Simulation Models of the Effects of Race- and Socioeconomic-Based Affirmative Action Policies

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ABSTRACT

This paper develops intuition about socioeconomic-based affirmative action and the extent to which it can replicate the levels of racial diversity evident in selective colleges. Using stylized simulation models, we investigate the potential relative effects of race- and/or socioeconomic-based affirmative action policies on the racial and socioeconomic distribution of students into colleges. Results suggest three important patterns: (1) reasonable SES-based affirmative action policies do not mimic the effects of race-based policies on racial diversity; (2) there is little evidence of systemic "mismatch" induced by affirmative action policies; on average there are only small effects on the mean achievement of students' peers; and (3) the use of affirmative action policies by some colleges affects enrollment patterns in other colleges.

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Draft: April, 2015

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Abstract

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In their 2013 decision in *Fisher v. University of Texas*, the Supreme Court upheld the concept of

affirmative action but issued a challenge to university administrators and scholars: in order to use race-

based affirmative action, they must show "that no workable race-neutral alternatives would produce the

educational benefits of diversity" (*Fisher v. the University of Texas*, 2013, p. 11). As a result, developing

and assessing the effectiveness of admissions policies designed to increase racial diversity in selective

colleges is crucial. One way to begin to evaluate alternative policies is to use simulations of the college

application, admission, and enrollment processes. Well-designed simulations have the advantage of

allowing rapid experimentation with a variety of policies. While simulations are not definitive about what

will actually happen in the real world under a given policy, they can help build intuition and provide

guidance for the types of policies that may be most effective. With these aims in mind, this paper uses a

simulation model to investigate the dynamic effects of various types of affirmative action college

admission policies.

Any race-neutral affirmative action approach faces a difficult challenge. Even with the legality of

race-conscious affirmative action policies, racial minority students remain under-represented in higher

education, particularly at selective institutions. Figure 1 shows the postsecondary destinations of the high

school class of 2004 by college selectivity (Reardon, Baker, and Klasik, 2012). In this figure, the width of

each bar represents the percent of the college-age population enrolled at the given level of school. Very

selective colleges (those colleges with Barron's Selectivity rankings of 1, 2, or 3[1]) have many more White,

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[1] Barron's Profiles of American Colleges (www.barronspac.com) provides selectivity rankings for most four-year colleges in the United States. Colleges are ranked on a scale from 1-7, where 1 is the most selective and 6 is the least selective (colleges with a ranking of 7 are specialty colleges with unique admissions criteria). These rankings are based on the high school GPAs, high school class rank and SAT/ACT scores of enrolled students, as well as the proportion of applicants admitted. To give a concrete example, colleges ranked in the top two categories (1 and 2) in 2004 had median SAT scores of at least 575, admitted fewer than 50% of applicants, and enrolled students with

and many fewer Black and Hispanic, students than the population of 18-year-olds overall. However, despite the pattern of decreasing racial diversity with increasing selectivity, the most selective colleges (Barron's 1s) are slightly more diverse than the colleges just below them in the selectivity rankings. This relative diversity may be the result of race-based affirmative action policies used in at least some of the most selective colleges. While we cannot know what the racial composition of these most selective colleges would be in a world without any race-based affirmative action, it's clear that racial minority students would be even more dramatically under-represented.[2]

Figure 1 here

Proposed alternatives to race-based affirmative action policies have generally taken one of two forms: "percent plans" and socioeconomic-based affirmative action policies. In this paper we focus on simulations of the second option, socioeconomic-based affirmative action. We focus our attention on these policies for two reasons: there is already a large body of literature that examines percent plans, and, quite importantly, these plans have not been shown to be effective at increasing or maintaining racial diversity (e.g. Arcidiacono & Lovenheim 2004; Bastedo & Jaquette, 2011; Howell, 2010; Long, 2004, 2007).[3]

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media GPAs of about 3.5 and in the top 35% of their high school classes.

[2] Appendix A Figure 1 similarly gives postsecondary destinations for the high school class of 2004, but this time by family income rather than race (Reardon, Baker, & Klasik, 2012). Similar to Figure 1 the more selective an institution is, the higher the average family income of its students. However, the most selective colleges have more students from low-income families than do slightly less selective schools. This may be an ancillary effect of race-based affirmative action policies, or may result from other factors, including perhaps the greater prevalence of need-blind admissions practices, need-based financial aid, and income-based recruitment practices. Reardon, Baker, and Klasik (2012) give a more detailed description of these figures and their creation.

[3] Under percent plans any student who graduates in some pre-specified top percentage of their high school class automatically gains admission to the public university system. In order to increase the racial diversity of university admissions, such plans leverage the existing racial segregation of high schools; any plan that takes the top portion of a school with a high minority population is bound to admit a sizeable number of minority students. Three public systems (the University of California, the University of Texas, and the Florida State University systems) have already enacted some version of a percent plan because of existing affirmative action bans or because of anticipation of future restrictions on race-conscious affirmative action. The extant research indicates that such plans tend to reduce racial and ethnic diversity relative to the affirmative action plans that preceded them (Arcidiacono & Lovenheim 2004; Bastedo & Jaquette, 2011; Howell, 2010; Long, 2004, 2007), and it was the legal challenge of Texas's attempt to increase its Universities' diversity above and beyond what their Percent Plan yielded that led to the Fisher case.

The failure of percent plans to deliver on their promise has been part of what has prompted some scholars and colleges to propose a second race-neutral form of affirmative action, one that relies on socioeconomic status (SES) instead of race to determine admissions preferences (Gaertner & Hart, 2013; Kahlenberg, 1996). Under SES-based affirmative action, students are given an admissions advantage because of their socioeconomic background rather than their race or ethnicity. The presumption is that such plans can effectively capitalize on the correlation between race and income in order to construct a racially diverse class of students. The potential effects of such policies are not clear. Some existing research suggests that substituting SES for race in college admissions decisions can at least partly maintain rates of minority enrollment while increasing college access for economically disadvantaged students (Carnevale & Rose, 2004; Carnevale, Rose, & Strohl, 2014; Gaertner & Hart, 2013; Kahlenberg, 2012). Other research suggests that SES is not a sufficiently good proxy for race for SES-based policies to be effective at producing substantial racial diversity (Gaertner & Hart, 2013; Reardon & Rhodes, 2011; Reardon, Yun, & Kurlaender, 2006; Kane, 1998). At the very least, socioeconomic-based affirmative action may help to increase socioeconomic diversity on college campuses, which in and of itself may be a desirable outcome for colleges. It is difficult to evaluate the effects of SES-based affirmative action, in practice, however, because such plans are not widely used.

Our aim in this paper is to develop general intuition about socioeconomic-based affirmative action and the extent to which it can replicate, or even improve, the modest levels of diversity evident in selective colleges under current admissions practices. Specifically, we investigate the potential relative effects of race- and/or socioeconomic-based affirmative action policies on the racial and socioeconomic distribution of students into colleges.

In addition to this basic question of the potential for policy efficacy, we also investigate two other issues that have been understudied in the affirmative action literature. First, some critics of affirmative action claim that race-based affirmative action does a disservice to racial minority students because it

places them in environments where their academic preparation systematically falls below that of their peers (e.g. Arcidiacono, Aucejo, Coate, & Hotz 2012; Sander 2004). This "mismatch" might lead to a lower likelihood of degree completion or segregation due to homophily based on academic backgrounds (Arcidiacono, Khan, & Vigdor, 2011). There is little consensus on the extent to which mismatch due to affirmative action results in such consequences, so in this paper we pay particular attention to how different affirmative policies might alter the academic preparation of the peers that students of difference races are exposed to within the colleges in which they enroll.

Second, we attend to the effects that affirmative action policies at one or more colleges have on enrollment patterns at other schools. College admission and enrollment processes take place in an interrelated, dynamic system, where admissions policies at one college might affect enrollment patterns at other colleges. If students are aware of affirmative action admissions policies, they may alter their application behavior to account for how the policies might affect their likelihood of admission to particular colleges. Changes in applicant pools may then change admission probabilities, even at colleges not using affirmative action, as colleges adjust their admission selectivity to account for changes in their applicant pools or yield rates due to changing student application and enrollment behavior. The number of colleges using particular affirmative action policies may therefore affect enrollment patterns throughout the system, and diversity gains in some colleges may be offset in whole or part by diversity losses in others. Our simulations here are designed to provide some insight into these potential system-wide, dynamic effects of affirmative action admissions policies.

We build intuition about the answer to these questions through an agent-based simulation model, which incorporates a realistic and complex (though certainly highly-stylized) set of features of the college application, admission, and enrollment processes.

The Utility of Agent-Based Simulation

By using an agent-based simulation model (often called an ABM) we are able to compare the effects of a range of policies on enrollment patterns in a way that takes into account how a policy would affect the full system of colleges. This model allows us to investigate how affirmative action policies might affect university composition in a world in which students 1) have somewhat idiosyncratic preferences about colleges; 2) have some uncertainty about their own admissibility to each college; and 3) use their resources and limited information to strategically apply to a small subset of colleges, and in which colleges 1) differ in their use of affirmative action policies; 2) have idiosyncratic perceptions and preferences regarding students; and 3) strategically admit enough students to fill their seats under the expectation that not all students admitted will enroll. Although this model falls short of being completely realistic, it captures important dynamic features of the application/admissions/enrollment processes that enable us to investigate the ways that affirmative action might affect enrollments.

This simulation approach improves upon previous assessments of socioeconomic-based affirmative action in several important ways. First, unlike prior simulations, it models a dynamic system of colleges, rather than a single, static college. Both Gaertner and Hart (2014) and Carnevale, Rose, and Strohl (2014) simulate effects of just one cohort of students applying to college in one year and, in the case of Gaertner & Hart (2014) at just one university. Gaertner & Hart (2013), for example, simulate the effects of SES-based affirmative action using real university applicants to a single university (the University of Colorado). Their simulation, by its nature, does not incorporate dynamic processes: it provides no intuition on how application behavior might change as subsequent cohorts of students learn how the policy might affect their likelihood of admission, nor on how enrollment patterns at the University of Colorado might differ if other colleges also changed their admissions policies. Our simulation, in contrast, allows student behavior to change in response to different admission policies and investigates the enrollment patterns across an entire system of colleges.

Second, it is more realistic than other simulations in some important ways. Whereas the simulation in Carnevale, Rose, and Strohl (2014) assumes that all students apply to all colleges, our model has students strategically applying to a small portfolio of colleges based on their (imperfect) assessments of college quality and their likelihood of admission. Moreover, in the Carnevale, Rose, and Strohl (2014) simulation of socioeconomic-based affirmative action, the model measures socioeconomic disadvantage using many variables not typically available to admissions officers (for example, the percent of individuals in an applicant's neighborhood who hold a college degree). Our model, in contrast, uses an index that is implicitly based on the types of factors (family income, parental education, parental occupation) that would be available to admissions officers.

Simulating the Mechanics of Affirmative Action Policies

Selective colleges generally try to admit classes of students that are both academically qualified and also diverse along numerous dimensions. These dimensions may include race or SES, but also academic interests, extracurricular talents, geography, and other factors. For example, colleges may want to boost enrollment in an under-subscribed major or program, or find a new English horn player for their orchestra. Selective colleges across the country demonstrate admissions preferences for these students who will add to the different types of diversity of their campus. These preferences—as well as racial or socioeconomic diversity preferences—are typically enacted through a holistic review process in which the overall academic preparation of an applicant is assessed across a host of dimensions.

Because it is part of a holistic process, the added weight given in the admissions process to students' non-academic characteristics such as race is not explicit or directly measurable. Indeed, by law it cannot be: the Supreme Court has prohibited colleges from assigning numeric values to race-based characteristics (*Gratz v. Bollinger*, 2003). That is not to say, however, that the *average* admissions weight given to a characteristic like race (or horn-playing skill, for that matter), cannot be quantified after the

fact given the right data. One can ask, for example, how much higher, on average, are the SAT scores of White students than those Black students with similar chances of admission. The answer to questions of this type provides a way of quantifying the weight given to race and factors associated with race in a holistic admissions process. A non-zero answer to this question does not, however, imply that admissions officers simply add a certain number of SAT points to each Black student's score and then admit all students simply on the basis of their (adjusted) SAT scores.[4]

To make the simulations in this paper realistic, we simulate a holistic admissions process in which race and/or SES are given more or less (or no) weight in admissions decisions. For this, we need a sense of the average weight given to these factors by real selective colleges and universities so that the simulations produce patterns that are grounded in real-world data. The existing empirical evidence on the size of admissions weights given to applicants' race, however, is limited and variable. Simply comparing the average SAT scores of students of different races enrolled at select elite colleges, as Herrnstein and Murray (1994) did, can be misleading for a number of reasons. First, because of racial disparities in SAT score distributions, we would expect the mean scores of admitted Black and White students to be different even if a college admitted solely on the basis of test scores.[5] Second, this approach cannot disentangle differences in average scores that are due to differential admission criteria from differences in scores that are due to racial differences in application or enrollment patterns.

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[4] The difference between a post-hoc inference of the average weight given to race and assigning a numerical value to race in an admissions process is subtle but important. To see the difference, consider a baseball team that would like players who can play a range of positions, and would also like each of them to be skilled hitters (e.g. having a high on-base percentage). If the pool of potential players includes a large number of fielders who are great hitters but few pitchers who are good hitters, the team may reasonably pass up a player who is an excellent fielder and hitter in order to sign a pitcher who is a weaker hitter because it needs some great pitchers. If one then compared the average pre-draft on-base percentages of pitchers and fielders to measure the "weight" assigned to being a pitcher in the signing process, this difference would likely be large—maybe 200 points. But this does not mean the team added 200 points to each pitcher's observed pre-draft on-base percentage and then simply signed the players with the on-base percentage, regardless of whether they were a fielder or pitcher.

[5] This may seem counterintuitive, but it results from the fact that racial differences in mean test scores mean that there are more minority students with very low scores, and more White students with very high scores. If a college simply admitted every student with an SAT score above, say, 1200, the mean score for White students in this group would be higher than that of minority students, because of the higher proportion of White students with very high scores.

A better approach to estimating average affirmative action weights is to use data on a pool of applicants to one or more selective colleges and to estimate the relationship between race/SES and the probability of admissions. Both Kane (1998) and Espenshade and Radford (2009) use this approach. They fit a model predicting admission on the basis of race, academic, and other observable factors and then compare the coefficients on the race variables with the coefficient on SAT scores. This allows them to express the weight given to race in terms of the weight given to SAT scores. For example, if a Black student's odds of admission were 7 percent greater than an otherwise observationally identical White student, one can calculate what change in SAT score would be needed to yield the same 7 percent boost in the odds of admission. Using different data sets and slightly different models, they both estimate that the implicit weight given to race (being Black, specifically, in their models) in the admission to selective colleges is roughly equivalent to the weight given to an additional 300-400 SAT points (as measured on the 1600 point SAT scale). It is worth reiterating that this is not to say that the colleges in their sample add 300-400 points to Black students' SAT scores and then admit students on the basis of (adjusted) SAT scores. Rather, it is to say that the implicit weight given to race and race-related factors in whatever holistic review process the colleges use is roughly equivalent to the weight that is given to a difference of 300-400 SAT score points.[6]

It is important to note that these estimates apply only to the most selective colleges and universities. Espenshade and Radford's data set contains only seven selective, four-year colleges or universities. Kane's estimates come from an analysis of the top 20% of four-year colleges in terms of

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[6] The Kane (1998) and Espenshade & Radford (2009) SAT-equivalent weight estimates are likely too high. Their models include a number of control variables, such as high school grade point average and extracurricular involvement. Because these variables are positively correlated with SAT scores, their inclusion in the model will tend to attenuate the coefficient on the SAT score variable. This, in turn, will exaggerate the SAT-equivalent weight (because it is a ratio of the coefficient on race to the coefficient on SAT scores). Another way to see this is to realize that two students who differ by 300-400 SAT score points will tend to differ also on many other factors that affect college admission, so the average difference in admission probabilities between two students who differ by 300-400 SAT points will be much larger than that implied by the SAT coefficient alone. This means that a smaller difference in SAT points (along with the other differences in correlated characteristics) will yield an average difference in admission odds equal to that implied by the race coefficient.

selectivity. His models based on all four-year colleges yield estimated weights one-third as large. Such findings are in keeping with the patterns in Figure 1 above that suggest there is greater use of race-based affirmative action at the most selective colleges.

Because of concerns that the estimates of the SAT-equivalent weight given to race may be too high (see footnote 5 above), and because existing estimates do not describe the SAT equivalent weight that colleges give to Hispanic students or to low-SES students, we conduct our own simple analysis of recent college admission data. Using data from the Education Longitudinal Study of 2002 (ELS), a study that includes college application and admission data for a nationally-representative sample of students who were 10th graders in 2002, we estimated SAT-equivalent racial and SES admissions weights using methods similar to those of Espenshade and Radford (2009) and Kane (1998). We fit a much more parsimonious models than they do, however: we predict the odds of admission using only SAT scores and dummy variables for race or a standardized variable for SES. To account for the possibility that the implicit weights vary in magnitude along with the selectivity of the college, we repeated this analysis for admission to each of the six Barron's Selectivity categories. Similar to Kane, we find notable racial admissions preferences only in the top Barron's category, which represents approximately 10% of four-year colleges with that are not open admission. We estimate significant positive admissions preferences for both Black and Hispanic students applying to these most selective colleges. We estimate that black students are given an implicit weight that is roughly equivalent to that given to students with an SAT score 250 points higher than another student (slightly more than one standard deviation on the SAT scale); for Hispanic students the estimated implicit weight is similar to that given to students with an SAT score about 260 points higher than another student. We find very little or no evidence of racial preferences in admissions to colleges in lower selectivity tiers (for details, see Appendix B, Table 1).

We conduct a similar analysis to estimate the average implicit weight given to low-SES students in admissions. Here we find evidence of slight socioeconomic-based affirmative action in the most selective

colleges (the weight given to a standard deviation difference in family SES is roughly the same as given to a 30-point SAT score difference). Moreover, the evidence indicates that students applying to less selective colleges were *penalized* for their lower SES in the admission process (in these colleges higher-SES students were given implicit preference in admissions). The SES weights are, however, relatively small in all cases, reflecting perhaps the fact that existing SES-based admissions preferences work in two directions: on the one hand, most colleges rely heavily on student tuition and must take ability to pay into account in admissions; on the other hand, many colleges, particularly very selective colleges, actively recruit and admit low-SES students (for details, see Appendix B, Table 2).

In sum, it appears that, in 2004, affirmative action or other related policies at the most selective colleges increased the odds of minority students' admission substantially, by an amount that may be as high as the difference between students whose SAT scores differ by several hundred points. SES-based affirmative action policies, however, appear to have been much less prevalent. On average, low-SES applicants appear to have received little or no admissions preference at most colleges.

Method

We use a modification of the agent-based model (ABM) of college applications, admissions, and enrollment developed by Reardon, Kasman, Klasik, and Baker (2014). Their model includes two types of entities: students and colleges. In their model, students had only two attributes: family resources and academic records. We assign each student a race as well. The racial composition of our student cohorts, race-specific distributions of academic achievement and resources, and race-specific correlations between resources and academic achievement are constructed to match the characteristics of the high school class of 2004 (as estimated from the ELS study).[7] The parameters used in our model are presented in Table 1.

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[7] We base our achievement distribution on the NCES administered standardized assessment of English Language Arts and Mathematics given to tenth grade students in ELS.

For simplicity, as well as the availability of real-world data, we limit our model to the four largest racial groups in the United States: White, Hispanic, Black, and Asian. Five percent of our students are Asian, 15 percent are Black, 20 percent are Hispanic, and 60 percent are White. Our family resources measure is meant to represent the economic and social capital that a student can tap when engaging in the college application process (e.g. income, parental education, and knowledge of the college application process) and is based explicitly on the SES index variable from ELS.[8] The family resource measure is standardized to have a mean of zero and standard deviation of one. Academic record represents the academic qualities that make a student attractive to a college (e.g., test scores, GPA, high school transcripts). We construct our sample of simulated students to match the joint distribution of race, SES, and composite math and reading scores in the ELS sample. We convert the scores from the original ELS test score scale to a scale that approximates the 1600-point SAT because of the ubiquity of this scale, and because we calibrated our race and socioeconomic implicit admission weights in terms of SAT points.

There are 40 colleges in our model, each of which has a target enrollment for each incoming class of 150 students, meaning there are a total of 6,000 seats available for each cohort of students. The ratio of total students to total college seats was selected to be roughly the same as the proportion of 2002 tenth graders who attended any type of college by 2006[9]. The only attribute that colleges have is "quality", which operationally represents the average academic achievement of students enrolled in the school. In the real world, this mean academic achievement is probably correlated with, but not the same as, the quality of educational experience for students at a given college. Quality is measured in the same units as student academic achievement.

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[8] In ELS, this SES index is a composite measure of mother's and father's education, mother's and father's occupation, and family income.

[9] Although 100% of students in our model "apply" to colleges, roughly 40% don't get in anywhere because there are fewer seats than students. An alternative model would have students with near-zero probabilities of admission not apply to any colleges. Our results are not sensitive to this modeling choice, however, because these students' applications have no aggregate effect on what type of students are admitted to colleges – the colleges in our model end up with the same students they would have using either approach.

The model iterates through three stages during each simulated year: application, admission, and enrollment.[10] During the application stage, a cohort of prospective students observe (with some uncertainty) the quality of each of the 40 colleges in a given year and select a limited number of colleges to which to apply, based on their (uncertain and somewhat idiosyncratic) perceptions of the quality of each college and of their probability of admission to each. In the admission stage, colleges observe the academic records of students in their applicant pools (again, somewhat uncertainly and idiosyncratically) and admit those they perceive to be most qualified, up to a total number of students that colleges believe will be sufficient to fill their available seats based on yield information from previous years. During this stage, some colleges use affirmative action strategies that take students' race, SES, or both, into consideration when they evaluate students' academic records. In the enrollment stage, students compare the colleges to which they have been admitted and enroll in the one which they perceive to be of highest quality. At the end of each simulated year, college quality is updated based on the average academic records of students who enrolled in that year. These three stages are repeated in the next year with a new set of 10,000 students and the same set of colleges.

Although the model abstracts away many of the complexities of the actual application process, we do introduce several elements into our model that are intended to mimic real-world college selection and enrollment processes. The first are imperfect information and idiosyncratic preferences: students do not rank colleges identically, and colleges do not rank students identically. This represents the presence of idiosyncratic preferences (e.g. a student might be impressed by a college's dormitories or a college might place a premium on talented quarterbacks) as well as imperfect information on the part of both types of agents.

Second, students do not apply to every college, but instead strategically engage in the application process. Using admissions results from prior years, students estimate their probability of admission to

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[10] For a more detailed and analytic explanation of the agent-based model, see Appendix B.

each college, though their estimates are imperfect because they have imperfect information about each college's selectivity and about their own academic record and attractiveness. Using these probabilities and their perceived utility of each college, students determine the expected utility of applying to each college and select a set of applications that maximizes their expected utility. Although most high school students likely do not engage in such an explicit process of utility maximization in choosing where to apply to college, the algorithm applied by the students in the ABM, in conjunction with their imperfect information and idiosyncratic preferences, produces very realistic patterns of application (students apply to colleges appropriate to their academic record) (Reardon, et al. 2014).

Finally, the model allows students' family resources to influence the college application and enrollment process in four ways. First, students' resources and academic record are positively correlated (using the empirical race-specific correlations estimated from the ELS data); this means that high-resource students are more likely than low-resource students to apply, be admitted, and enroll in higher quality colleges. Second, students with more resources submit more applications than their lower-resource peers, increasing their probability of being admitted to a desired college. Third, students with higher resources have higher-quality information both about college quality and their own academic achievement relative to other students; this increases their likelihood of applying to colleges that are a good match for their academic records. Fourth, higher resource students are able to enhance their apparent academic records (analogous to engaging in test preparation or other private tutoring, obtaining help writing college essays, or strategically participating in extracurricular activities). These features of the model are explained and calibrated by Reardon, Kasman, Klasik, & Baker (2014), who use ELS data to determine appropriate values for the parameters governing them. Reardon et al (2014) show that, taken together, imperfect information, idiosyncratic preferences, strategic application behavior, and socioeconomic influences create patterns of college selection and enrollment that are similar to those in the real world; low-resource students tend to apply to a limited set of lower-quality colleges, while their

high-resource counterparts tend to create larger application portfolios with "safeties," "targets," and "reaches" that increase their chances of attending a high-quality college.

In order to examine the influence of affirmative action strategies, we modify the Reardon et al (2014) ABM to allow colleges to exercise preferences for racial or socioeconomic diversity by weighting race and/or SES in the admissions process. We conducted a set of simulations, each with a different combination of affirmative action policy conditions. We explore a "baseline" scenario in which no colleges use affirmative action. We then explore scenarios in which the top four colleges use moderate race-based affirmative action, strong race-based affirmative action, moderate SES-based affirmative action, strong SES-based affirmative action, moderate race-and-SES-based affirmative action, and strong race-and-SES-based affirmative action.[11] While empirical observation of college admissions in the ELS dataset indicates that only colleges in the most elite group (roughly the top 10%) employ racial affirmative action policies, we experiment with different numbers of colleges using moderate race-and-SES-based affirmative action in order to explore dynamic system-wide effects that result from different numbers of colleges using these policies. For these experiments, we include scenarios where the top one, four, ten, 20, or all 40 colleges use affirmative action in admissions; we also include a scenario where four of the top 10 colleges (those ranked 1, 4, 7, and 10) use affirmative action. In each scenario, the model runs for 30 years, with our top-tier colleges starting to use affirmative action strategies after a 15-year burn-in period, in which the simulation runs, but no colleges use affirmative action; we do this so that both colleges' qualities and students' perceptions of admission stabilize before the introduction of affirmative action. Using the

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[11] In our models, "moderate" and "strong" race-based affirmative action policies give minority students an implicit weight equivalent to 150 or 300 academic achievement points, respectively. "Moderate" and "strong" SES-based affirmative action gives students an implicit weight of plus or minus 75 or 150 points, respectively, for each standard deviation they are above or below the average student in resources. While the magnitude of the implicit SES-based affirmative action weight is half that of the implicit race weight, recall that the SES weight is used across the SES distribution and the size of these weights are expressed in terms of the weights given for students 1 standard deviation below the mean resource level. Because of this approach, the difference in weights between students +/- 1 SD from the average resource level is 300 achievement points—and students farther from the mean have even larger weight differences. So, despite their apparently smaller magnitude, the SES weights produce larger admissions advantages, top to bottom, than the race-based weights.

results of these simulations, we are able to examine how affirmative action influences the racial and SES composition of colleges, and the quality of colleges that students attend.

Results

We start by comparing the effects of race- and SES-based affirmative action policies on the racial and socioeconomic composition of the top colleges. Figure 2 shows the racial composition among the four colleges that use affirmative action by simulated affirmative action policy. The proportion of Black and Hispanic students is positively affected by both types of affirmative action policies, but increases more rapidly when the magnitude of racial affirmative action increases than when the magnitude of socioeconomic affirmative action does. This is evident when one compares the rate of change in the proportion of minority students in bars 1, 2, and 3 (increasing race-based affirmative action with no SES-based affirmative action) with the rate of change in the proportion of minority students in bars 1, 4, and 5 (increasing SES-based affirmative action with no race-based affirmative action). Bars 6 and 7 show that colleges are most racially diverse when both race- and SES-based affirmative action policies are used.

Figure 2 here

Figure 3 shows the socioeconomic composition of colleges that use affirmative action (in terms of student resource quintiles) by simulated affirmative action policy. SES-based affirmative action policies have a large effect on socioeconomic composition of colleges. Racial affirmative action policies, on the other hand, have a small effect, especially relative to that of socioeconomic affirmative action policies. The first quintile students—the poorest students—experience the greatest gain in overall enrollment rate under both affirmative action strategies. The highest quintile experiences the greatest reduction in enrollment. There are only small changes in enrollment for the second, third, and fourth quintiles.

Figure 3 here

Next we turn to how affirmative action policies affect the mean academic achievement of the

other students enrolled in one's college. Figure 4 shows mean academic achievement of enrolled students as a function of the student's own achievement, race, and affirmative action type. Here again, only the top four colleges in the simulation use affirmative action. For minority students (defined as Black and Hispanic students), race- and the combination race- and SES-based affirmative action policies increase the mean academic record of peers relative to no affirmative or SES-based affirmative action policies alone (see right panel). This increase in the mean academic achievement of students is experienced through most of the achievement distribution, and amounts to as many as 40 SAT points. This consistent increase in mean achievement is evidence that on average minority students experience modestly better academic settings under affirmative action policies. Conversely, White students (left panel) experience small decreases in the mean academic achievement of their peers under all types of affirmative action, although this decrease is only appreciable under the joint SES- and race-based affirmative action policies, and only at the high end of the student academic achievement distribution. On average, most White students do not experience any changes to their academic environment as an effect of affirmative action policies.

Figure 4 also includes a 45-degree line, which indicates a student's own achievement. When the lines indicating the average achievement of students' peers are below the 45-degree line, this means that minority students, on average, have scores above the average for their school. For minority students with achievement above roughly 1100 on our scale (one half standard deviation above the population mean achievement of 1000), the average achievement of their classmates is typically below their own achievement in each of the affirmative action scenarios shown in Figure 4. For minority students with slightly lower achievement, race-specific affirmative action does lead to them enrolling, on average, in schools where their own achievement is below the school average, but only slightly. These patterns suggest that concerns about affirmative action leading to minority students enrolling in schools for which they are not academically prepared may not be well-founded.

Figure 4 here

Similar patterns are evident in Figure 5, which shows the mean academic achievement of enrolled students as a function of student academic record, low- or high-SES, and type of affirmative action policy. Low-SES students see an increase in the mean academic achievement of their peers under any affirmative action policy that utilizes SES, but only minor increases as a result of race-based affirmative action. This increase is relatively consistent in the upper two-thirds of the student academic achievement distribution, with the largest increases for students with achievement above 1200. High-SES students, however, see a decline in the mean academic achievement of their peers under all affirmative action policies, and particularly for the combined SES- & race-based policy. While these decreases are not large through much of the student achievement distribution, they do increase as student academic achievement increases; at the high end of the student achievement distribution, the decrease is a much as 40 SAT points under the joint race- and SES-affirmative action policies. Note also that there is no evidence in Figure 5 that affirmative action leads to low-SES students being enrolled in schools for which they are academically unprepared.

Figure 5

Figure 6 compares the mean academic achievement of enrolled students by student achievement and race, under scenarios where race-based affirmative action policies are used by different numbers of colleges. For White students (left panel), there is little difference in the mean achievement of peers under any affirmative action admissions policy; the lines are close throughout the distribution. For minority students, however, there are increases in the mean achievement of enrolled peers under all affirmative action policies; these gains are evident across the majority of the student achievement distribution. As one might expect, when only one college uses affirmative action, only students in the top of the achievement distribution experiences gains in peer achievement, whereas when ten colleges use these admissions policies students across the distribution experience gains.

Figure 6

Because students and colleges comprise an interconnected system, the effects of affirmative action policies will not be isolated to the colleges that use them. Colleges that do not use affirmative action policies are affected by the presences of such policies in other schools. Figures 7 and 8 illustrate these system dynamics—the effect of different numbers of colleges using affirmative action policies on the kinds of students (achievement, race, and SES) enrolled in all colleges. In each of these figures, grey arrows indicate the colleges that use affirmative action and black arrows show colleges that do not. The movement of colleges (length and direction of the arrow) indicates changes in mean achievement of enrolled students and proportion of enrolled students who are either black or Hispanic (Figure 7) or low-income (Figure 8). In both figures, the colleges using affirmative action policies use moderate levels of both SES- and race-based affirmative action.

A few results are immediately clear in Figures 7 and 8. First, colleges that are using affirmative action move *up* and to the *left* in the figures. That is, these colleges become more diverse (racially and socioeconomically) and their students' average achievement declines slightly. Second, the slope of these grey arrows is quite steep, which indicates that the changes in mean achievement are much less pronounced than the changes in the proportion of minority or low-income students. Third, the less selective colleges that use affirmative action experience the greatest changes in both diversity and average achievement—their lines move the furthest. Fourth, colleges that do not adopt affirmative action policies but that are close in mean achievement to those that do also experience significant changes in diversity and average achievement, though in the opposite direction as those using affirmative action. That is, they become less diverse and the mean achievement of their enrolled students increases. Fifth, the effects on colleges that use affirmative action vary relatively little by the number of colleges using affirmative action; once a school is using these admissions policies it seems to matter little whether colleges near it are also using them. Finally, only in the most extreme cases (20 or 40 colleges using

affirmative action policies) is the margin of college attendance affected. Under the other scenarios the arrow representing un-enrolled students (the left most arrow) remains mostly unchanged.

Figures 7 and 8 here

Discussion

The results of our simulations suggest at least three important patterns: (1) reasonable SES-based affirmative action policies do not mimic the effects of race-based policies on racial diversity and reasonable race-based affirmative action policies do not mimic the effects of SES-based policies on SES diversity; (2) there is little evidence of any systemic "mismatch" induced by affirmative action policies; on average there are only small effects on the mean achievement of students' peers; and (3) the use of affirmative action policies by some colleges affects enrollment patterns in other colleges as well.

From a policy perspective, SES-based affirmative action policies do not seem effective at producing racial diversity – socioeconomic-based affirmative action produces only modest gains in racial diversity. These results are consistent with Sander (1997), who found that SES-based affirmative action at the UCLA law school did not produce the levels of diversity achieved under race-based affirmative action policies. Our simulations suggest that unless SES-based affirmative action policies use a very high, probably untenable, preference for lower-resource students, these policies are unlikely to result in the same racial composition in colleges as under current race-based affirmative action policies. Similarly, our models suggest that socioeconomic affirmative action results in considerable economic diversity in selective colleges. In contrast, race-based affirmative action alone yields relatively little socioeconomic diversity.[12] SES-based affirmative action policies can only work to produce racial diversity (and race-based policies to produce SES diversity) if the correlation between SES and race is high. Our analysis makes clear

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[12] If colleges are looking to create socioeconomic diversity, one concern that may limit colleges' use of SES-based affirmative action, however, is that it necessarily increases the enrollment of students from the bottom of the socioeconomic distribution. It may carry a heavy cost in terms of financial aid (a factor not included in our models).

that the correlation between SES and race is not high enough to make SES-based affirmative action a realistic alternative to race-conscious admissions policies.[13] In sum, this suggests that SES-based affirmative action policies will be unable to meet the *Fisher* standard of "workable race-neutral alternatives [that] would produce the educational benefits of diversity" (*Fisher v. the University of Texas*, 2013, p. 11).

It is also worth noting that our models suggest that affirmative action policies are unlikely to change the margin of college attendance. That is, they do not have much effect on *who* attends college, but only on *which* college they attend if they do. Unless affirmative action policies are targeted at much lower achieving students or are implemented much more widely than they currently are, these policies are unlikely to affect the overall racial and socioeconomic distribution of college attendees.

Second, while it has been argued that affirmative action can lead to academic "mismatch" for minority students, we find no evidence that this is a systematic result of affirmative action policies. Moderate levels of race- and/or SES-based affirmative action resulted in high-achieving minority or low-SES students enrolling, on average, in colleges where their academic preparation was below the average level for the college they enrolled in. Similarly, we find that affirmative action has little effect on the average academic preparation of students in the colleges of the typical White and high-SES student.

These results, of course, focus on only the average level of academic preparation in a college. If affirmative action policies have effects on the spread of academic achievement within in a college, and if students' college experiences are partially segregated by academic level (by ability tracking in classes or study groups, for example), affirmative action policies may affect students' experiences in ways our models do not capture. Our results also focus on the average effects experienced by students. If affirmative action policies operate by changing the colleges that marginal students attend (that is,

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[13] This is not to say that the correlation isn't high—it is—just that it is not high enough that one can be used as a proxy for the other in affirmative action policies. This conclusion is consistent with the ineffectiveness of SES-base K-12 school integration policies at producing racial integration (Reardon, Yun, and Kurlaender 2006; Reardon and Rhodes 2011).

pushing a few students into more selective colleges), these average results could hide significant changes for some students. While these possibilities are important to examine in greater detail, the small average changes indicate that such policies might not induce large problems with mismatch on a system-wide level.

Third, system dynamic effects are an important, and often overlooked, factor in affirmative action policies; because colleges and students are operating in an interconnected and interdependent system, the policies of one college can affect all colleges. We find that these effects are particularly strong for colleges that are not using affirmative action policies but are close in quality to schools that are. This could be a particularly important dynamic in states in which public colleges are unable to use race-based affirmative action but private colleges of similar quality can use race conscious admissions policies. This suggests that any complete assessment of affirmative action policies must attend to effects not only within colleges that use affirmative action, but also those that do not.

The models presented in this paper do not address issues of cost or financial aid. It is likely that cost and financial aid decisions will mute some of the effects of affirmative action policies unless the policies are accompanied by increased financial aid or other greatly modified tuition structures. This is a direction for future research and an area that policy makers should pay close attention to.

In *Fisher*, the Supreme Court challenged states and universities to find race-neutral strategies that can achieve educationally-beneficial diversity. Racial diversity is, the Court has agreed, educationally-beneficial (*Grutter v. Bollinger*, 2003). The question, then, is how to best achieve such diversity in Constitutionally-permitted ways. Perhaps the best way would be to eliminate racial achievement and high school graduation gaps; this would certainly go a long way toward equalizing access to selective colleges and universities without the need for race-based affirmative action. But, although these gaps have narrowed moderately in the last two decades (Reardon, Robinson-Cimipan & Weathers 2015; Murnane 2013), they are still very large, and far from eliminated.

Until racial disparities in educational preparation are eliminated, then, other strategies are needed. Our analysis here suggests that affirmative action policies based on socioeconomic status are unlikely to achieve meaningful increases in racial diversity. That is not to say that socioeconomic affirmative action would not be valuable in its own right—it would increase socioeconomic diversity on university campuses and would benefit low-income college applicants—but only that it is not an effective or efficient means to achieving racial diversity. Race-conscious affirmative action does, however, increase racial diversity effectively at the schools that use it. Although imperfect, it may be the best strategy we currently have.

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Table 1

Agent-Based Simulation Model Parameters

Parameter	Value	Source
Number of students	10,000	N/A
% White	63%	ELS
% Black	16%	ELS
% Hispanic	15%	ELS
% Asian	6%	ELS
Number of colleges	40	N/A
College capacity	150 students/college	N/A
Student achievement		ELS
White	$achievement \sim N(1052, 186)$	
Black	$achievement \sim N(869, 169)$	
Hispanic	$achievement \sim N(895, 185)$	
Asian	$achievement \sim N(1038, 202)$	
Student resources		ELS
White	$resources \sim N(.198, .657)$	
Black	$resources \sim N(-.224, .666)$	
Hispanic	$resources \sim N(-.447, .691)$	
Asian	$resources \sim N(.012, .833)$	
Resources-achievement correlations		ELS
White	$r=0.395$	
Black	$r=0.305$	
Hispanic	$r=0.373$	
Asian	$r=0.441$	

Quality reliability (how well students see college quality)	$0.7 + a(resources)$; $a=0.1$	Reardon et al. 2014
Own achievement reliability (how well students see their own achievement)	$0.7 + a(resources)$; $a=0.1$	Reardon et al. 2014
Achievement reliability (how well colleges see student achievement)	0.8	Reardon et al. 2014
Apparent achievement (perceived achievement, increased or decreased through "achievement enhancement")	*perceived achievement* + $b(resources)$; $b=0.1$	Becker 1990; Buchmann et al. 2010; Powers and Rock 1999; Reardon et al. 2014
Number of Applications	$4 + INT[c(resources)]$; $c=0.5$	ELS

Note. Quality and achievement reliability bound by minimum values of 0.5 and maximum values of 0.9
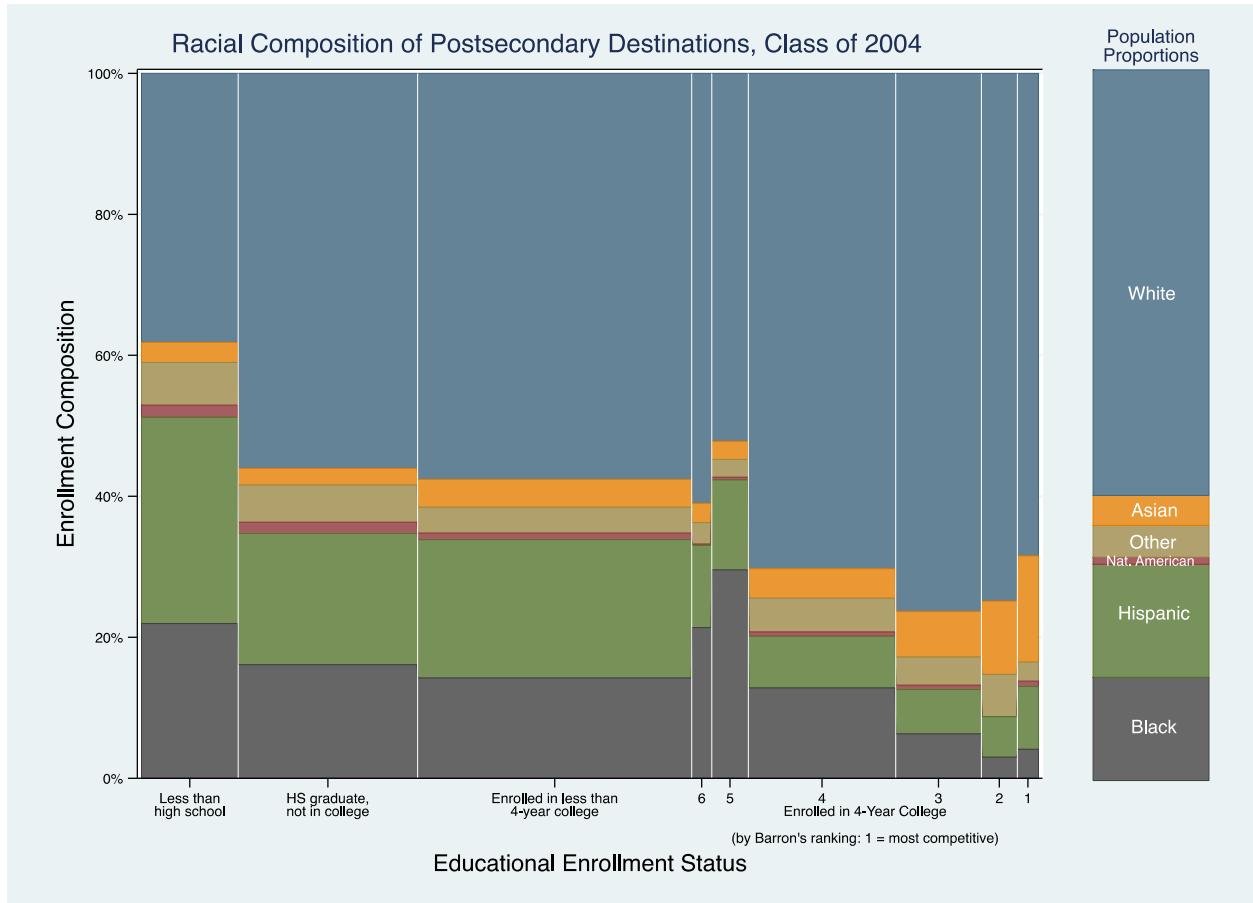
Figure 1

Figure 1. Racial Composition of Postsecondary Destinations, Class of 2004

Figure 2

Racial Composition of Colleges Using Affirmative Action, By Affirmative Action Type

| Race Type: | none | moderate | strong | none | none | moderate | strong |
| SES Type: | none | none | none | moderate | strong | moderate | strong |

Black   Hispanic   Asian   White

31

Figure 3

Socioeconomic Composition of Colleges Using Affirmative Action, By Affirmative Action Type

Figure 4

Mean Achievement of Students in Own College
By Race, and Affirmative Action Type; Top 4 Schools Use Affirmative Action

Figure 5

Mean Achievement of Students in Own College
By SES, and Affirmative Action Type; Top 4 Schools Use Affirmative Action

Figure 6

Mean Achievement of Students in Own College

By Race and Number of Affirmative Action Schools; Moderate Race-Based Affirmative Action

Figure 7

Mean Achievement and Proportion Minority, by Number of Schools Using Affirmative Action

Moderate race- and SES-based affirmative action policies used
Arrows start at school's position in year 15 and end at school's position in year 30
Left-most arrow represents unenrolled students

schools that don't use AA   schools that use AA

Figure 8

Mean Achievement and Proportion Low-income, by Number of Schools Using Affirmative Action

Moderate race- and SES-based affirmative action policies used
Arrows start at school's position in year 15 and end at school's position in year 30
Left-most arrow represents unenrolled students

schools that don't use AA   schools that use AA
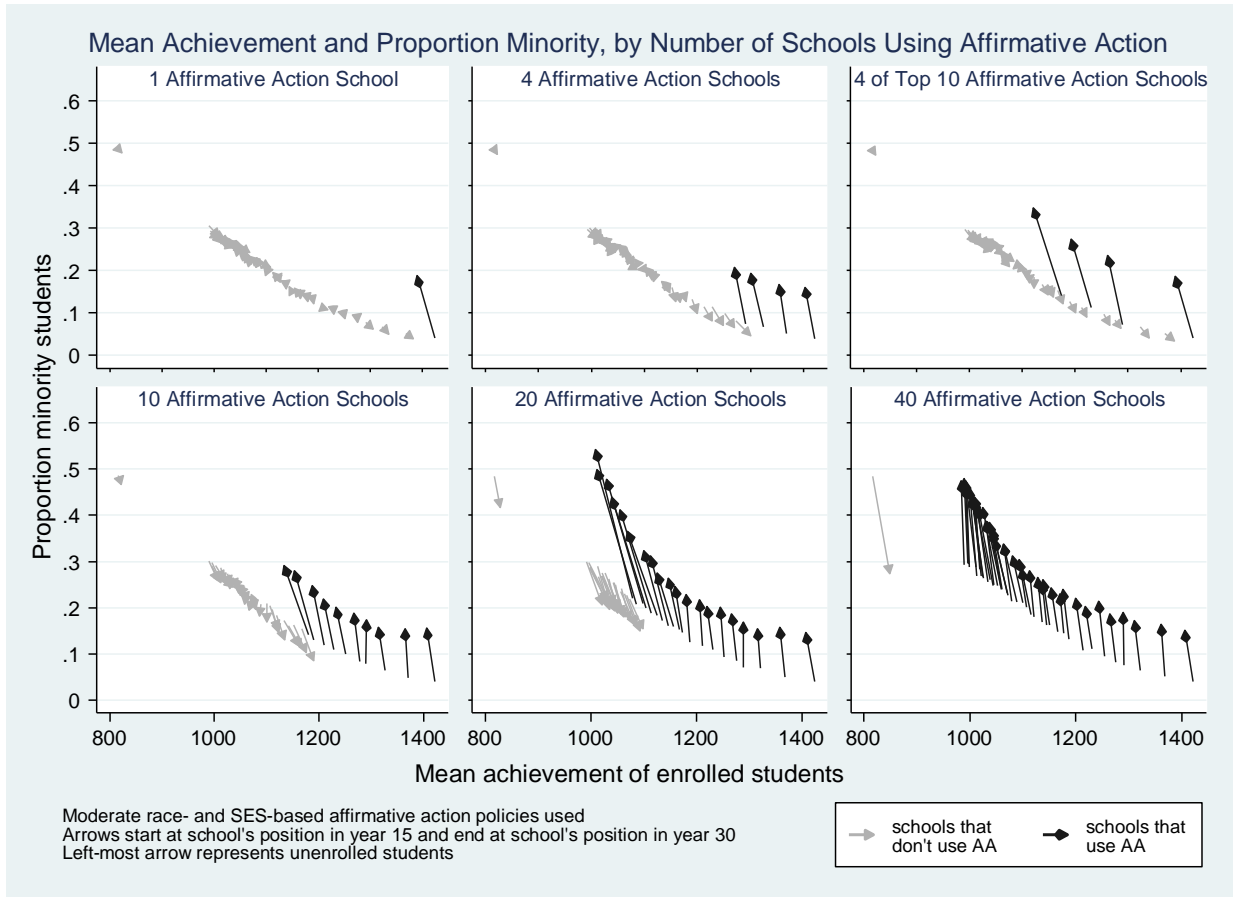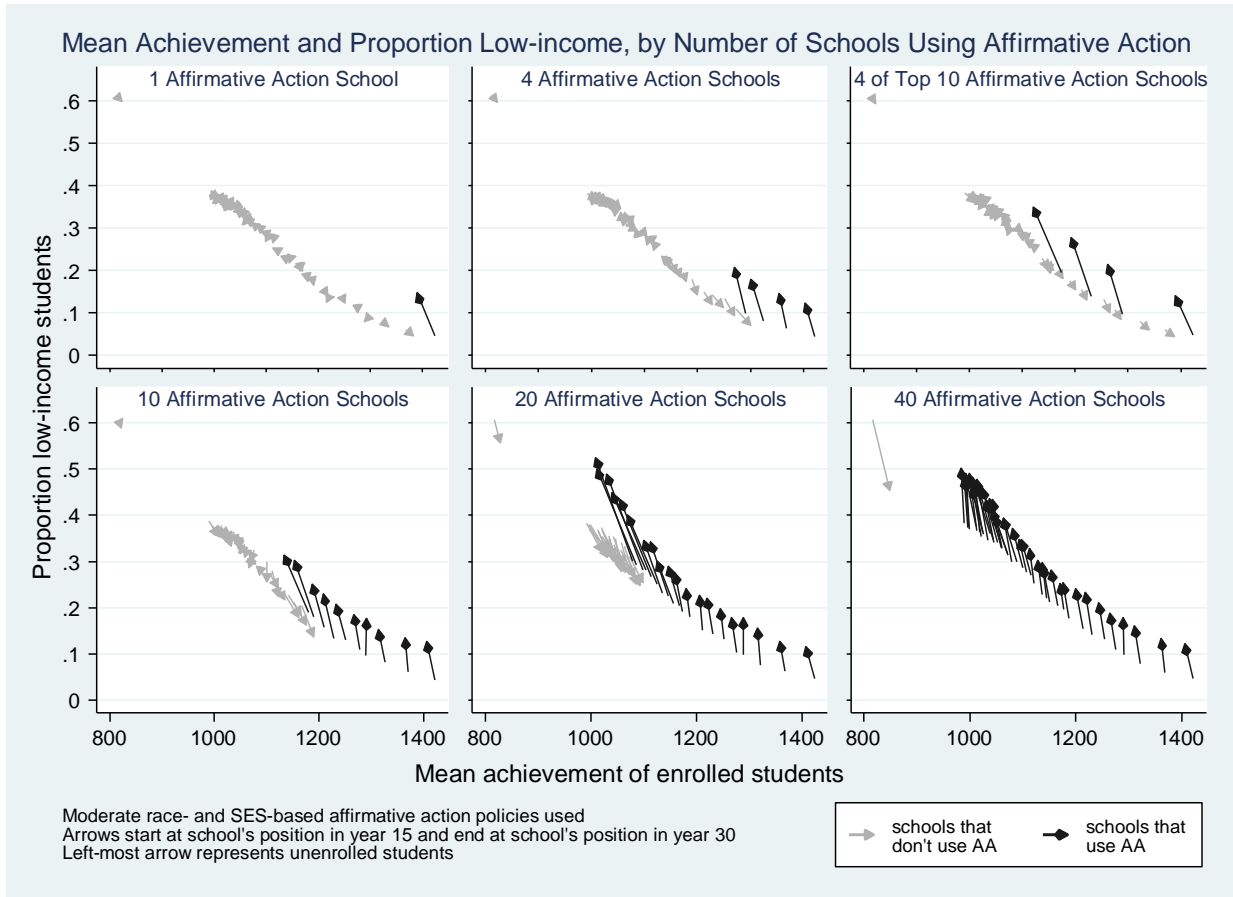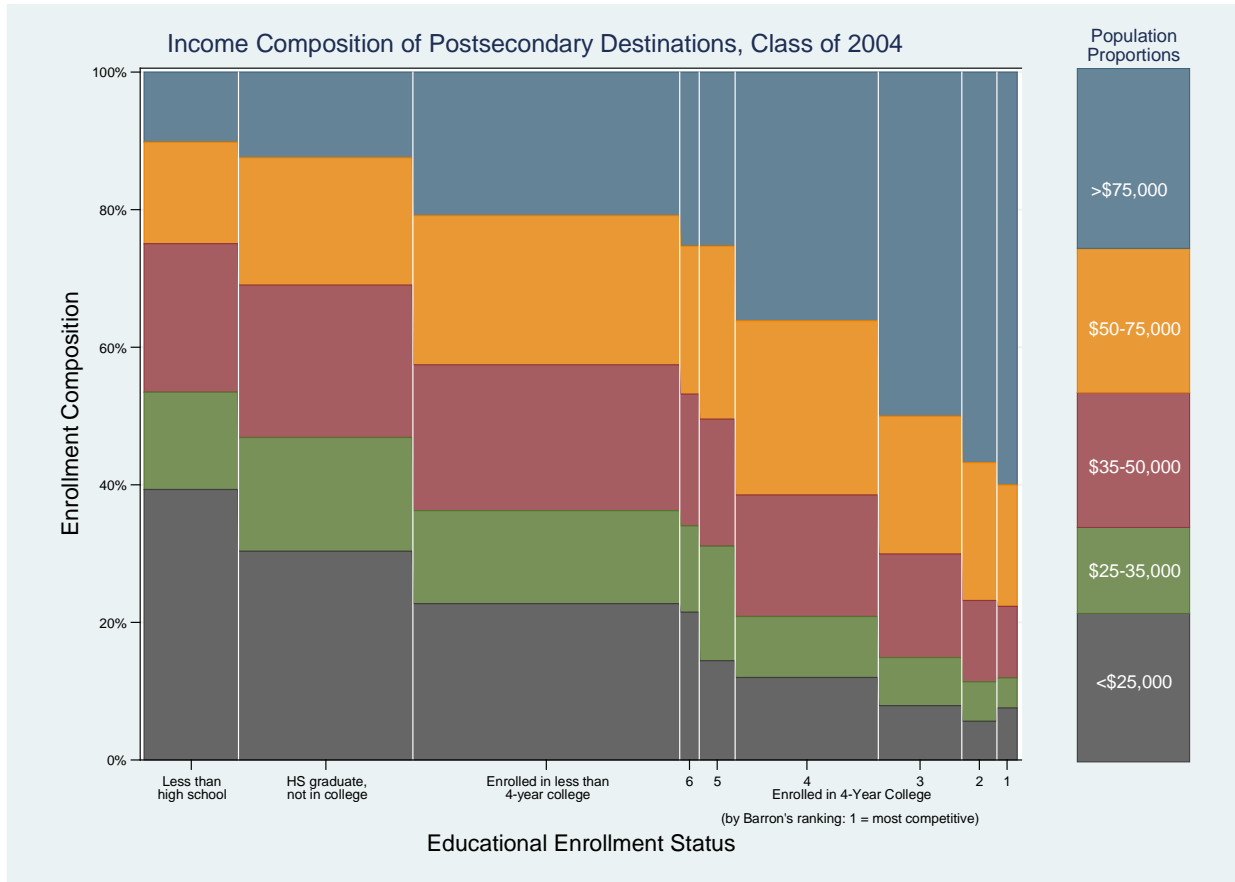
Figure A1

Appendix B

Table B1: Estimates of Implicit Weight Given to Minority Students in Admissions Process, High School Class of 2004

	All schools		Barrons 4		Barrons 3		Barrons 2		Barrons 1	
SAT	0.076	***	0.079	***	0.09	***	0.093	***	0.115	***
	(0.002)		(0.003)		(0.003)		(0.005)		(0.006)	
Asian	-0.004		-0.028		0.026		0.006		0.007	
	(0.011)		(0.022)		(0.021)		(0.029)		(0.024)	
	-5.26		*-35.44*		*28.89*		*6.45*		*6.09*	
Black	-0.04	***	-0.098	***	-0.044	*	-0.028		0.303	***
	(0.010)		(0.016)		(0.021)		(0.034)		(0.040)	
	-52.63		*-124.05*		*-48.89*		*-30.11*		*263.48*	
Hispanic	0.024	*	-0.025		0.01		0.037		0.294	***
	(0.010)		(0.018)		(0.021)		(0.031)		(0.034)	
	31.58		*-31.65*		*11.11*		*39.79*		*255.65*	
Intercept	-0.015		0.038		-0.197		-0.376		-1.102	
	(0.019)		(0.033)		(0.038)		(0.061)		(0.080)	
N	23,000		6,700		5,000		2,800		2,700	

+ $p<0.10$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Source: Authors' calculations from ELS:2002 study. Estimates are from a linear probability model predicting acceptance to a given selectivity of school as a function of SAT score and dummy variables for race. Sample sizes have been rounded to the nearest 100. The implicit admissions weight (in SAT points) is included in italics below the standard error for each model.

Table B2: Implicit Weight Given to Socioeconomic Status in Admissions Process, High School Class of 2004

	All schools		Barrons 4		Barrons 3		Barrons 2		Barrons 1	
SAT	0.076	***	0.083	***	0.092	***	0.094	***	0.09	***
	(0.002)		(0.003)		(0.003)		(0.005)		(0.006)	
SES	0.01	*	0.027	***	0.003		0.001		-0.033	*
	(0.004)		(0.007)		(0.008)		(0.013)		(0.014)	
	13.2		*32.5*		*3.2*		*1.1*		*-36.6*	
Intercept	-0.025		-0.026		-0.216		-0.381		-0.716	
	(0.017)		(0.030)		(0.035)		(0.057)		(0.073)	
N	23,000		6,700		5,000		2,800		2,700	

+ $p<0.10$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Source: Authors' calculations from ELS:2002 study. Estimates are from a linear probability model predicting acceptance to a given selectivity of school as a function of SAT score and the ELS SES variable (continuous and standardized). Sample sizes have been rounded to the nearest 100. The implicit admissions weight (in SAT points) is included in italics below the standard error for each model.

Appendix C

Explanation of Model

Initialization

For each scenario of the model, we generate J colleges with m available seats per year (for the sake of simplicity, m is constant across colleges). During each year of the model run, a new cohort of N students engages in the college application process. Initial college quality (Q) is normally distributed, as are race-specific distributions of student achievement (A) and student resources (R). We allow for race-specific correlations between A and R. The values used for these parameters, and their sources, are specified in Table 1. We select these values to balance computational speed and distribution density (e.g. for number of colleges and students); real-world data (e.g. for achievement and resource distributions); and based on the original version of the model (ELS 2002; Reardon et al., 2014).

Submodels

Application. During this stage of our model, students generate an application portfolio, with each student selecting n_s colleges to which they will apply. Every student's perception of each college's quality (where student s's perception of college c's quality is denoted Q_{cs}^*) is a function of the college's true quality (Q_c) plus a random noise term (u_{cs}), which represents both imperfect information and idiosyncratic preferences.

$$Q_{cs}^* = Q_c + u_{cs}; \;\; u_{cs} \sim N(0, \tau_s).$$

(B.1)

The noise in students' perceptions of college quality has a variance that depends on a students' resources; students from high-resources families have better information about college quality. Specifically,

$$\tau_s = Var(Q_c)\left(\frac{1 - \rho_s^Q}{\rho_s^Q}\right),$$

(B.2)

where ρ_s^Q, the reliability of student perceptions of college quality, is a function of student resources, and bounded between 0.5 and 0.7, as described in Table 1.

Students then use perceived college quality (Q_{cs}^*) to evaluate the potential utility of their own attendance at that college (U_{cs}^*), based on how much utility they place on college quality:

$$U_{cs}^* = a_s + b_s(Q_{cs}^*), \tag{B.3}$$

where α_s is the intercept of a linear utility function and β_s is the slope. Reardon et al (2014) showed that allowing α_s and β_s to vary with students' socioeconomic resources had little effect on college application decisions; as a result we fix both to be constant across students.

Students may augment their own achievement, and they perceive their own achievement with noise. Thus, their assessment of their achievement, for purposes of deciding where to apply is:

$$A_s^* = A_s + a_s + e_s; \quad e_s \sim N(0, \sigma_s), \tag{B.4}$$

where a_s represents enhancements to perceived achievement that are unrelated to achievement itself (e.g. strategic extracurricular activity participation or application essay consultation) and e_s represents a student's error in her perception of her own achievement. The values that are used for these parameters and their relationships with student resources are listed in Table 1. As above, the error in a student's assessment of her own achievement has a variance that depends on her family resources:

$$\sigma_s = Var(A)\left(\frac{1 - \rho_s^A}{\rho_s^A}\right),$$

(B.5)

where ρ_s^A, the reliability of student perceptions of their own achievement, is a function of student

resources, and bounded between 0.5 and 0.7, as described in Table 1.[14]

Based on their noisy observations of their own achievement and college quality, students estimate their probabilities of admission into each college as a logisitic function of the difference between their perception of their own achievement and their perception of a given college's quality:

$$P_{cs}^* = f(A_s^* - Q_{cs}^*) = \left(1 + e^{\alpha + \beta(A_s^* - Q_{cs}^*)}\right)^{-1} \tag{B.6}$$

where the parameter of f are based on admission patterns over the prior 5 years. In each year of the model, the parameters α and β of f are estimated by fitting a logit model predicting the observed admissions decisions using the difference between (true) student achievement and college quality for each submitted application over the past 5 years. We set $\alpha = 0$ and $\beta = -0.015$ for the first 5 years of our simulation (since there are no prior estimates to use). These values were selected based on observing the admission probability function over a number of model runs; the starting values do not influence the model end-state, but do influence how quickly the function (and the model itself) stabilizes.

Each student applies to a set of n_s colleges, where n_s is determined by the student's resources, as described in Table 1. Given n_s, a student applies to the set of n_s colleges that maximize her overall expected utility. To determine the expected utility of an application portfolio, we do the following. Let $E_s^* \{C_1, C_2, \dots, C_{n_s}\}$ indicate student s's expected utility of applying to the set of n_s colleges $\{C_1, C_2, \dots, C_{n_s}\}$, where the colleges in the set are ordered from highest to lowest perceived utility to student s: $U_{C_1 s}^* \geq U_{C_2 s}^* \geq \dots \geq U_{C_n s}^*$. Define $E_s^* \{\emptyset\} = 0$. Let P_{cs}^* indicate student s's perceived probability of admission to

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[14] The intercept value, minima, maxima, and linear relationships with resources used for the reliabilities with which students perceive their own achievement and college quality, as well as the intercept and slope values used for students' evaluation of the utility of attending colleges are based on those used in previous work (Reardon et al., 2014). Briefly, the resource relationships are based on experimentation into the role of differential information quality in the observed sorting of students into colleges by socioeconomic status (Reardon et al., 2014). In the absence of available empirical evidence, the other values used are plausible estimates: the average student has moderately high, but not perfect, perception of college quality (e.g. familiarity with college rankings) as well as their own achievement (e.g. knowledge of their SAT scores); and because of resource, effort, and opportunity costs the utility of attending a very low-quality college is less than 0 (i.e. lower than not attending college). Extensive model testing suggests that our selections of these specific parameter values did not affect the overall interpretation of our results.

college c. Then the expected utility of applying to a given set of colleges is computed recursively as

$$E_s^*\{C_1, C_2, \dots, C_{n_s}\} = P_{C_1 s}^* \cdot U_{C_1 s}^* + \left(1 - P_{C_1 s}^*\right) \cdot E_s^*\{C_2, \dots, C_{n_s}\}.$$

(B.7)

In our model, each student applies to the set of colleges $\{C_1, C_2, \dots, C_{n_s}\}$ that maximizes

$E_s^*\{C_1, C_2, \dots, C_{n_s}\}$. In principle, this means that a student agent in the model computes the expected

utility associated with applying to every possible combination of three colleges in the model, and then

chooses the set that maximizes this expected utility. The model developed by Reardon et al (2014) uses a

fast algorithm for this maximization; we use the same algorithm here.

Although the model assumes all students are rational, utility-maximizing agents with enormous

computational capacity, this is moderated by the fact that the student agents in the model have both

imperfect information and idiosyncratic preferences, both of which are partly associated with their family

resources. This means that there is considerable variability in student application portfolios, even

conditional on having the same true academic records, and that high-resource students choose, on

average, more optimal application portfolios than lower-resource students. Both of these features mimic

aspects of actual students' empirical application decisions (e.g. Hoxby & Avery 2012). More generally, the

assumption of rational behavior is an abstraction that facilitates focus on the elements of college sorting

that we wish to explore. We recognize that real-world students use many different strategies to

determine where they apply.

Admission. Colleges observe the apparent achievement ($A_s + a_s$) of applicants with some

amount of noise (like the noise with which students view college quality, this also reflects both imperfect

information as well as idiosyncratic preferences):

$$A_{cs}^{**} = A_s + a_s + w_{cs}; \quad w_{cs} \sim N(0, \phi).$$
(B.8)

As described in Table 1, colleges assess students' achievement with a reliability of 0.8. Given that true

achievement has a variance of 200^2 in the population, this implies that the error variance colleges'

assessments of student achievement is

$$\phi = Var(A)\left(\frac{1 - 0.8}{0.8}\right) = .25 \cdot 200^2 = 100^2.$$

(B.9)

Thus, in the model, colleges' uncertainty and idiosyncratic preferences have the effect of adding noise with a standard deviation of 100 points (half a standard deviation of achievement) to each student's application.[15]

Affirmative action policies are activated after year 15 of model runs (in order to allow college quality and application, admission, and enrollment behavior to stabilize first). At this point, colleges' affirmative action policies are activated and remain stable through the remainder of the model run. Letting G_c and H_c indicate the magnitude of affirmative action weights used in college c's race- and resource-based affirmative action policies, respectively, and letting B_s, H_s, and R_s indicate a student's race (black or Hispanic, respectively) and resources, colleges rank students according to

$$A_{cs}^{***} = A_{cs}^{**} + G_c(B_s + H_s) + H_c R_s.$$

(B.10)

Colleges rank applicants according to A_{cs}^{***} and admit the top applicants. In the first year of our model run, college's expected yield (the proportion of admitted students that a college expects to enroll) is given by:

$$Yield_c = 0.2 + .06 \cdot (College\ Quality\ Percentile)$$

(B.11)

with the lowest-quality college expecting slightly over 20% of admitted students to enroll and the highest quality college expecting 80% of admitted students to enroll. In subsequent years, colleges admit $\frac{m}{Yield_c}$ students in order to try to fill m seats (where m=150 in our model). After the first year of a model run,

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[15] As with the parameter values that describe student perception, the means, minima, and maxima used for the reliability with which colleges perceive student achievement is based on what was used in previous work (Reardon et al., 2014). Although there is a lack of extant empirical evidence to inform these values, we made estimates that seem sensible: collectively, college admission officers have quite a bit of experience evaluating students and thus colleges have a highly accurate (but also not perfect) perception of student achievement. Extensive model testing suggests that our selections of these specific parameter values did not affect the overall interpretation of our results.

colleges are able to use up to 3 years of enrollment history to determine their expected yield, with $Yield_c$ representing a running average of the most recent enrollment yield for each college.

Enrollment. Students enroll in the college with the highest estimated utility of attendance (U_{cs}^*) to which they were admitted.

Iteration. Colleges' quality values (Q_c) are updated based on the incoming class of enrolled students (whose average achievement is denoted $\bar{A}_c$) before the next year's cohort of students begins the application process:

$$Q_c' = 0.9 \cdot Q_c + 0.1 \cdot \bar{A}_c \tag{B.12}$$

We run our model for 30 years (this appears to be a sufficient length of time for our model to reach a relatively stable state for the parameter specifications that we explore).