Ova and Out: Using Twins to Estimate the Educational Returns to Attending a Selective College

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Abstract: Research has shown that attending a relatively selective four-year college over a less selective alternative is positively related to bachelor's degree completion. This paper revisits that question with a novel dataset of over 11,000 sets of twins and information on colleges to which they apply, enroll, and potentially graduate. I show that a student's probability of bachelor's degree completion within four years increases by 5 percentage points by choosing an institution with a median SAT score 100 points higher than the alternative. Moreover, the estimated magnitude of impact is insensitive to several methodologies, including OLS, twin fixed effects, and controlling for the application portfolio. This suggests that in certain contexts, sources of bias perceived as barriers to obtaining causal estimates of the returns to college selectivity, such as unobserved family characteristics and student aspiration, may be of little concern.

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1. Introduction

Research shows that there is a strong positive relationship between college selectivity and graduation rates (Bowen and Bok 1998; Kane 1998; Alon and Tienda 2005; Horn and Carroll 2006; Long 2008; and Bowen et al. 2009). Similarly, there is a strong relationship between college selectivity and future wages (James et al. 1989; Loury and Garman 1995; Behrman, Rosensweig, and Taubman 1996; Daniel, Black, and Smith 1997; Hoxby 1998; Kane 1998; Brewer, Eide, and Ehrenberg 1999; and Monks 2000; Long 2008). Identifying causal relationships has been more challenging because selection on student unobservables is likely to bias estimates of the return to selectivity. However, researchers, typically looking at the effect on future wages, have developed compelling identification strategies to overcome the bias. For example, Dale and Krueger (2002) match students who have similar college application portfolios and acceptances to a highly selective set of institutions, arguing that these students are similar on unobservables. They find that college quality has no impact on future wages.[1] This analysis is replicated and confirmed with a broader set of institutions in Long (2008), who finds that there is a positive impact on the probability of graduating college.[2] Hoekstra (2009) uses a regression discontinuity approach based on SAT admission cutoffs at a single flagship university and finds that white men who matriculate at this university earn approximately 20 percent more than applicants with SAT scores below the admission threshold. Finally, Cohodes and Goodman (2012) use a regression discontinuity that exploits cut scores for merit scholarships at public universities in Massachusetts. They find that high achieving students who are compelled to enroll in a less selective (public) university than their peers have a 40 percent lower probability of graduating on time.

The aforementioned research has made great progress in controlling for selection bias. However, additional unobservable family characteristics are still likely to exist in most of the analyses and potentially bias estimates. For example, parents may insist that their children attend a selective institution and graduate, regardless of parental income and education or other typical family-level observables. To address this, several researchers have overcome the selection bias related to family background by using twins (Ashenfeter and Krueger 1994; Rouse 1999). In a related paper, Behrman, Rosensweig, and Taubman (1996) use female twin data and find that wages are affected by college quality and years of schooling but stop short of suggesting that college quality directly impacts years of schooling.

This paper estimates the effect of attending a relatively selective college on the probability of graduating by using a novel set of twins and a rich set of information on students' application portfolios. Using College Board data, I identify 11,008 sets of twins, who both take the SATs and enroll in a four-year college, by matching students in the same high school, with the same last name, address, and date of birth. This sample

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[1] There is a positive impact for minorities and when using net tuition as a measure of quality.

[2] Long (2008) not only uses the Dale and Krueger (2002) method, but also uses propensity scores methods from Black and Smith (2004) and an instrumental variables method.

size dwarfs previous twin studies, and therefore, I am able to examine heterogeneity in outcomes and to obtain precise estimates.

As a starting point, I regress whether a student graduates in four years on college selectivity, as measured by the median SAT score of enrollees, controlling for student characteristics and achievement measures and parent characteristics.[3] I find that attending a college that has a median SAT 100 points above the alternative is associated with a 5.8 percentage point increase in graduation probability.

Following Dale and Krueger (2002), I include controls for the number of applications and quality of colleges in the portfolio because there may exist unobservable differences among students who apply to different sets of colleges, such as aspiration or ability, which may bias estimates. Including these controls reduces the graduation impact estimate slightly to 5.2 percentage points per 100 point median SAT increase. I also match students on application portfolios so as to include portfolio fixed effects, but results are largely unchanged.[4] The robustness of these results, even when including application portfolio controls, is inconsistent with Long (2008), whose OLS estimate of the effect of selectivity on graduation rates is cut in half and not statistically different than zero.

Next, I estimate a twin fixed effects model and find, again, an estimate of 5.2 percentage point improvement in the probability of graduating when enrolling in a school with a median SAT score 100 points greater than the alternative. This result is consistent with previous research on twins, which suggests that controlling for the selection on unobservable family characteristics reduces the magnitude of estimates, but usually by very little (Ashenfelter and Krueger 1994; Rouse 1999). Finally, I combine the twin fixed effects model and include application portfolio controls and find that the estimate is largely unchanged- 4.8 percentage point increase in four-year graduation probability per 100 SAT point increase in median SAT.

The large sample size affords me the opportunity to test for nonlinear effects, which do exist: the largest gains in graduation probability occur when choosing moderately selective colleges over less selective colleges, rather than highly selective colleges over moderately selective colleges. Enrolling in a moderately selective college (median SAT between 1100 and 1199) has almost a 10 percentage point graduation advantage relative to enrolling in a less selective college (median SAT below 1100) whereas enrolling in a highly selective college (median SAT above 1199) has an additional 5 percentage point graduation advantage relative to enrolling in a moderately selective college (and a 15 percentage point advantage over less selective colleges). There are few differences in graduation rates within finer gradations of less selective colleges and highly selective colleges.

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[3] Controls include student SAT, high schools GPA, whether participates in AP, number of SAT2's taken, ethnicity, first language, parental income and education, state residence, local unemployment and education attainment, and cohort.

[4] Dale and Krueger (2002) match on application portfolio and acceptances. The costs and benefits of my approach are discussed in the empirical strategy.

Next, I test for heterogeneous effects. I find that the relationship between institutional selectivity and four year graduation probability is nearly twice as large for males compared to females. Compared to White students, Black, Hispanic and Asian students are less impacted, in terms of graduation rates, by institutional selectivity. The relationship between institutional selectivity and graduation probability is also larger for students from suburban high schools, compared to their urban and rural counterparts. Finally, I find evidence that undermatching does reduce a student's probability of graduating whereas overmatching has no pronounced effect.[5]

2. Data

2.1. General Data

The College Board data consists of all high school students who take the SAT. The data include the student's SAT score and performance on other College Board products, including the SAT2s and Advanced Placement (AP) tests. The data also include where students send their SAT scores (Score Sends), which is often required when applying to college. Though I do not know to which colleges students apply, I use Score Sends as a proxy for application - a decision that is not unique to this paper (Pallais 2012). As an alternative interpretation, colleges that receive scores from students are in a student's choice set, which is an equally important metric.[6]

Finally, students fill out a questionnaire when they register for the SAT that provides demographic information (family income, parental education, race/ethnicity, gender, citizenship, and first language) as well as basic background information (name, address, date of birth, high school enrolled, and GPA). The student's high school was linked to the Common Core of Data, which provided school urbanicity.

In the summer of 2011, The College Board data for the graduating high school classes of 2004, 2006, and 2007 were merged with National Student Clearinghouse (NSC) data, which traces students' postsecondary careers.[7] It identifies all colleges to which the students enroll, whether they transfer to other colleges, and if applicable, when they graduate. Since, these three cohorts were merged in 2011, the 2004 cohort can trace students seven years after high school graduation while students from the 2007 cohort can only be observed for four years after high school graduation.

Finally, I merge these data with the Integrated Postsecondary Education Data System (IPEDS) to generate the final data set, which contains information on the colleges to which students apply and enroll. This information includes type of institution, two-year

[5] Undermatching is when high ability students enroll in relatively unselective schools. Overmatching is when low ability students enroll in relatively selective schools.

[6] Throughout, I interchangeably use the terms "Score Send and "application" despite the potential differences.

[7] NSC contains information from over 3,300 colleges, which covers 96 percent of the student population.

versus four-year, median SAT score of matriculates, acceptance rate, six-year graduation rate, freshman retention rate, expenditures per student, and faculty per student.[8]

2.2. Identifying Twins

From this final data set, I identify twins by matching students within the same high school who share the same last name and date of birth. To verify that these linking criteria are adequate, I visually inspected the home addresses, which cannot easily serve as a formal linking criterion due to extensive use of shorthand entry (e.g. Eighth St. versus 8th Street). This results in approximately 30,000 sets of twins. This does not identify all twins because some twins are likely to attend different high schools or one twin may not have used a College Board product. I also check that the twins have distinct social security numbers so that I do not pick up the same person twice and declare twins.

After identifying all possible twins in the data, I keep only the sets of twins in which both students went to a four-year college and both twins sent scores to at least one four-year college.[9] I also eliminate the 2004 students who matriculate three years or more after high school graduation, the 2006 students who matriculate after two years, and the 2007 students who matriculate after one year and the corresponding twin. This ensures that both twins have the opportunity to graduate from college in four years. I also exclude some students who are missing critical information, such as gender. This leaves 11,008 sets of twins.

I am unable to identify whether twins are identical or fraternal twins. However, male-female pairs must be fraternal twins and the male-male and female-female comprise of both.

2.3. Descriptive Information

Table 1 presents summary statistics for twins, the differences between sets of twins, and the full sample.[10] The median SAT score for a student's last SAT attempt is 1118. Within sets of twins, the average difference between SAT scores is 105.4 points. These differences are displayed in Figure 1, which is a scatter plot with one twin's SAT score plotted against the other's. There is a clear linear relationship between the test scores that follows the 45 degree line, and approximately 52 percent of the variability in

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[8] Median SAT of enrolled students is approximated by taking the average of A) the sum of the 25th percentile scores on critical reading and math and B) the sum of the 75th percentile scores on critical reading and math. In the few instances that a college reports only average ACT scores, the ACT is converted to SAT scores using the concordance table available here: http://www.act.org/aap/concordance/.

[9] Some students may have enrolled in a four-year college that does not participate in NSC and would consequently be eliminated from the sample.

[10] The full sample excludes students for the same reasons that twins are excluded.

one twin's SAT score is explained by variability in the other's. The final column in Table 1 shows that overall, the twins are quite similar to the full sample of all four-year college-going students, who have an average SAT of just over 1110.

The college's selectivity is measured by the institution's median SAT score, and this measure is commonly used as a proxy for selectivity (Dale and Krueger 2002; Long 2008). This is only one imperfect measure of selectivity and alternative measures, including acceptance rate, expenditures per student, graduation rates, persistence rates, and student-faculty ratio are tested. However, all selectivity measures are highly correlated with one another.

Despite the similarity in SAT scores between the twin and non-twin subsamples, there exist sizeable differences in the main outcome measure- four-year graduation rates. 52 percent of sampled twins graduate in four-years, whereas the graduation rate among the non-twin subsample is about 45 percent. The twin and non-twin subsamples also differ somewhat on academic measures like self-reported high school GPA and AP participation and. On both of these measures, twins exceed non-twins. Twins also tend to have wealthier parents, with the twin subsample reporting family incomes $6,000 above the non-twin subsample.[11]

In addition to the aforementioned variables there exist several other family level variables, which are used in future analyses. Family characteristics that vary between, but not within, sets of twins include ethnicity, state residence, native language, citizenship, father's and mother's educations, county unemployment rate, county educational attainment (percent of population with at least a bachelor's degree), and the student's high school's percent free and reduced price lunch. If students are missing any of these variables, the value is coded as zero and an indicator for missing value is created.

3. Conceptual Framework and Empirical Strategy

3.1. Conceptual Framework

Let g_{1i}^* and g_{2i}^* equal the propensity of the first and second twin, respectively, in the *i*th pair of twins to graduate from a four-year college. Let X_i represent observable characteristics that vary across sets of twins. This includes parental income, ethnicity, state residence, native language, citizenship, father's and mother's education, and cohort. There are also unobservable characteristics of sets of twins, denoted μ_i.

Let Z_{1i} and Z_{2i} represent variables that vary between and within sets of twins, such as median SAT of college enrolled, student SAT score, number of AP tests taken, number of SAT2's taken, number of Score Sends, and gender. Let P_{1i} and P_{2i} represent application portfolio characteristics that also vary within and between twin sets, such as the number and selectivity of the schools to which a student applies.

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[11] Income is reported in $10,000 buckets up to $100,000 and then top-coded at over $100,000. For each student, the midpoint of each bucket is used and the top income is set to $120,000.

College outcomes may also be influenced by student characteristics that are unobservable to the researcher, which are denoted by ε_{1i} and ε_{2i}. This leads to the following equations:

$$g^*_{1i} = \alpha X_i + \mu_i + \beta Z_{1i} + \gamma P_{1i} + \varepsilon_{1i} \tag{1}$$

and

$$g^*_{2i} = \alpha X_i + \mu_i + \beta Z_{2i} + \gamma P_{2i} + \varepsilon_{2i} \tag{2}$$

One advantage to having data on twins, is that the difference between equations (1) and (2) is as follows:

$$g^*_{1i} - g^*_{2i} = \beta(Z_{1i} - Z_{2i}) + \gamma(P_{1i} - P_{2i}) + \varepsilon_{1i} - \varepsilon_{2i} \tag{3}$$

Conveniently, the unobservable family characteristics μ_i has been eliminated from the equation.

3.2. Empirical Strategy

This study strives to obtain an unbiased estimate of β, which in this context represents the coefficient on college selectivity, as measured by median SAT of college enrolled. I observe and set $g_{1i} = 1$ (or $g_{2i} = 1$) if the student graduates in four years, and $g_{1i} = 0$ (or $g_{2i} = 0$) otherwise.

There will be two main estimation strategies: OLS and twin fixed effects. In each strategy, I incorporate specifications that exclude and include application portfolio controls. The four methods allow for a comparison of previous methodologies and take the research a step further by combining methodologies.

3.2.1. OLS

I estimate β by pooling equations (1) and (2) and running OLS. Standard errors are clustered at the twin level.

Within OLS, I use two specifications. The first excludes controls for application portfolio characteristics, P_{1i} and P_{2i}, and the second includes them. Portfolio characteristic controls include number of Score Sends, and the minimum, mean, and maximum of the median SAT score of enrolled students for the colleges in the application portfolio.

Including these portfolio controls is in the spirit of Dale and Krueger (2002). In their seminal paper, which estimates the impact of college selectivity on wages, they control for the set of schools to which students apply and are accepted. Their main specification includes portfolio fixed effects by matching students with similar or exact portfolios and acceptance outcomes. They also use a “self-revelation model,” which controls for the number of applications and mean selectivity of those applications. The two approaches yield similar results in their paper. This paper uses the latter approach for ease and precision but a variant of the former approach is tested and presented as a robustness check and results are consistent across the two approaches.

3.2.2. Twin Fixed Effects

By utilizing the sets of twins, I difference out the unobservable family effect in equation (3). Formally, I use twin fixed effects.[12] Therefore, identification comes from variation within a set of twins. Table 1's column of differences within twins suggest that there is substantial variation to exploit. Similarly, Figure 2 plots the relationship between twins' differences in the median SAT scores of enrolled college (selectivity) and differences in graduation rates. The upward sloping line is suggestive that the twin who enrolls in the more selective school is more likely to graduate. Of course, this does not control for other important characteristics that the model includes so as to get the true causal relationship.

Again, I use two specifications: excluding and including application portfolio controls. And relative to OLS, observable family characteristics (e.g. income, ethnicity, state, cohort, etc.) must be excluded.

3.2.3. Identification

OLS

When running OLS, I use the variation in enrollment both between and within twins to estimate the effect of college selectivity on four-year graduation rates. This variation is conditional on student, parent, and local characteristics. Assuming equations (1) and (2) are correctly specified, one must assume that $\mu_i = 0$ or that $Corr(\mu_i, Z_{1i}) = Corr(\mu_i, Z_{2i}) = 0$ to get an unbiased estimate of β. In other words, is there something, such as an unobserved parental characteristic or student aspiration, that influences both a student's enrollment decision and the likelihood of graduating? Correctly specifying equations (1) and (2) means that there can be no student level or twin level unobservables that are correlated with the median SAT score of the enrolled college to obtain causal estimates. These valid concerns motivate other specifications.

Application Portfolio Controls

Next, I include controls for application portfolio characteristics, P_{1i} and P_{2i}. Dale and Krueger (2002) argue that by including application portfolio controls (or fixed effects), the econometrician can compare two students with the same motivation or aspiration. Identification comes from variation within students who have the same portfolio. The hope is that conditional on the same portfolio and student characteristics,

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[12] When the group size equals two, first differences and fixed effects models are equivalent.

there are no unobservables that affect the probability of graduating and that also correlate with the enrollment decision.

As an example, suppose students A and B have identical observable characteristics and both apply to only Sun University and Snow University and both students are admitted to both schools. Snow University is more selective than Sun University. Since student A prefers the snow, she definitely chooses the more selective Snow University. However, student B prefers the sun and she chooses the less selective school. Hence two observationally identical students end up at two schools of differing selectivity, but not because one is more motivated than the other.

However, unlike Dale and Krueger (2002), I do not observe where students are admitted, only where they apply. They argue that including controls for where students are accepted controls for student ability that is unobservable to the econometrician but is observable to the admissions committees: a potential source of bias. For example, students who write strong admissions essays may be more likely to graduate than observationally identical students, simply because a strong essay is an indicator of talent or motivation that is not easily quantifiable. To mitigate this issue, I include as many controls as possible including student, family, and local characteristics. But there may still be unobservable student characteristics that determine admission. This introduces both opportunity and threats.

There may exist randomness in the admissions decisions unrelated to unobservable student ability. For example, two students identical on all measures related to graduation rate probability, may write essays of identical quality that differ in their appeal to an admissions officer. Hence, two identical students may have different choice sets by virtue of an essay topic. As another example, two students may be identical but live in different states. If they apply to the same schools they may have different admission outcomes based on preferences of the schools or cohorts sizes within states. And as a final example, one student may get a 1200 on her SATs and another student may get an 1190, which may produce differential choice sets.

Overall, once the application is controlled for, identification comes from randomness in student and college preferences that are unrelated to unobservable student quality.

Twin Fixed Effects

Including twin fixed effects eliminates unobservable family characteristics that may influence enrollment and graduation decisions. This relaxes the assumptions that $\mu_i = 0$ and the assumption that μ_i must be uncorrelated with Z_{1i} and Z_{2i}. Hence, identification comes from variation in school enrollment choices within sets of twins. And when controlling for the application portfolio, the variation is within a family and within a portfolio.

Once again, the remaining threat to validity is the existence of unobservable student-level characteristics that influence college choice, and independently, the probability of four-year graduation rates, after controlling for family fixed-effects and application portfolio. It is difficult to entirely eliminate this threat but the specifications in this paper do eliminate the likely culprits of bias.

4. Results

Table 2 presents the main set of results. Column (1) presents OLS results when using the full sample of SAT test takers and controlling for student and family varying characteristics. The coefficient on median SAT of college enrolled is 0.054 and the very small standard errors generate statistical significance. This implies that attending a college where the median student SAT is 100 points above the alternative college results in a 5.4 percentage point increase in graduation probability. Column (2) includes controls for the type of application portfolio, and results in a very similar estimate of 0.051. This suggests that, after controlling for student demographics and measures of academic achievement, the composition of the application portfolio has very little explanatory power.

The next two columns run the same regressions but only for the sets of twins. Coefficient estimates are over 5 percentage points and statistically significant. Similar to the full sample estimate, portfolio characteristics controls do not change the estimates in a meaningful way.

Columns (5) and (6) are results from the twin fixed effects models. The coefficient estimates here are 0.052 and 0.048 when excluding and including portfolio controls, respectively. These estimates are comparable to the OLS estimates.

Overall, these results suggest that, when choosing between two colleges where the typical students differ by 100 SAT points, the student will enjoy a five percentage point increase in graduation probability by attending the college with the higher median SAT score. Moreover, the results also suggest that many of the major selection issues that researchers discuss, such as family unobservables and unobservable desire to attend and graduate from college, do not have a strong impact on the estimates.

4.1. Robustness Checks

4.1.1. Portfolio Fixed Effects

The first robustness check identifies whether the previous controls for application portfolios are too restrictive. Hence, I follow the methodology of Dale and Krueger (2002) by creating dummy variables for students with similar portfolios. I then re-estimate the models but only include students that have at least one other student who has a similar portfolio.[13]

To construct similar portfolios I use the median SAT of enrolled students for every school that received a Score Send.[14] Schools are then placed into 25 SAT point buckets. For example, there is a bucket for schools with median SATs between 1101 and1125 and a bucket for schools with median SATs between 1126 and 1150. This

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[13] I present results that include students who only apply to one school while Dale and Krueger (2002) exclude these students. The results are not sensitive to the exclusion of them.

[14] This excludes two-year institutions and the few non-academic institutions (e.g. financial aid institutions). Some schools only report the average ACT score but I convert them with the aforementioned ACT/SAT concordance table.

generates 34 buckets. For each student, I construct the count of Score Sends in each of the 34 buckets. A student's portfolio is described by the 34 element vector. I then create a set of dummy variables for each unique vector. I only include students who have the same portfolio as at least one other student.[15]

Results are presented in Table 3. The first two columns use the full sample of students with matched portfolios. The first column yields an estimate of 0.052 and once portfolio fixed effects are included, the estimate drops slightly to 0.049. Using the sample of twins and OLS gets very similar results. The estimate is 0.054 when using twin fixed effects but no portfolio fixed effects. The last column, which has both fixed effects, actually presents an increase in the estimate to 0.063.

Including portfolio fixed effects is much less restrictive but comes at the cost of a smaller sample and less precision. However, estimates across the table are very near five percentage points and statistically different than zero.

4.1.2. Alternative Measures of Selectivity

Median SAT of enrolled students is an imperfect measure of college selectivity. Consequently, I re-run the regressions with five different measures of selectivity: acceptance rate, six-year graduation rate, freshman retention rate, expenditures per student, and faculty to student ratio. These selectivity measures are also imperfect but collectively, if they yield similar results to the previous table, then the estimated effect is strongly supported.

Table 4 presents results from the four main regressions and only use the twin sample. A clear pattern appears when scanning the rows: all estimates are statistically significant and directionally consistent with the median SAT result. For example, in the first column, there is a negative relationship between acceptance rates and graduation rates. And a high acceptance rate is not considered to be a sign of a selective school. All other coefficients in the column are positive because the greater each measure, the more selective a school is likely to be.

There is also a clear pattern when scanning across the columns: including twin fixed effects and portfolio controls reduces the coefficient estimates' magnitudes. That is, the last column's estimates are all smaller in magnitude than the first column's estimates. Together with Table 2, there is slight evidence that OLS results are biased upwards, but not by much.

5. Extensions

5.1. Nonlinear Effects

The previous results assumed a linear relationship between median college SAT and graduation probability, but the true effect may be nonlinear. To capture the potential nonlinearities, I create several dummy variables for the median SAT of the school enrolled: less than 1000, between 1000 and 1099, between 1100 and 1199, between 1200

[15] Including students who had a portfolio that no one else applied to does not affect estimates because there is no within portfolio variation when including portfolio fixed effects.

and 1299, and greater than or equal to 1300. Table 5 presents results of the four main models that use the twin sample. The omitted category includes schools where the median SAT is less than 1000-the least selective schools.

The first column is the result of running OLS. Students who enroll in the most selective schools are about 20 percentage points more likely to graduate than those who enroll in the least selective schools. There is a substantial 10 percentage point increase in the magnitude of the coefficient when going from schools with a median SAT between 1000-1099 to those with a median SAT between 1100-1199. All other coefficients change by approximately 3 to 4 percentage points across categories.

When looking at the next few columns, a few results stand out. First, there always appears to be a noticeable increase in the graduation rate when going from schools between 1000-1099 and 1100-1199, even with more controls. Second, the differences between schools with median SATs less than 1000 and 1000-1099 are small (and statistically insignificant). Third, there are no statistical differences between the most selective schools and schools with median SATs between 1200 and 1299.

Overall, the full model with twin fixed effects and application portfolio controls implies that there are nonlinearities. The nonlinearities suggest that the largest gains in graduation probability occur when choosing moderately selective colleges over less selective colleges, rather than highly selective colleges over moderately selective colleges.

5.2. Heterogeneous Effects

This subsection uses subsamples to test whether there are heterogeneous effects on the outcome by gender, race/ethnicity, parental income, and high school urbanicity.[16] The four main specifications are used.

5.2.1. Gender

I first split the sample by twins' genders: male only, female only, and mixed gender sets. This exercise offers two pieces of information. First, it sheds light on who is driving the previous results. Second, same sex twins are comprised of identical and non-identical twins. But identical twins are, as the name implies, genetically identical. Berman, Rosensweig, and Taubman (1996) argue that identical twins not only eliminate family fixed effects, but also genetic fixed effects that may bias results. Hence, if the coefficient estimates substantially differ between the mixed gender and same gender twins, there is suggestive evidence that genetic differences play an important role in the estimation.

Table 6 presents results of the estimation by gender subsample. Using male only twins, the full model's estimate is 0.061 and this does not differ much from the basic OLS estimate. On the other hand, female only twins have an estimate of only 0.032,

[16] Some students have missing data and are excluded so subsample counts do not necessarily sum to the full twin sample.

which is also substantially lower than the OLS estimate. Finally, the mixed gender twins have an estimate of 0.056.

Combined, this is evidence that college selectivity has a greater impact on graduation probability for males, compared to females. Also, the unobservable family fixed effect is stronger for female twins. Moreover, mixed gender twins estimates fall in between the same sex estimates. Though it is impossible to disentangle the mixed gender effect from the non-identical twin effect, this is supportive evidence that the non-identical effect is not driving results.

5.2.2. Race, Income, Urbanicity

The next set of results uses only White students and estimates a coefficient of 0.046 in the full model. The analogous coefficient in the Black/Hispanic subsample is 0.030, but is less precisely estimated and not statistically different from the White students' coefficient.

When comparing results across income groups, there are larger coefficients for wealthier students compared to less wealthy students. Finally, when stratified by the urbanicity of the student's high school, all students' impact estimates are positive and statistically significant in the full model, but the suburban high school estimate is at least 60 percent greater than all other coefficients.

5.3. Longer Term Graduation Rates

Thus far, I use whether or not a student graduates from college in four years as the outcome variable. But only 38 percent of students at four-year institutions graduate in four years, whereas 54 percent and 58 percent graduate within five and six years, respectively (NCES 2011).[17] Hence, the effects of college selectivity may have differential effects when examining longer term outcomes.

Table 7 compares results for varying degree attainment lengths.[18] In the OLS specification, there are no statistical differences between the coefficient estimates. However, with both twin fixed effects and application portfolio controls, the estimates are larger for five year graduation rates (5.8 percentage points) and still even larger for six-year graduation rates (7.8 percentage points). This evidence suggests that the previous results may be underestimating the true effect of enrolling in a relatively selective institution.[19]

5.4. Undermatch/Overmatch

[17] The 38 percent four year graduation rate is lower than the graduation rates in this analysis because I use relatively motivated students who enroll soon after high school and take the SATs.

[18] The samples differ because longer term outcomes can only be considered for earlier cohorts.

[19] Appendix 1 shows that some, but not all, of the estimates are driven by differences in cohort s.

Finally, I compare whether the selectivity of the institution, relative to the student's own SAT has an effect on graduation probabilities. This is in the spirit of the undermatch and overmatch literatures.[20] Formally, I subtract the median SAT at the college to which the student enrolls from the student's SAT. I then create several indicators for whether there is a substantial difference between the two (e.g. more than 100 SAT points).

Table 8 displays the results of this exercise. The first three rows have different measures of undermatch but have relatively consistent results: undermatching can negatively affect the probability of graduating. However, there are not big differences in the effects across the different magnitudes of undermatch. That is, undermatching by more than 50 points is not estimated to have substantially different effects than undermatching by more than 200 points.

Relative to undermatching estimates, the overmatching estimates are smaller in magnitude and the opposite sign. There is suggestive evidence of positive benefits to overmatching, but it is not strong.

6. Conclusion

This paper has presented several results that deserve further consideration. First, the results show that enrolling in a relatively selective college increases the probability of graduating. I estimate that enrolling in a school with a median SAT score 100 points greater than an alternative school increases the probability of graduating in four years by approximately five percentage points. Long (2008) finds convincing evidence of a similar effect using instrumental variables, propensity score matching, and the Dale and Krueger (2002) method.

Second, the results are quite stable across several methodologies, including twin fixed effects and controlling for application portfolios. The stability is reassuring for researchers who do not have access to such a large set of controls but are interested in unbiased estimates between college selectivity and a host of other outcomes. The stability slightly differs from Long (2008), who identifies estimate sensitivity across models.

Third, related research is often concerned with wages, which I do not observe. Several papers find mixed evidence that there is a small but positive effect of college quality on wages, at least for some subset of students (Dale and Krueger 1994; Behrman, Rosensweig, and Taubman 1996; Long 2008). These small and often statistically insignificant estimates are consistent with the above results. Let's take the median wages of a person with an associate's degree ($42,000) and bachelor's degree ($55,700).[21] If

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[20] Undermatch first appeared in Roderick et al. (2006) and *Crossing the Finish Line* (2009). Overmatch is typically in the context of affirmative action. For a complete review of both literatures, see Smith and Pender (2012). Strictly speaking, this is not undermatch and overmatch because it does not account for where students could enroll. But relative SAT scores is a good proxy.

[21] For full-time workers over the age of 25 in 2008 and it excludes those who get more advanced degrees (Baum, Ma, and Payea 2010).

there is a five percentage point increase in probability of graduating by enrolling in a more selective school, then there is a 1.4 percent increase in expected wages. So if an increased probability of graduation is the only mechanism by which wages are higher for those who attend more selective colleges, these results are consistent with previous work since there are small effects on wages that would be difficult to precisely estimate.

Finally, despite the small back of the envelope calculation on wages, there may be other benefits to enrolling in a more selective college. Those who do attend college are more likely to have a healthier lifestyle, employment and insurance, vote, and volunteer (College Board 2012). There also exist differences between individuals who graduate college and those who attend some college (i.e. leaving before graduating) or get an Associate's degree. There is also the consumption value of college, such as students enjoying sports, activities, friendships, and other non-academic aspects of college, which has been documented to be an important decision for students (Jacob, McCall, and Stange 2012).

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Table 1: Summary Statistics

Variable	Twins Levels	Twins Differences	Full Sample Levels
Student SAT (100s)	11.180	1.054	11.105
	(1.875)	(0.923)	(1.879)
Median SAT of College Enrolled (100s)	11.454	0.602	11.323
	(1.279)	(0.826)	(1.285)
Graduated College in Four Years	0.518	0.301	0.449
	(0.500)	(0.459)	(0.497)
Number of AP Tests Taken	2.096	0.954	1.840
	(2.523)	(1.418)	(2.375)
Number of SAT2's Taken	0.882	0.361	0.835
	(1.442)	(0.868)	(1.415)
Number of Score Sends	6.034	1.660	5.951
	(3.327)	(2.000)	(3.402)
High School GPA[1]	3.611	0.336	3.526
	(0.521)	(0.374)	(0.542)
Parents' Income[2]	76,012	--	69,773
	(38,680)	--	(39,049)
Observations	22,016	22,016	2,029,483
Sets of Twins	11,008	11,008	--

Notes: Standard deviations in parentheses. Population includes SAT test takers that went to a four-year institution in the 2004, 2006, and 2007 graduating high school cohorts. Twins are identified in the population by date of birth, last name, high school, and street address.

1. Only 10,142 sets of twins and 1,872,468 of the full sample report GPA.

2. Only 6,842 sets of twins and 1,280,908 of the full sample report parents' income.

Table 2: Effect of College Selectivity on Graduation

Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise

	Full Sample		Twins			
Variable	OLS		OLS		Twin Fixed Effects	
	(1)	(2)	(3)	(4)	(5)	(6)
Median SAT of College Enrolled (100s)	0.054***	0.050***	0.058***	0.052***	0.052***	0.048***
	(0.000)	(0.000)	(0.004)	(0.004)	(0.006)	(0.007)
Family Characteristic Controls	Yes	Yes	Yes	Yes	No	No
Application Portfolio Controls	No	Yes	No	Yes	No	Yes
Observations	2,029,483	2,029,483	22,016	22,016	22,016	22,016
R-squared	0.175	0.176	0.173	0.175	0.056	0.057

Notes: Robust standard errors are in parentheses. Twins results cluster standard errors at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. Family characteristics include income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.

Table 3: Effect of College Selectivity on Graduation - Portfolio Fixed Effects

Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise

Students With Macthed Portfolios[1]

	Full Sample		Twins			
Variable	OLS		OLS		Twin Fixed Effects	
	(1)	(2)	(3)	(4)	(5)	(6)
Median SAT of College Enrolled (100s)	0.052***	0.049***	0.053***	0.051***	0.054***	0.063***
	(0.000)	(0.000)	(0.008)	(0.013)	(0.016)	(0.020)
Family Characteristic Controls	Yes	Yes	Yes	Yes	No	No
Portfolio Fixed Effects	No	Yes	No	Yes	No	Yes
Observations	1,530,932	1,530,932	7,206	7,206	7,206	7,206
R-squared	0.167	0.253	0.171	0.145	0.106	0.857

Notes: Robust standard errors are in parentheses. Twins results cluster standard errors at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. Family characteristics include income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch.

1. Students portfolios are described by the number of Score Sends to each selectivity bucket. Selectivity buckets are 25 SAT point bands (e.g. 1101-1125 and 1126-1150, etc.). A macthed portfolio is when at least two students have the same portfolio.

Table 4: Effect of College Selectivity on Graduation - Alternative Measures of Selectivity

Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise

Each Coefficient Estimate from Separate Regression

Twins Only

College Enrolled Measure of Selectivity:	OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
Median SAT of College Enrolled (100s)	0.058***	0.052***	0.052***	0.048***
	(0.004)	(0.004)	(0.006)	(0.007)
Acceptance Rate	-0.188***	-0.145***	-0.200***	-0.177***
	(0.023)	(0.024)	(0.037)	(0.038)
Six-Year Graduation Rate	0.581***	0.555***	0.500***	0.480***
	(0.030)	(0.031)	(0.048)	(0.049)
Freshman Retention Rate	0.351***	0.301***	0.367***	0.336***
	(0.037)	(0.038)	(0.068)	(0.069)
Expenditures per Student ($10,000s)	0.043***	0.037***	0.033***	0.030***
	(0.004)	(0.004)	(0.005)	(0.005)
Faculty to Student Ratio	0.012***	0.009***	0.009***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends. Some colleges do not report selectivity measures so some observations missing.

Table 5: Nonlinear Effect of College Selectivity on Graduation

Dependent Variable = 1 if Graduates from Four-Year College, 0 Otherwise

Omitted Variable = Avg. SAT of Enrolled College less than 1000

Twins Only

Variable	OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
Median SAT of Enrolled College 1000 - 1099	0.029**	0.021*	0.019	0.014
	(0.012)	(0.013)	(0.022)	(0.022)
Median SAT of Enrolled College 1100 - 1199	0.133***	0.118***	0.105***	0.096***
	(0.013)	(0.013)	(0.022)	(0.023)
Median SAT of Enrolled College 1200 - 1299	0.169***	0.149***	0.156***	0.145***
	(0.015)	(0.016)	(0.025)	(0.025)
Median SAT of Enrolled College Greater Than 1300	0.204***	0.170***	0.172***	0.154***
	(0.018)	(0.020)	(0.029)	(0.030)
Observations	22,016	22,016	22,016	22,016
R-squared	0.174	0.176	0.057	0.058

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.

Table 6: Heterogeneous Effect of College Selectivity on Graduation
Coefficient Estimates of Median SAT of College Enrolled (100s)
Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise
Each Coefficient Estimate from Separate Regression
Twins Only

	OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
All Twins (obs = 22,016)				
	0.058***	0.052***	0.052***	0.048***
	(0.004)	(0.004)	(0.006)	(0.007)
Male Only (obs = 7,220)				
	0.057***	0.049***	0.063***	0.061***
	(0.007)	(0.008)	(0.011)	(0.011)
Female Only (obs = 9,340)				
	0.054***	0.049***	0.034***	0.032***
	(0.006)	(0.007)	(0.010)	(0.011)
Mixed Gender (obs = 5,456)				
	0.066***	0.059***	0.064***	0.056***
	(0.008)	(0.008)	(0.012)	(0.012)
White Students (obs = 14,314)				
	0.054***	0.046***	0.049***	0.046***
	(0.005)	(0.006)	(0.008)	(0.009)
Black and Hispanic Students (obs = 2,974)				
	0.045***	0.040***	0.036**	0.030**
	(0.009)	(0.010)	(0.014)	(0.015)
Parents' Income Less Than $50,000 (obs = 4,248)				
	0.040***	0.042***	0.039***	0.038**
	(0.008)	(0.009)	(0.015)	(0.016)
Parents' Income More Than $50,000 (obs = 9,436)				
	0.053***	0.046***	0.049***	0.044***
	(0.006)	(0.007)	(0.011)	(0.012)
Urban High School (obs = 5,792)				
	0.062***	0.056***	0.039***	0.039***
	(0.007)	(0.008)	(0.012)	(0.012)
Small City/Town High School (obs = 3,220)				
	0.033***	0.035***	0.039**	0.036**
	(0.011)	(0.012)	(0.016)	(0.017)
Suburban High School (obs = 9,256)				
	0.064***	0.057***	0.069***	0.066***
	(0.006)	(0.007)	(0.010)	(0.010)
Rural High School (obs = 2,620)				
	0.055***	0.044***	0.049**	0.041**
	(0.012)	(0.013)	(0.019)	(0.021)

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.

Table 7: Effect of College Selectivity on Longer Graduation Rates
Coefficient Estimates of Median SAT of College Enrolled (100s)
Each Coefficient Estimate from Separate Regression
Twins Only

OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise (obs = 22,016)			
0.058***	0.052***	0.052***	0.048***
(0.004)	(0.004)	(0.006)	(0.007)
Dependent Variable = 1 if Graduates in Five Years, 0 Otherwise (obs = 14,709)			
0.061***	0.062***	0.059***	0.058***
(0.005)	(0.005)	(0.008)	(0.008)
Dependent Variable = 1 if Graduates in Six Years, 0 Otherwise (obs =7,134)			
0.059***	0.065***	0.076***	0.078***
(0.007)	(0.008)	(0.011)	(0.012)

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.

Table 8: Effect of Undermatch/Overmatch on Graduation

Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise

Each Coefficient Estimate from Separate Regression

Twins Only

Binary Indicator of Undermatch/Overmatch:	OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
SAT Score 50 Points Greater Than Median at College Enrolled	-0.095***	-0.076***	-0.062***	-0.056***
	(0.009)	(0.009)	(0.012)	(0.012)
SAT Score 100 Points Greater Than Median at College Enrolled	-0.114***	-0.095***	-0.078***	-0.072***
	(0.010)	(0.010)	(0.013)	(0.013)
SAT Score 200 Points Greater Than Median at College Enrolled	-0.095***	-0.070***	-0.083***	-0.076***
	(0.016)	(0.016)	(0.020)	(0.020)
SAT Score 50 Points Less Than Median at College Enrolled	0.084***	0.066***	0.044***	0.037***
	(0.009)	(0.009)	(0.011)	(0.011)
SAT Score 100 Points Less Than Median at College Enrolled	0.074***	0.055***	0.020*	0.012
	(0.009)	(0.009)	(0.012)	(0.012)
SAT Score 200 Points Less Than Median at College Enrolled	0.058***	0.040***	0.034**	0.026*
	(0.012)	(0.012)	(0.016)	(0.016)

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.

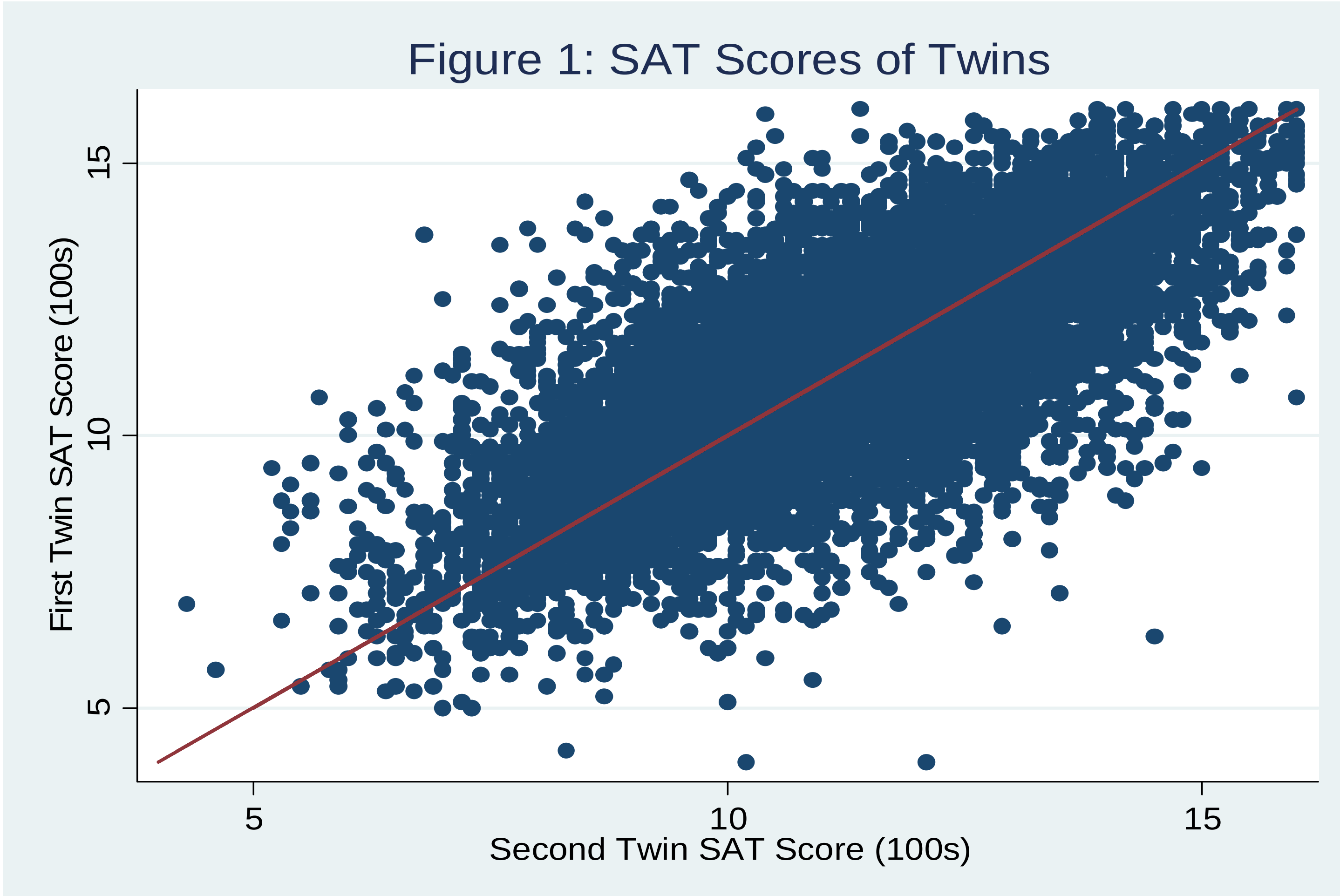
Figure 1: SAT Scores of Twins
First Twin SAT Score (100s)
5
10
15
Second Twin SAT Score (100s)
5
10
15

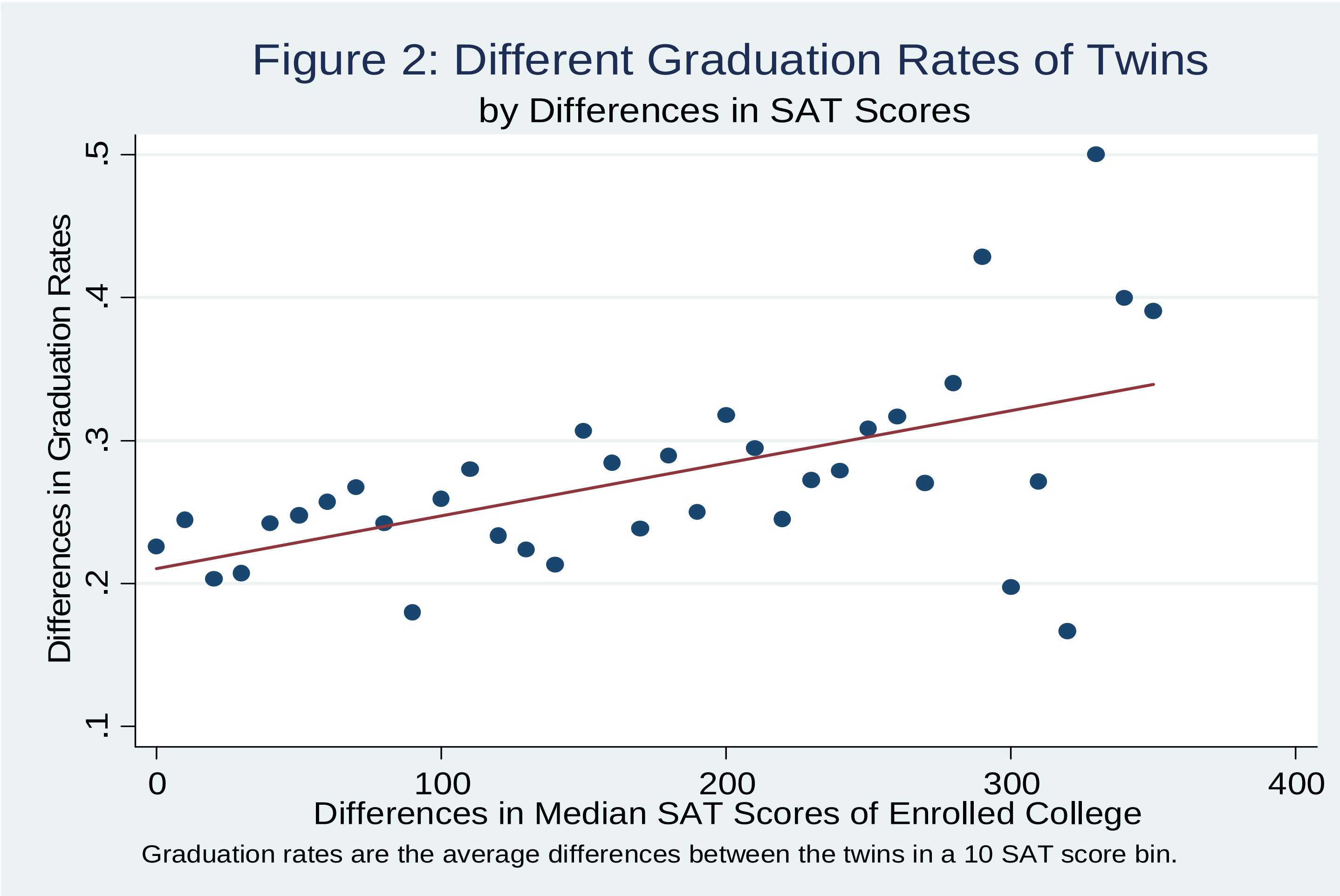

Figure 2: Different Graduation Rates of Twins
by Differences in SAT Scores
Differences in Graduation Rates
.1
.2
.3
.4
.5
0
100
200
300
400
Differences in Median SAT Scores of Enrolled College
Graduation rates are the average differences between the twins in a 10 SAT score bin.

Appendix 1: Effect of College Selectivity on Graduation by Cohort
Coefficient Estimates of Median SAT of College Enrolled (100s)
Dependent Variable = 1 if Graduates in Four Years, 0 Otherwise
Each Coefficient Estimate from Separate Regression
Twins Only

OLS	OLS with Portfolio Controls	Twin FE	Twin FE with Portfolio Controls
All Twins (obs = 22,016)			
0.058***	0.052***	0.052***	0.048***
(0.004)	(0.004)	(0.006)	(0.007)
2004 Cohort (obs = 7,134)			
0.073***	0.068***	0.066***	0.064***
(0.007)	(0.008)	(0.011)	(0.012)
2006 Cohort (obs = 7,574)			
0.056***	0.051***	0.055***	0.050***
(0.007)	(0.008)	(0.010)	(0.011)
2007 Cohort (obs = 7,308)			
0.047***	0.038***	0.038***	0.032***
(0.007)	(0.008)	(0.011)	(0.011)

Notes: Standard errors in parentheses and clustered at the twin level. *** means significant at 1% level, ** at 5%, and * at 10%. All regressions control for SAT score, number of SAT2's taken, dummies for number of AP tests taken and GPA, and a male dummy. OLS regressions control for income, ethnicity, state residence, native language, citizenship, father's and mother's education, county unemployment rate and education, and high school percent free and reduced price lunch. Application portfolio controls include number of Score Sends and the minimum, mean, and maximum average SAT score of enrolled students for the colleges in the portfolio of Score Sends.