-27.8	2.5
(D) Tuition + Grants + $\overline{L}$	17.8	3.2	2.9
(E) (D) + ψ_0	33.9	12.7	2.7

Note: The table shows the change in the SAT score of all four-year college students (column (1)), the SAT score of selective-university attendees (column (2)), and the share of low-income students in selective universities between 2004 and 2014. Data are from 2004 and 2014 IPEDS. The detail of each counterfactual analysis can be found in the main text.

(column (2), row A). Increasing the borrowing limits (row B) can raises the aggregate SAT score by 6.8 points and the SAT score of selective-university attendees by 80 points compared to the case that only increases tuition (row A). Consistent with section 6.2, relaxing borrowing constraints can boost overall high school achievement. Relaxing borrowing constraints also raises the SAT score of selective-university attendees, because the elevated competition not only raises the admission cutoff value for selective universities but also boosts the effort level of the high school students, especially among high-ability students who are at the margin of applying/attending selective universities.

Next, once I use the 2014 values for grants in addition to tuition and borrowing limits (row C), the aggregate SAT score further increases by 32.4 ($17.8 + 14.6$) points, and the SAT score among selective-university attendees increases by 30.3 ($3.2 + 27.8$) points compared to the counterfactual simulation whereby I only change tuition and borrowing constraints in row B. First, more grants from selective and nonselective universities further relaxes borrowing constraints. Second, by reducing the gap in the direct cost to attend selective and nonselective universities, the changes in grants further increase the overall application rates to selective universities, elevates the competition in the college-admission process, and boosts the effort level of a larger number of high school students. The results in row B and C suggest financial aid policies play an important role in determining overall high school achievement and the quality of students in high-quality universities.

The trend inn tuition, grants, and borrowing limits are not sufficient to explain a large increase in SAT scores among selective-university attendees observed in the data (29 points). Increased competition in the college-admission process can be related. Based on IPEDS, I find the average number of applicants to selective universities increased by 74% from 9,230 students in 2004 to 16,090 students in 2014, whereas the share of admitted students among applicants decreased from 44% to 33%. Changes in the nonpecuniary benefit of attending selective universities can increase the number of applicants and the competitiveness in the admission process for selective universities, independent of changes in tuition, grants, and borrowing limits. In row D, I increase the nonpecuniary benefit and examine how much it can further explain the increase in the SAT score among attendees in selective universities. In particular, I increase the value of ψ_0 by doubling the baseline estimate, while using 2014 data for tuition, borrowing constraints, and grants. Doing so increases the SAT score of selective-university attendees by 12.7 points, which explains about a 44% increase in the SAT score of selective-university attendees.[34]

Finally, column (3) of Table 11 shows how the share of students from the lowest qunitile of the family income distribution in selective universities changes as I update tuition, borrowing limits, and grants data for 2014 values. The model can explain a moderate increase in the share of low-income students in high-quality universities. I add to the literature by showing the trends in tuition, grant, and borrowing limits not only affect the share of low-income students in high-quality universities, but also affect high school students' academic achievement. Without the rapid increase in grants amounts from selective universities, the overall high school achievement as well as the academic quality of selective-university attendees in recent years would have been substantially lower than the data, due to the large increase in tuition for both selective and nonselective universities.

7 Conclusion

I examine how the competitive admission process for selective universities and borrowing constraints affect the achievement gap between rich and poor students. Borrowing constraints substantially magnify the achievement gap, especially when students compete for limited seats in high-quality universities. Additional need-based aid from selective universities for low-income students can not only reduce the achievement gap between rich and poor, but also increase the achievement level of all high-ability students. I also find need-based aid can close the achievement gap better than merit-based aid, while keeping the aggregate achievement level of the entire population almost the same.

[34] Compared with the data, the counterfactual analysis accounting for the change in tuition, grants, and borrowing constraints predicts substantially higher aggregate SAT scores than the data. As discussed before, this is related to the increasing number of low-ability students in four-year colleges during this period.

Appendix

A Proof of Propositions

A.1 Proof of Proposition 1

For given (h_1, θ, W), let $\Delta v_c^j(h_1, \theta, W) = v_c^{*j}(h_1, \theta, W) - \hat{v}_c^j(h_1, \theta, W)$ be the loss in the value from consumption of a student with (h_1, W) when borrowing constraints bind and the student attending a college of type $j \in \{s, n\}$. From equations (5) and (6), I have

$$\Delta v_c^j(h_1, \theta, W) = (1+\beta)u(\frac{W - \tau_j + \beta m_j(h_1, \theta)}{1+\beta}) - u(W - \tau_j + \overline{L}) - \beta u(m_j(h_1, \theta) - (1+r)\overline{L}).$$

When the borrowing constraints bind, the individual consumes less than the optimal amount during the college period and consumes more than the optimal amount after the college period, which implies $\frac{W - \tau_j + \beta m_j(h_1, \theta)}{1+\beta} < m_j(h_1, \theta) - (1+r)\overline{L}$. As $u'' < 0$, I have

$$\frac{\partial \Delta v_c^j(h_1, \theta, W)}{\partial m_j} = \beta u'(\frac{W - \tau_j + \beta m_j(h_1)}{1+\beta}) - \beta u'(m_j(h_1, \theta) - (1+r)\overline{L}) > 0. \tag{13}$$

Similarly, I have

$$\frac{\partial \Delta v_c^j(h_1, \theta, W)}{\partial \tau_j} = -u'(\frac{W - \tau_j + \beta m_j(h_1, \theta)}{1+\beta}) + u'(W - \tau_j + \overline{L}) > 0. \tag{14}$$

For a given (h_1, θ), $m_s(h_1, \theta) > m_n(h_1, \theta)$ always holds. If $\tau_s \geq \tau_n$ also holds, then from (13) and (14), I have

$$\Delta v_c^s(h_1, \theta, W) = (1+\beta)u(\frac{W - \tau_s + \beta m_s(h_1, \theta)}{1+\beta}) - u(W - \tau_s + \overline{L}) - \beta u(m_s(h_1, \theta) - (1+r)\overline{L}) >$$
$$(1+\beta)u(\frac{W - \tau_s + \beta m_n(h_1, \theta)}{1+\beta}) - u(W - \tau_s + \overline{L}) - \beta u(m_n(h_1, \theta) - (1+r)\overline{L}) \geq$$
$$(1+\beta)u(\frac{W - \tau_n + \beta m_n(h_1, \theta)}{1+\beta}) - u(W - \tau_n + \overline{L}) - \beta u(m_n(h_1, \theta) - (1+r)\overline{L}) = \Delta v_c^n(h_1, \theta, W),$$

which proves part (i) of Proposition 1. Next, it is straightforward to show that

$$\frac{\partial \Delta v_c^j(h_1, \theta, W)}{\partial W} = u'(\frac{W - \tau_j + \beta m_j(h_1, \theta)}{1+\beta}) - u'(W - \tau_j + \overline{L}) < 0.$$

for a given $(m_j(h_1,\theta),\tau_j)$ $(j \in \{s,n\})$, which proves the part (ii) of the Proposition 1.

A.2 Proof of Proposition 2

Suppose $\overline{L} \geq \frac{\beta}{1+\beta}\big[m_j(h_1,\theta)+\tau_j-W\big]$. Then, from (4), the borrowing constraints do not bind if the student attends a college of type $j \in \{s,n\}$. Thus, if $\overline{L} \geq max\{\frac{\beta}{1+\beta}\big[m_s(h_1,\theta)+\tau_s-W\big], \frac{\beta}{1+\beta}\big[m_n(h_1,\theta)+\tau_n-W\big]\}$, the borrowing constraints do not bind regardless of which type of college the student attends. In this case,

$$v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W)=(1+\beta)u\Big(\frac{W-\tau_s+\beta m_s(h_1,\theta)}{1+\beta}\Big)-(1+\beta)u\Big(\frac{W-\tau_n+\beta m_n(h_1,\theta)}{1+\beta}\Big).$$

If $\beta(m_s(h_1,\theta)-m_n(h_1,\theta))>\tau_s-\tau_n$, I have

$$\frac{\partial(v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W))}{\partial W}=u'\Big(\frac{W-\tau_s+\beta m_s(h_1,\theta)}{1+\beta}\Big)-u'\Big(\frac{W-\tau_n+\beta m_n(h_1,\theta)}{1+\beta}\Big)<0,$$

which proves part (i) of the Proposition 2. Next, suppose $\frac{\beta}{1+\beta}\big[m_n(h_1,\theta)+\tau_n-W\big] \leq \overline{L} < \frac{\beta}{1+\beta}\big[m_s(h_1,\theta)+\tau_s-W\big]$ so that the borrowing constraints bind if the student attends a selective university, but do not bind if the student attends a nonselective university. Then,

$$v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W)=u(W-\tau_s+\overline{L})+\beta u(m_s(h_1,\theta)-(1+r)\overline{L})-(1+\beta)u\Big(\frac{W-\tau_n+\beta m_n(h_1,\theta)}{1+\beta}\Big),$$

which implies

$$\frac{\partial(v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W))}{\partial W}=u'(W-\tau_s+\overline{L})-u'\Big(\frac{W-\tau_n+\beta m_n(h_1,\theta)}{1+\beta}\Big).$$

Therefore, $\frac{\partial(v_c^s(h_1,W)-v_c^n(h_1,W))}{\partial W}>0$ iff

$$W-\tau_s+\overline{L}<\frac{W-\tau_n+\beta m_n(h_1,\theta)}{1+\beta}.$$

For a given (h_1,θ), let $\overline{W}(h_1,\theta)=m_n(h_1,\theta)+\frac{1}{\beta}(\tau_s-\tau_n)+\tau_s-\frac{1+\beta}{\beta}\overline{L}$. Then, $\frac{\partial(v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W))}{\partial W}<0$ if $W>\overline{W}(h_1,\theta)$ and $\frac{\partial(v_c^s(h_1,\theta,W)-v_c^n(h_1,\theta,W))}{\partial W}>0$ if $W\leq\overline{W}(h_1,\theta)$, which proves part (ii) of the Proposition 2.

A.3 Proof of Proposition 3

Equation (9) characterizes a student's college-application decision. Because the right-hand side of equation (9) does not depend on W, for a given (h_1, θ, W), a student's application decision is determined by $v_c^s(h_1, \theta, W) - v_c^n(h_1, \theta, W)$. In Proposition 2, I show how $v_c^s(h_1, \theta, W) - v_c^n(h_1, \theta, W)$ changes by W in case (i) and (ii). Thus, based on Proposition 2 and equation (9), it is straightforward to show $W^*_{(h_1,\theta)}$ and $W^{bc}_{(h_1,\theta)}$ satisfy the following:

$$(1+\beta)u\Big(\frac{W^*(h_1,\theta) - \tau_s + \beta m_s(h_1,\theta)}{1+\beta}\Big) - (1+\beta)u\Big(\frac{W^*(h_1,\theta) - \tau_n + \beta m_n(h_1,\theta)}{1+\beta}\Big)$$
$$= \frac{\zeta}{\beta \cdot p(h_1,\theta)} - u_{sel}(h_1, \theta, \epsilon_\psi),$$

$$u(W^{bc}(h_1,\theta) - \tau_s + \overline{L}) + \beta u(m_s(h_1,\theta) - (1+r)\overline{L}) - (1+\beta)u\Big(\frac{W^{bc}(h_1,\theta) - \tau_n + \beta m_n(h_1,\theta)}{1+\beta}\Big)$$
$$= \frac{\zeta}{\beta \cdot p(h_1,\theta)} - u_{sel}(h_1, \theta, \epsilon_\psi),$$

which proves part (i) and (ii) of Proposition 3. For a given τ_s, $\frac{\partial(v_c^s(h_1,\theta,W) - v_c^n(h_1,\theta,W))}{\partial(\tau_s - \tau_n)} < 0$. Applying the implicit function theorem, I have $\frac{\partial W^*(h_1,\theta)}{\partial(\tau_s - \tau_n} < 0$ and $\frac{\partial W^{bc}(h_1,\theta)}{\partial(\tau_s - \tau_n} > 0$, which proves part (iii) of Proposition 3.

B Robustness Check

In the baseline model, I define college selectivity based on Barrons' Admission Competitive Index, which is constructed based on the SAT scores of attendees, high school GPAs, the class rank of each college's incoming students, and the percentage of students accepted. In this section, I discuss how the main results change if I define selective universities differently.

In the IPEDS 2004, each university reports the 25th and 75th percentiles of the SAT score of incoming students. I use the 75th percentile of the SAT score of each university (which I denote as s_r) to compare the academic-preparation level of incoming students across different universities. Looking at the distribution of s_r across all four-year colleges, I choose a cutoff value s_r^* such that colleges with s_r greater than s_r^* are classified as selective universities. In specification (2), s_r^* is the top th percentile of the distribution of s_r across all four-year colleges. In specification (3), s_r^* is the top 20th percentile of the distribution of s_r across all four-year colleges.

Table A1 compares summary statistics for samples that use different definitions for selective universities. In the baseline model, 16% of students in the sample attend selective universities. If I define selective universities based on s_r, 6% and 10% of students in the sample attend selective universities in specification (2) and (3), respectively. The sample characteristics conditional on college selectivity in the baseline model are similar to those in specification (3), in which selective universities are defined as institutions from the top 20% the distribution of s_r across all four-year colleges. If I define selective universities as universities in the top 10% of the distribution of s_r, I observe a larger difference in students' characteristics and the sticker price between selective and nonselective universities.

Table A2 shows the estimates for grants. The estimates for grants for selective universities are quite similar across different specifications. Grants from nonselective universities are relatively more need-based and more merit based if I look at the top 10 universities (specification (2)) compared to the baseline. Looking at the top 20 universities, grants from nonselective universities are relatively more need-based and less merit based compared to the baseline model.

Table A3 summarizes how the main results change as the definition of selective universities changes. The main findings remain robust. For all alternative specifications, borrowing constraints widens the gap in the application rate and the attendance rate to selective universities between low- and high-income students (Panel B). Increasing need-based aid from selective universities by $2,600 per year reduces the gap in annual income between rich and poor students by 3%-15% (Panel C). The impact of borrowing constraints is greater in the baseline model compared to alternative specifications of selective universities, which is related to the fact that more students are at the margin of attending selective universities in the baseline model compared to alternative specifications. I also find that across all specifications, need-based aid is better than merit-based aid in closing the achievement gap, while having similar impacts on the average annual income (Panel C and D).

A1. Summary Statistics Based on Different Definition for Selective Universities

		(1) Baseline	(2) SAT 90th	(3) SAT 80th
% of students in selective univ.		16	6	10
SAT	Selective	1,240	1,338	1,296
	Nonselective	1,025	1,065	1,055
Family income	Selective	104,780	115,350	108,540
	Nonselective	74,930	80,940	80,510
Wage	Selective	22.18	25.29	23.58
	Nonselective	18.18	18.95	18.88
Math score in 10th grade	Selective	68	66	67
	Nonselective	48	49	48
Sticker price	Selective	22,750	22,970	22,920
	Nonselective	9,650	9,010	9,850

Note. The table shows summary statistics of samples according to the different definition of selective universities.

A2. Estimation for Grants

	(1) Baseline	(2) SAT 90th	(3) SAT 80th
δ_{n0}	-2,313	-2880.53	-2151.44
δ_{n1}	-0.0034	-0.0050	-0.0047
δ_{n2}	2.755	2.998	2.558
δ_{n3}	0.423	0.525	0.486
δ_{s0}	324.8	5209.0	2854.29
δ_{s1}	-0.013	-0.013	-0.015
δ_{s2}	0.317	0.181	0.267

Note. The table shows the first-stage estimation results for wage rate and grants according to the different definition of selective universities.

A3. Robustness-Check Analysis

	(1) Baseline	(2) SAT 90th	(3) SAT 80th
Panel A: Structural Parameters			
α_1	0.118	0.156	0.122
α_2	0.041	0.028	0.048
γ_0	6.642	6.458	6.674
α_3	0.532	0.464	0.534
α_4	0.109	0.129	0.122
γ_1	-0.902	-0.474	-0.904
s^*	5.825	10.366	6.880
π_1	0.0047	0.0078	0.0051
π_2	1.535	1.532	1.341
κ	2.995e-04	3.778e-04	1.229e-04
ψ_0	6.536e-04	5.761e-05	4.652e-04
ψ_1	2.651e-07	1.319e-06	2.147e-07
ψ_2	1.774e-04	1.734e-07	1.553e-07
σ_ψ	9.599e-04	1.087e-03	1.049e-03
ζ	7.474e-05	3.280e-05	8.641e-04
λ	1.091-06	4.105e-07	1.168e-06
σ_θ	2.222e-06	7.824e-06	2.201e-06
Panel B: Relaxing Borrowing Constraints ($\lambda = \infty$)			
Change in average SAT score	21	5	18
Change in average income	387	122	317
Change in SAT gap (%)	-16 (17%)	-3 (3%)	-7 (7%)
Change in income gap (%)	-671 (8%)	-234 (6%)	-346 (4%)
Change in application rate gap (%)	-0.197 (50%)	-0.049 (30%)	-0.070 (25%)
Change in attendance rate gap (%)	-0.095 (44%)	-0.029 (44%)	-0.045 (34%)
Panel C: Impact of Increasing Need-based Aid ($2,600 per year)			
Change in SAT gap (%)	-15 (16%)	-3 (4%)	-11 (12%)
Change in annual income gap (%)	-$576 (7%)	-$153 (4%)	-$349 (4%)
Average annual income (%)	$38,2		
Panel D: Impact of Increasing Merit-based Aid (same budget as need-based aid)			
Change in SAT gap (%)	-1 (1%)	0 (0%)	0 (0.2%)
Change in annual income gap (%)	-$136 (1.5%)	-$6 (0.3%)	-$18 (0.2%)
Average annual income	$38,297	$38,888	$39,207

Note. The table summarizes the robustness-check analysis. Gaps are the difference between students from the top and the bottom quintile of the income distribution.

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