The Impact of International Students on U.S. Graduate Education

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Abstract

This paper examines whether international students affect native enrollment in graduate programs. I study a unique boom and bust cycle in international graduate enrollment at U.S. Research universities from 1995-2005. To mitigate endogeneity bias I develop supply-driven instruments by interacting historical university-level graduate enrollment by country of origin with college age (18-30) population growth in the respective sending countries, for the boom, and 9/11 policy induced declines in student visa issuance to each country group, for the bust. Results reveal that foreign students crowd in natives–1 additional (fewer) foreign student leads to 1 additional (fewer) native. Effects appear stronger for natives in STEM than certain non-STEM fields (i.e. Education, Law, and Business). Peer effects that spur native demand, and complementarities with faculty that relax supply constraints appear to explain the crowd in effects.

JEL Codes: F22, I21, I23, J11
Keywords: Foreign students, International enrollment, Native enrollment, Graduate Education, Crowd out, Crowd in.

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1 Introduction

Over the last half-century U.S. graduate education sustained a remarkable internationalization. Non-citizens on temporary student visas, commonly referred to as international or foreign students, grew from 130,000 in 1970 to 720,000 in 2010, even outpacing immigration which grew four-fold over this period. Currently, at the graduate level 15% of all students and 1-in-3 degree recipients in Science, Technology, Engineering, and Mathematics (STEM) hail from overseas (NSF 2013). The strength of U.S. higher education and an unusually open door policy towards foreign students has helped attract growing numbers of students from abroad. However, curiously little is understood about how this internalization has affected U.S. graduate education, and in particular, the educational outcomes of U.S. natives.

This paper examines whether international students impact the enrollment of native students in graduate programs. If graduate education is inelastically supplied, increased competition from abroad may reduce admittances of U.S. natives or exacerbate attrition of continuing native students. Alternatively, foreign students may bring new opportunities for research collaboration or diverse knowledge that increases native demand for graduate education. Additionally, as research and teaching assistants foreign students may complement faculty in producing research and providing undergraduate education, or bolster resources through full-sticker price tuition payments, thereby alleviating supply constraints in graduate schools.

Several scholars have explored how foreign students affect native educational outcomes in elementary school, high school, and college (e.g. Hoxby 1998; Betts 1998; Hunt 2012; Jackson 2013; Ohinata & Van Ours 2013). My work, however, focuses specifically on graduate education, encompassing first-professional, masters, and doctoral degree programs. Compared with other levels of education, international student presence is very high at the graduate level. For example, international students comprise only 4% of total enrollment at the undergraduate level, compared to 15% at the graduate level. Furthermore, in many graduate level STEM disciplines, and even some non-STEM fields like economics, over 50% of all students are from overseas (Bound, Turner, & Walsh 2009; Freeman 2010).

Additionally, high attrition rates in graduate schools have raised concern amongst policymakers and educators. Survey data from the Council of Graduate Schools revealed only 57% of Ph.D. students in the 1992-93 through 1994-95 cohorts had completed their degree by 2004-05 (Sowell 2008). In many STEM programs, native completion rates are much lower than their foreign-born peers. For example, Sowell (2008) reveals that within 10 years of beginning their Ph.D. programs in Math and Physical Sciences, nearly 70% of foreign students had completed their Ph.D. compared with only 51% of natives. In Masters programs, nearly a quarter of students in STEM disciplines have dropped out within 2 years (CGS 2013). Especially high attrition rates of native Black and Hispanics in STEM programs have also widened gaps in educational attainment for minorities. The widespread failure in completing graduate programs is costly and may directly lead to shortages of high skill workers. Examining whether foreign students affects native enrollment in graduate programs helps inform whether foreign competition is culpable for these concerns.

Focusing on graduate education is also important because it endows workers with the advanced skills necessary for innovation and technological progress, which in turn spur economic growth (e.g. Romer 1990; Jones 1995). The effect of international students on native enrollment is especially relevant to the supply of skills as immigration policy tightly restricts the number of individuals who can remain in the U.S. after completing their studies.[1] Finn (2003) estimates that approximately 32% of foreign doctoral recipients have left the U.S. within the two years after receiving their degree. Therefore, if each foreign student crowds out one native, this would directly translate into reductions in the supply of high skill workers and hinder innovation. Alternatively, if foreign nationals increase the number of natives in graduate schools, this would expand the supply of advanced skills and help stimulate technological progress.

A growing body of related research has found that highly educated immigrants tend to concentrate in STEM occupations, and that foreign STEM workers have had both competitive and complementary effects on the labor market outcomes of natives (e.g. Kerr & Lincoln 2010; Borjas & Doran 2012, 2013; Moser, Voena, & Waldinger 2014; Peri, Shih, & Sparber 2014). Foreign graduate students, who also concentrate heavily in STEM fields, may impart similar externalities on their native peers. This research expands the scope of studies on the economic impact of immigration by shifting the focus from labor markets to higher education.

Finally, renewed efforts at immigration reform have sparked intense policy debate over international students. Industry leaders argue that labor market skill shortages necessitate increased pathways for foreign students to secure U.S. jobs after graduating, while others

[1]While there are no caps on the number of foreign students, there are strictly regulated caps on the entry of nearly all other groups of foreign nationals, making it very difficult for international students to secure work in the U.S. The main channel for foreign graduates of U.S. universities to work in the U.S. is to secure an H-1B visa, which has a cap of 65,000 per year, plus an additional 20,000 for graduates from U.S. universities with a masters degree or higher.

counter that native workers would suffer. Curiously, however, few ask whether foreign students affect the educational attainment of native students, even though U.S. immigration policy places no numerical limits on student visa issuance, and increased foreign competition in graduate programs might directly create labor market skill shortages. By identifying how native enrollment in graduate programs is affected by international students, this research directly evaluates how U.S. student visa policy has impacted U.S. graduate education.

Studies have uncovered positive links between international graduate students, university patenting, and academic research in STEM departments (Chellaraj, Maskus, & Mattoo 2008; Maskus, Mobarak, & Stuen 2012). Previous research on whether international students affect native outcomes at the graduate level has been sparse. While these studies all focus on understanding whether foreign students crowd in or crowd out natives, they arrive at vastly different findings.

Bound, Turner, & Walsh (2009) explore a large inflow of Chinese students into U.S. Physics Ph.D. programs after the renormalization of relations with China in 1979. Using descriptive analysis they show the number of native Ph.D. recipients in Physics actually grew over the 1980s. While this evidence supports the hypothesis that foreign students do not crowd out natives, and may actually crowd in natives, the authors acknowledge that such trend analyses lack a causal interpretation.

Borjas (2007) adopts regression-based methods to assess whether foreign students crowd natives out of graduate education. Using panel fixed-effects regressions on university-level enrollments from the Institutional Post-secondary Education Data System (IPEDS), Borjas (2007) finds negative associations between foreign and enrollment of White natives. While this finding suggests that international students crowd out natives, positive correlations appear for native Asians, Blacks, and Hispanics. Regets (2007) implements an identical panel regression specification on enrollment data from the Survey of Graduate Students and Postdoctorates in Science and Engineering (SGSPE) from 1982-1995. Quite different from Borjas (2007), foreign enrollments in Science and Engineering programs are positively correlated with native White enrollment, and negatively correlated with enrollment of native Asians.

Using data on doctoral degrees conferred by field of study from the Survey of Earned Doctorates (SED) from 1966-2002, Zhang (2009) adopts a similar panel approach that leverages within-field instead of within-university variation. Within Science and Engineering (S&E) disciplines, the number of doctoral degrees awarded to foreign students is positively correlated with the number awarded to natives. In contrast, non-S&E fields show a negative correlation between foreign and native doctoral degree attainment, suggesting that the effects of international students on natives may differ across field of study.

Different sources of variation, data, and periods of study make reconciling these inconsistent findings difficult. Furthermore, the potential endogeneity bias underlying the methodological approaches clouds any causal inference that can be drawn from these studies. The regression-based studies (Borjas 2007; Regets 2007; Zhang 2009) attempt to abate such concerns by using panel fixed effects models to remove bias from time-invariant characteristics of universities or fields of study. Nonetheless, confounding factors that vary within universities (or fields) over time remain problematic. Increases in university quality, for example, may attract both natives and foreign students, and lead to upward biased estimates.

I extend the existing research in several important ways. Primarily, I address endogeneity bias by focusing on an unprecedented boom and bust cycle in foreign graduate enrollment over the 1995-2005 decade. From 1995-2001 U.S. Research I and II (Research) universities experienced nearly 50% growth in graduate enrollment from abroad–a tremendous figure considering the mild 8% growth from 1990-1995. The terrorist attacks of September 11th, 2001, and the subsequent discovery that several hijackers had exploited student visas, led to the creation of new security policies focused on monitoring foreign students. Flaws in the design of these new policies led to lengthy processing times for student visa applications, which effectively put an end to the dramatic boom in foreign students during the late 1990s. Graduate programs saw their foreign enrollment decline from 2002 to 2005. By 2006 the initial design flaws and student visa processing times began to clear up and foreign graduate enrollment resumed its upward climb (GAO 2005; Freeman 2010).

To correct for endogeneity bias I utilize supply-side forces that contributed to this boom and bust in foreign graduate students to augment an instrumental variables technique often used to evaluate the impact of immigration on native labor market outcomes (e.g. Card 2001, Kerr & Lincoln 2010 and Peri, Shih, & Sparber 2014). Importantly, growth in the college age (18-30) population in sending nations helped sustain the boom until the September 11th, 2001 terrorist attacks and ensuing policy response shuttered foreign student entry. Crucially, these supply-side forces were unrelated to endogenous factors affecting graduate education within U.S. universities.

To construct a powerful instrument, I exploit the notion that universities with large historical international graduate enrollment develop strong foreign student networks which attract future international students when supply shocks occur. Since these networks are likely to operate more strongly among individuals from the same country[2], I require detailed data on historical foreign graduate enrollment by country of origin at each university. While publicly available data only contain aggregate counts of foreign students by university, I obtain restricted-access data from the Institute of International Education (IIE) which provides foreign graduate enrollment by country of origin and by university in 1993.[3] This novel data source allows me to capture the strength of student networks and develop a powerful instrument.

I group countries into 17 nationality groups, and for each university I interact the nationality distribution of foreign graduate enrollment in 1993 with growth in the college age population by nationality over the boom, and 9/11 policy induced aggregate declines in student visa issuance to each nationality group over the bust. Summing these interactions across all nationalities forms exogenous, supply-driven predictions of actual international graduate enrollment over the 1995-2005 decade. These supply-driven predictions help form powerful instruments for actual university-level foreign enrollment, and distill exogenous variation to identify impacts on native enrollment.

In addition to addressing endogeneity bias through instrumental variables, I also adopt a more demanding panel specification that accounts not only for time-invariant university factors, but also for university-specific factors that grow linearly over time. Also distinct from prior literature, I explore two different sources of variation–my empirical analysis separately estimates the effect of increases in foreign enrollment over the boom, and decreases in foreign enrollment over the bust.

I find that foreign graduate students increase native enrollment. Results for the boom period are precisely estimated and suggest that an additional foreign student leads to one additional native. Analysis of the bust period results in effects of the same magnitude that are less precisely estimated–a decline in one foreign student also leads to a loss of one native student. As nearly 50% of foreign graduate students study STEM fields, I explore heterogeneity across fields of study. I find crowd in effects to be stronger in STEM fields than the non-STEM fields available in the data (Law, Business, and Education). Data limitations, however, preclude definitively ruling out effects in other non-STEM fields.

[2]For example, consider the case where Chinese students from UC Davis return home and tell younger Chinese students about their experiences. This builds name brand recognition for UC Davis, which is a useful advantage in recruiting new Chinese students. It is less clear that such networks would operate across countries.

[3]Data prior to 1993 was not available.

Lastly, I explore various mechanisms that explain the observed crowd in effects. The 1-for-1 crowd in effects appear to be due to both increases in native demand and expansions in the supply of graduate education. To assess effects on native demand for graduate education, I develop an index of similarity to foreign students for different groups of native students using information on both native and foreign student distributions across fields of study. Point estimates from 2SLS regressions on enrollment of these different native groups increase with the groups similarity to foreign students. This suggests positive externalities or peer effects accrue to groups more likely to interact or more exposed to foreign students, and spur native demand for graduate education. Additionally, growth in foreign enrollment is associated with increases in faculty, which may alleviate supply constraints. Growth in faculty may arise from complementarities between foreign graduate students and faculty in the production of research or undergraduate and graduate education. After examining the effect of foreign students on per student revenues or tuition prices, I find no evidence to support the hypothesis that international students cross-subsidize the education of natives by paying full sticker-price tuition.

The next section provides a brief summary of the boom and bust in international graduate students over the 1995-2005 decade to provide a richer context to the period under analysis. Section 3 then describes the methodology and data. Section 4 details the construction of the instrumental variables and demonstrates the first stage power. Section 5 presents the main 2SLS results for native enrollment. Section 6 examines the validity of the instruments, providing a detailed discussion of exclusion restrictions and also various robustness checks of the main results. Section 7 examines the mechanisms underlying the crowd in effects, assessing whether peer effects that stimulate native demand, or growth in faculty that expands the supply of graduate education can explain the findings. Lastly, section 8 concludes.

2 International Graduate Students and the Boom and Bust of 1995-2005

Over recent decades, U.S. graduate programs have seen rising international enrollment (figure 1A). The decade between 1995 and 2005 was particularly volatile–a rapid boom in students from abroad lasted until 2002, after which foreign graduate enrollments declined until 2005. During this boom and bust[4] cycle the percentage of foreign graduate students

[4]Though the declines in international enrollments after 2002 were not as large or as fast as increases during the boom, I refer to the 2002-2005 period as a bust as it marks an unprecedented fall in international graduate students in the United States. The 2002-2005 period may also be characterized as a break in trend.

climbed nearly 3 percentage points from 1995-2002 and then fell by more than 1 percentage point from 2002-2005 (figure 1B).

Curiously, this boom and bust in international graduate students was not felt equally across all swaths of higher education. Figure 2 plots foreign enrollment from 1995-2005 by academic level (graduate and undergraduate) and by university type according to the 2000 Carnegie Classification (Baccalaureate, Masters, or Research). Baccalaureate and Masters institutions saw little fluctuation in foreign enrollment. Interestingly, it was Research universities that sustained the majority of the boom and bust in foreign graduate students. Remarkably, from 1995-2005 foreign undergraduate enrollment at Research universities exhibited almost no change.

By the mid-1990s there was much uncertainty over the ability of U.S. universities to remain the world leaders in hosting international students. Stagnant international enrollment in the early 1990s, combined with investigations into foreign student visa policy after the 1993 World Trade Center bombing generated concern that the global allure of American Universities was in decline.[5] Few signs hinted at the surge in international graduate students at Research universities that was to come.

Unexpectedly, Research universities began to see graduate enrollments from abroad grow after 1995 and accelerate through the turn of the millennium. By 2002 foreign graduate enrollment had grown by over 45% from its 1995 level (see figure 3A). Significantly, the U.S. experienced two other boom and bust cycles over the same period that may have contributed to the foreign graduate student boom and bust. In the late 1990s Congress temporarily raised the cap on H-1B visas and then lowered the cap to its original level in 2004, leading to a rise and subsequent fall in the number of highly skilled foreign professionals working in the U.S. Additionally, the late 1990s saw a large bubble in the equity values of U.S. internet-based companies that burst in 2000 which became known as the "Dot Com" boom and bust. Figure 3 compares the boom and bust in foreign graduate enrollment (figure 3A) with expansions and contractions to H-1B visa policy (figure 3B), and the rise and fall in stock prices of U.S. internet-based companies (figure 3C).

While such economic phenomena may have encouraged this sudden acceleration in for-

[5] Investigations revealed that Eyad Ismoil, one of the terrorists in the 1993 bombing, had overstayed his student visa and should have been deported. A New York Times article, "Fewer Foreigners Choosing U.S. Colleges" published on November 23rd, 1995 expressed concern that declining international enrollment and increased competition other nations would threaten U.S. higher education. See http://www.nytimes.com/1995/11/24/us/fewer-foreigners-are-choosing-us-colleges.html.

eign enrollment, demographic shifts in sending nations also helped sustain the large inflows of graduate students from abroad. In particular, expansions in the college age (18-30) population in countries around the world also raised the supply of international students to the United States, and importantly, were plausibly unrelated to other factors affecting U.S. graduate education. My empirical strategy exploits college age population growth in sending countries to develop an exogenous, supply-push instrument for actual increases in foreign enrollment over the boom.

The surging graduate enrollment from abroad was suddenly interrupted after the September 11th, 2001 terrorist attacks. Upon discovering several terrorists had exploited student visas, policy makers scrambled to close loopholes in the student visa program.[6] The passage of the USA Patriot Act in October of 2001 and the Enhanced Border Security and Visa Reform Act in May of 2002 slowed foreign student entry in two broad manners.

First, they broadened the sharing of educational records by Federal agencies for security purposes. This lengthened the time needed to check student visa applications for potential fraud, thereby raising wait times for student visa processing (GAO 2005).[7] Second, the passage of these acts generated funding and hard deadlines for the implementation of a comprehensive internet-based student tracking system entitled the Student Exchange and Visitors Information Service (SEVIS). By January 1st, 2003 all universities hosting international students were required to enter all information on their foreign students to SEVIS. The initial rollout of SEVIS, however, created severe complications for university administrators– technical glitches in software and complex new regulations led to further delays in student visa processing (Alberts 2007).[8]

The combination of increased security checks on student visa applications and the bungled implementation of SEVIS interrupted the boom in foreign graduate enrollment. Interestingly, in the first year after 9/11 international graduate enrollment continued to grow (between 2001 and 2002), even though the number of student visas issued saw a large drop.[9] After

[6]Notoriously, two 9/11 hijackers obtained a student visa but never actually showed up to classes. Loopholes in the student visa program were so severe that in March 2002, the INS sent student visa approval notices for two of the 9/11 hijackers to the flight school to which they had applied. See Wasem (2002) or the September 27th, 2001 New York Times article, "Suspects in Hijackings Exploited Loopholes in Immigration Policy" for more details.

[7]For example, by October of 2003 the average processing time for petitions that fell under Visa Mantis, a security clearance program for students and scholars working with sensitive technologies had grown to over 80 days.

[8]Of the many problems the SEVIS created includes an instance where documents from one University printed out at a different University (Miller 2003).

[9]Appendix figure A.1 displays visa issuances for all classes of student visas (F-1, J-1, M-1). Importantly,

2002, graduate enrollment from abroad first stagnated and then began to decline. The bust in foreign graduate students was temporary–issues with SEVIS and visa processing delays were cleared up by 2005, after which graduate enrollment from abroad continued its upward climb.

My empirical strategy leverages these post-9/11 policies by using nationwide reductions in student visa issuance to form an instrument for declines in international graduate enrollment during the bust. These policies had a profound effect on reducing international enrollment, yet were plausibly exogenous to the enrollment of natives in graduate programs. Before describing the instrumental variables in greater detail, two additional features of international graduate students over the boom and bust cycle help enrichen the context underlying the analysis.

Figure 4 plots the share of international students across five fields of study from 1997-2005. More than half of all graduate students from abroad were enrolled in STEM disciplines, and this share was relatively constant over 1997-2005 period. Thus, the boom and bust in international enrollment was likely felt most strongly by STEM departments. The next largest fields of study were Social Science and Business, followed by Arts & Humanities. Overall, in the aggregate there did not appear to be substantial changes in the composition international students in terms of their distribution across fields of study.

A second interesting feature regarding the composition of international students pertains to their countries of origin. While the U.S. hosts international students from nearly every nation in the world, the majority of foreign students over this period came from only a few countries. Figure 5 reveals that 40-50% of all foreign graduate students came from Asia. Furthermore, China and India were the main contributors, each comprising roughly 20% of total international enrollment. The next largest groups include students from Europe and the Americas, followed by the Middle East and Africa.

Importantly, the boom and bust in graduate enrollment was not specific to any single country. Figure 6 plots standardized[10] enrollment trends from 1995-2006 by region (Asia,

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visa issuance data represents inflows while enrollment figures (e.g. figures 1A, 2, and 3A) represent stocks. Interestingly, figure A.1 shows a large drop in visas issued from 2001-2002, while figure 3A shows that foreign graduate enrollment grew from 2001-2002. This may be due to several factors, for example, perhaps the declines in student visa issuances applied to non-graduate students. Unfortunately, no data on graduate students by level (new vs. existing) is available. Therefore, 2001-2002 is dropped from the analysis of the boom period.

[10]Enrollment have been standardized within countries. Specifically, enrollment figures for each country-year are standardized by the mean and standard deviation of enrollments for that country over the entire 1995-2006 period.

Europe, Americas, Middle East, and Africa), and also for the two largest sending countries–China and India. During the boom, graduate enrollment from all regions grew by around 3 standard deviations of their foreign enrollment from 1995-2005. Although enrollment from predominantly Muslim nations declined immediately after 9/11, by 2002 the heightened security policies and the glitches in SEVIS began to take their toll on students from across the world.

In sum, the data reveal an unusual boom and bust cycle over the 1995-2005 decade. Nearly half of the international students over this period tended towards STEM disciplines, and a majority were from Asian countries–China and India in particular. Furthermore, the boom and bust manifested in enrollments from all countries/regions of origin, and was not unique to any sending region or nation. Foreign college age population growth and 9/11 security policies had an important role in raising and lowering the supply of foreign students from around the world, and were unrelated to endogenous changes to graduate education within U.S. universities. These supply-shifting forces propagated across Research universities, providing a quasi-experiment to analyze whether foreign graduate students affect native enrollment. Before proceeding to further analysis, the next section describes the methodology and data.

3 Methodology & Data

3.1 Methodology

If international students were randomly enrolled across universities, OLS estimates from the following specification would uncover the causal effect of international students on native enrollment in graduate schools:

$$N_u = \alpha + \beta F_u + \varepsilon_u \tag{1}$$

In specification 1, β measures how native enrollment at a university (N_u) would respond to an additional foreign student at that university (F_u).[11] In reality, however, endogenous unobserved features prevent a causal interpretation of OLS estimates from 1. Highly ranked universities, may attract both international and native students, which would positively

[11] The case where $\beta < 0$ would indicate foreign students displace or crowd out native students. If $\beta = 0$, then additional foreign students would have no effect on native enrollment. Lastly, $\beta > 0$ would suggest foreign students crowd in or increase native enrollment.

bias estimates of β. Alternatively, the bias would go in the other direction if, for example, graduate programs increase recruitment of foreign students to counteract declining native demand.

Prior research has tried to mitigate these concerns by estimating 1 on a panel of universities and controlling for university fixed-effects and year effects (e.g. Borjas 2007; Regets 2007). While this design removes bias from both time-invariant characteristics of universities and national trends, it fails to account for endogenous factors that vary within universities over time. For example, changes in the rank of graduate programs may lead to fluctuations in both domestic and international enrollment. Universities with declining state appropriations may have less capacity to attract both native and foreign students.

Additionally, such panel approaches to specification 1 may still suffer upward bias due to scale effects, even after controlling for fixed effects. Peri & Sparber (2011) uncover this problem in a meta-analysis of literature on whether immigrants crowd U.S. natives out of localities (e.g. cities or states), which often use similar panel-fixed effects variants of 1.[12] To prevent bias from scale effects, I use a transformed version of 1 to measure the impact of foreign students on native enrollment:

$$\frac{\Delta N_{ut}}{E_{ut-1}} = \alpha + \beta \frac{\Delta F_{ut}}{E_{ut-1}} + \gamma_u + \gamma_t + \varepsilon_{ut} \tag{2}$$

My analysis estimates 2, separately for the boom and bust. The dependent variable in 2 represents a standardized measure of native enrollment flows, dividing the yearly change in native graduate enrollment ($\Delta N_{ut} = N_{ut} - N_{ut-1}$) with total graduate enrollment in the initial year (E_{ut-1}). The key independent variable transforms foreign enrollment in the exact same fashion–taking first differences and standardizing by total enrollment in the initial year–to obtain a measure of standardized foreign enrollment for each university. The variables γ_u and γ_t represent university and time-period fixed-effects, respectively, and ε_{ut} is a zero-mean error term.

In addition to mitigating bias from scale effects, transforming native and foreign enrollment through first differencing also removes the influence of fixed university characteristics that correlat with both foreign and native graduate enrollment. Including additional uni-

[12] Peri & Sparber (2011) test various different empirical specifications from the literature against fictitious panel datasets, created from different DGPs that vary in their underlying values of β. OLS regressions of specification 1 on the different fictitious datasets tend to be positively biased even after including fixed effects, suggesting the large variance in city/state sizes over time alone is enough to create substantial positive bias.

versity fixed effects, γ_u, in 2 controls for unobserved university characteristics that grow linearly across periods. Hence, identification derives from changes in changes of foreign graduate enrollment within universities and over time.

While 2 controls for a wide array of potential biases, university-specific unobserved factors that evolve at non-linear rates and also correlate with foreign student flows remain a concern. For example, non-linear declines in state appropriations may lead to contractions in both foreign and native enrollment. To assuage these remaining issues I develop a novel instrumental variables approach that leverages college age population growth in sending countries and post-9/11 foreign student policies–two exogenous forces that altered the aggregate supply of international students in the US, but were unrelated to university-specific factors that affected graduate education. Before describing the instruments in further detail, the next section discusses the main data sources.

3.2 Data

Data on native and foreign students by university come from the Integrated Postsecondary Education Data System (IPEDS). IPEDS hosts data from mandatory surveys of U.S. higher education institutions conducted by the Department of Educations National Center for Education Statistics. International and native enrollment counts by university are taken from IPEDS' Fall Enrollment surveys. These enrollment counts reflect the number of enrolled students at universities around the fall quarter/semester of each academic year. I use graduate enrollment from Fall 1995 through Fall 2005.

IPEDS surveys require universities to distinguish enrollment counts for residents and non-residents. Specifically, a non-resident is any "person who is not a citizen or national of the United States and who is in this country on a visa or temporary basis and does not have the right to remain indefinitely." Residents include native-born students and immigrants who have been admitted legally with the purpose of obtaining permanent residency. Thus, I use this demarcation to identify international students (non-residents) from U.S. natives and permanent residents (residents).

Figure 2 reveals the boom and bust cycle was mostly concentrated in Research Universities, as defined by the 2000 Carnegie Classification, and thus I center my analysis on these institutions. The Carnegie classification categorizes colleges and universities based on cutoffs in the number different degrees awarded, as measured from the IPEDS surveys on degree completions. Revisions of the classification are performed every few years using the most recent IPEDS data. Therefore, universities near the cutoffs and those that failed to respond to survey items in certain years drop in and out of the Research classification. I obtain a time-consistent group of Research universities that represent the core of U.S. graduate education, by including all institutions that are ever classified as a Research school in any of 1994, 2000, 2005, or 2010 Carnegie classifications.[13] This definition results in a list of 300 U.S. universities, 292 of which consistently report enrollments in IPEDS from 1995 through 2005.

Careful examination of IPEDS data reveals what appear to be substantial survey errors. In particular, several schools appear to have recorded implausibly large jumps in enrollment from year to year–for example a prominent public university in Colorado reported around 500 foreign students enrolled in 1998, 0 in 1999, and then close to 600 in 2000. Furthermore, the implementation of SEVIS after 9/11 placed increased burden on university administrators–the initial design flaws may have increased errors in reporting enrollment figures to IPEDS surveys.[14]

Such data issues introduce measurement error and can threaten the instrumental variable approach. To partially assuage these concerns I remove from the analysis 34 universities reporting outliers, defined as having standardized international flows above the 99th percentile or below the 1st percentile of all international flows over the 1995-2005 period. Thus, my main sample is comprised of 258 Research universities. In addition, robustness checks remove universities whose data were imputed by survey administrators.

Table 1 displays basic summary statistics, measured in 1995, for non-Research universities (left panel), the 292 Research universities available in IPEDS (middle panel), and the main sample of 258 Research universities that excludes outliers (right panel). Comparing the middle panel with the left panel reveals that research institutions were much larger than non-research schools on average, both in terms of undergraduate and graduate enrollment. While nearly identical in the percentage of foreign undergraduates, the average percentage of foreign graduate students at Research universities (11%) was almost double that of non-Research institutions (6%). Additionally, Research universities had a much larger focus on graduate education, awarding over 10 times the average number of 1st professional, masters, and Ph.D. degrees conferred at non-Research institutions.

In addition to comprising the main group of institutions affected by the international

[13] Section A.1 of the appendix contains further details about this procedure.

[14] Section A.5 provides an analysis of measurement error. Indeed the pattern of errors in foreign and native enrollment appear to be highly correlated during the bust period, but not during the boom.

graduate student boom and bust, Research universities (middle panel) represented the core of graduate education in the U.S. They accounted for 60% of all graduate enrollment, 80% of foreign graduate enrollment, and awarded the majority of all 1st professional and masters degrees. Notice that removing outliers from the analysis does not seem to alter the baseline characteristics. Comparing the middle panel to the right panel reveals that the main sample of 258 Research universities is quite representative of all 292 Research universities. Furthermore, these 258 schools represent a large bulk of U.S. graduate education, awarding over half of all professional and masters degrees, over 80% of Ph.D. degrees, and accounting for nearly $\frac{3}{4}$ of all foreign graduate enrollment. The majority of the sample universities are public (62%), span the 50 states, and include large, prestigious flagship institutions, down to smaller, private universities.

Using this sample of 258 Research universities, I separately estimate whether foreign graduate students affected native enrollment during the boom and bust. Although increases in foreign enrollment persisted until 2002 (see figure 3A), the enactment of policies in late 2001 through 2002 and declines in student visa issuance over the 2001-2002 fiscal years make it unclear whether the 2001-2002 period should be considered as part of the boom or bust. Additionally, even though SEVIS was fully implemented in early 2003, testing of SEVIS began at 12 Boston area institutions in November 2001 (Wasem 2002). Therefore, I drop the 2001-2002 period from the analysis and define the boom period as lasting from 1995-2001. The bust period covers 2002-2005.

4 Instrumental Variables Strategy

To obtain causal estimates I develop instrumental variables that stem from an approach popularly used to estimate the labor market impacts of immigration (e.g. Altonji & Card 1991; Card 2001). These studies exploit the fact that the size of historical immigrant communities within an area (e.g. city or state) is a good predictor of future immigration flows to that area, because new immigrants tend to locate in areas with pre-existing enclaves of immigrants (Bartel 1989). This preference for locating near other immigrants helps abstract from selection issues, such the concern that immigrants may choose to locate in booming areas. Interactions of historical immigrant populations across areas with nationwide growth in immigration are used as an instrument, often referred to as a “shift share” or “enclave” instrument, for actual immigration to areas. These interactions are vouched for as viable instruments because nationwide immigration growth is likely unrelated to local factors that endogenously affect area-specific immigration.

Nonetheless the validity of the traditional shiftshare instrument rests on various assumptions that have been difficult to test. First, nationwide growth in immigration must not be endogenously driven by the economic productivity of top immigrant receiving areas. Second, the historical presence of immigrants in an area cannot correlate with other historical characteristics that determine future labor market outcomes in that area. Most studies rely on rhetoric to justify these assumptions, and only a small handful of recent papers have begun to implement formal checks (e.g. Kerr & Lincoln 2010; Peri, Shih, & Sparber 2014).

My approach improves upon the traditional shiftshare instrument by leveraging college age population growth in sending countries and 9/11-induced policy shocks to capture aggregate supply-shifts in international graduate enrollment in the U.S., rather than using nationwide growth in foreign graduate students. Importantly, these supply-side forces are more plausibly exogenous to other factors affecting the graduate enrollment of U.S. natives, and are much less likely to be driven by a small number of universities with large foreign enrollment. Additionally, while nationwide foreign student growth may reflect underlying economic patterns in U.S. higher education or labor markets, it is unlikely that college age population growth or the 9/11 attacks and ensuing policy response were related to such confounding factors. Because I only construct one instrument for each period, two-stage least squares (2SLS) regressions of 2 are just-identified, and thus the exclusion restriction cannot be tested. Nevertheless, I present a series of novel checks and falsification tests to rule out various concerns.

To build the instruments I propagate these supply-side forces across Research universities with varying intensity, based on each university's historical stock of foreign graduate students (measured in 1993) to instrument university-level growth in foreign graduate enrollment over the 1995-2005 decade. For the boom period I use growth in the college age population in sending nations that helped generate supply-push increases in international graduate enrollment. As the college age population expanded, the number of individuals seeking graduate education, and the number of individuals applying to and enrolling in U.S. graduate programs also grew (Bird & Turner 2014; Shih 2014). Native enrollment was likely unrelated to these demographic shifts to college age populations abroad. For the bust I capture the supply-restricting influence of post-9/11 policies, by measuring aggregate declines in student visa issuance by nationality group. Delays in student visa processing due to increase security clearance caseloads and the flawed implementation of SEVIS helped restrict international graduate enrollment. Importantly, these policies were created in response to 9/11 and were likely unrelated to other factors affecting native enrollment in graduate programs.

The predictive power of the instruments derives from the presence of strong foreign student networks (Beine, Noël & Ragot 2014). Previous foreign graduate students return to their home countries and inform younger cohorts of their experiences, helping build name-brand recognition and advantages in new foreign recruitment for those universities with large historical foreign graduate enrollment. Therefore, U.S. institutions with large historical foreign student populations felt the effects of college age population growth abroad and 9/11-policies more intensely.

Because these networks operate among students from the same country, constructing this instrument requires very detailed data on foreign graduate enrollment by country of origin. I use resricted-access data from the Institute of International Education (IIE) that provides graduate enrollment by country of origin at Research universities in 1993, the earliest year of data available.[15] To reduce the dimensionality of the data I collapse country level enrollment into 17 nationality groups based on ethnic/regional similarity. The top 10 countries that send international students to the U.S. (China, India, South Korea, Japan, Thailand, Indonesia, Germany, Canada, Mexico, and Turkey) are each their own nationality group. The remaining countries are aggregated into 7 nationality groups: Rest of Asia, Rest of Americas, Middle East/North Africa, Eastern Europe, Western Europe, Africa, and Oceania.

Yearly population counts of individuals of college age by country are available from the UNESCO Institute of Statistics, which I then also aggregated to the 17 nationality groups. Growth in the college age population from 1993 to through the boom period is calculated as follows:

$$g_{nt}^{pop} = \frac{pop_{nt}^{18\text{-}30}}{pop_{n1993}^{18\text{-}30}} \tag{3}$$

The numerator in 3 represents the total college age population–individuals between 18 and 30–of countries in nationality group n in year t, while the denominator is the same measure in 1993. This growth factor is calculated for each country and for each year during the boom period ($t = 1995, \ldots, 2001$).

For the bust I capture the aggregate impacts of post-9/11 foreign student policies by mea-

[15] The IIE conducts annual censuses of international students in U.S. colleges and universities. Specifically, I use data from the International Student Census surveys which IIE uses to publish its annual "Open Doors" reports. 201 of the main sample of 258 Research universities responded to the 1993 IIE Survey. For the 67 universities who failed to respond I impute their graduate enrollment from each country of origin. Section A.2 provides full details of this procedure. In the analysis I remove universities which did not report to IIE in 1993 as a robustness check.

suring declines in student visa issuance. I first aggregate data on F-1 visas issued by country of origin from 2001-2005 from the Department of States Non-immigrant Visa Statistics to the 17 nationality groups. Because these data largely represent inflows of new students rather stocks of all students enrolled, I develop a measure of total active F-1 visa recipients in each year from 2001-2005 by cumulating F-1 visas issued to each nationality group over the prior 4 years as follows:

$$\hat{F}_{nt}^{\text{F-1}} = Visas_{nt}^{\text{F-1}} + Visas_{nt-1}^{\text{F-1}} + Visas_{nt-2}^{\text{F-1}} + Visas_{nt-3}^{\text{F-1}} \tag{4}$$

In 4, $\hat{F}_{nt}^{\text{F-1}}$ represents the estimated stock of total active F-1 visas issued to nationality n in year t, and $Visas_{nt}^{\text{F-1}}$ represents visas issued to new students in fiscal year t. Thus, for example, the estimated stock of F-1 visas active in the United States in 2000 is equal to the number of visas issued in 2000, plus the number of visas issued in 1999, 1998, and 1997. These estimated stocks are then used to measure the aggregate impact of 9/11-induced policies on all foreign students by nationality group. I calculate the growth (or reduction) factor in student visas issued by nationality from 2001 over the bust period as follows:

$$g_{nt}^{9/11} = \frac{\hat{F}_{nt}^{\text{F-1}}}{\hat{F}_{n2001}^{\text{F-1}}} \tag{5}$$

Interacting university-level graduate enrollment of each nationality with college age population growth of the corresponding nationality group from 3, forms supply-push predictions of enrollment patterns by nationality group within each university over the boom (shown in 6). To construct policy-based predictions of actual enrollment over the bust, I build from the college-age population-based predictions of enrollment for each nationality group in 2001 and interact them with aggregate declines in student visa issuance to each nationality group (from 5) in 7.

$$\textit{if } t \leq 2001, \qquad \hat{F}_{nut}^{pop} = F_{nu1993} * g_{nt}^{pop} = F_{nu1993} * \left(\frac{pop_{nt}^{\text{18-30}}}{pop_{n1993}^{\text{18-30}}}\right) \tag{6}$$

$$\textit{if } t \geq 2002, \qquad \hat{F}_{nut}^{9/11} = F_{nu1993} * g_{n2001}^{pop} * g_{nt}^{9/11} = \hat{F}_{nu2001}^{pop} * g_{nt}^{9/11} = \hat{F}_{nu2001}^{pop} * \left(\frac{\hat{F}_{nt}^{\text{F-1}}}{\hat{F}_{n2001}^{\text{F-1}}}\right) \tag{7}$$

Forming the instrument requires first summing together the nationality-specific enrollment predictions to obtain a prediction of the university's overall international enrollment,

$$\hat{F}_{ut}^{pop} = \sum_{n=1}^{17} \hat{F}_{nut}^{pop} \tag{8}$$

$$\hat{F}_{ut}^{9/11} = \sum_{n=1}^{17} \hat{F}_{nut}^{9/11} \tag{9}$$

Recall the main specification 2 specifies foreign graduate enrollment in first differences standardized by initial total graduate enrollment. Thus, the instruments should be formed in a similar fashion (as shown in 10) by taking first differences in predicted foreign graduate enrollment and standardizing by total graduate enrollment in the initial period. This transformation, however, might introduce endogeneity in the denominator. Thus, I instead standardize using a prediction of total graduate enrollment ($\hat{E}_{ut}$), formed by predicting native graduate enrollment based on college age population growth of the U.S., and summing this with the prediction of foreign enrollment.[16]

$$\frac{\Delta \hat{F}_{ut}}{\hat{E}_{ut-1}} = \begin{cases} \frac{\Delta \hat{F}_{ut}^{pop}}{\hat{E}_{ut-1}} = \frac{\hat{F}_{ut}^{pop} - \hat{F}_{ut-1}^{pop}}{\hat{E}_{ut-1}} & \text{if } t \leq 2001 \\ \\ \frac{\Delta \hat{F}_{ut}^{9/11}}{\hat{E}_{ut-1}} = \frac{\hat{F}_{ut}^{9/11} - \hat{F}_{ut-1}^{9/11}}{\hat{E}_{ut-1}} & \text{if } t \geq 2002 \end{cases} \tag{10}$$

4.1 First Stage Power

The instruments must strongly predict actual foreign enrollment flows. To evaluate the power of the instruments I estimate the first stage equation 11, separately for the boom (1995-2001) and bust (2002-2005):

$$\frac{\Delta F_{ut}}{E_{ut-1}} = \alpha + \beta_{\text{fs}} \frac{\Delta \hat{F}_{ut}}{\hat{E}_{ut-1}} + \gamma_u + \gamma_t + \epsilon_{ut} \tag{11}$$

Specification 11 regresses actual foreign enrollment flows on the instrument, and controls for university fixed effects and year effects. For the boom period the instrument is the college

[16] To avoid introducing endogeneity when standardizing by total graduate enrollment, I also predict native enrollment in the same manner ($\hat{N}_{ut} = N_{u1993} * g_{usat}^{pop}$), using college age population growth in the US interacted with native graduate enrollment in 1993. The imputed denominator ($\hat{E}_{ut-1}$) is simply the sum of the foreign ($\hat{F}_{ut-1}$) and native ($\hat{N}_{ut-1}$) predictions.

age population growth-based prediction of foreign graduate flows, and for the bust period the instrument is the post-9/11 policy-based prediction, as detailed in 10.

Table 2 presents results from first stage regressions. All regressions, unless otherwise specified, are weighted by initial year total graduate enrollment to correct for a loss of precision due to heteroskedasticity induced by standardizing the key variables by total graduate enrollment in the initial year (Solon, Haider, & Wooldridge 2013).[17] Standard errors are clustered at the university level to account for within-university serial correlation in residuals. Panel A shows results for the boom, while panel B displays results for the bust.

Column 1 reports results from the main specification, which weights regressions of 11 using the main sample of 258 universities. The results show that both the population-based instrument and the 9/11-based instrument are good predictors of actual foreign student growth over the boom and declines over the bust, respectively. The F-statistics of 46.6 for the boom, and 20.8 for bust confirm that the instruments have sufficient power for two-stage least squares analysis (2SLS)–both are well above the often recommended level of 10 to avoid bias from weak instruments (Staiger & Stock 1997). Unweighted regression results are reported in column 2 justify the need for weighting. Heteroskedasticity induced by the standardization leads to lower precision causing the 9/11-based IV to lose substantial power during the bust period (F-statistic shrinks to 7.1). Weighting corrects this issue, increasing the precision of estimates without substantially altering point estimates. Thus, weighted regressions will be preferred over unweighted regressions for the remainder of the analysis.

Column 3 shows the importance of removing outliers by estimating 11 on data from all 292 Research universities. Including outliers results in a dramatic lack of precision in first-stage estimates, leading to insufficient power for the instruments. Nonetheless, the point estimates from regressions on all 292 Research universities are very similar to those from the preferred sample of 258 universities. Due to the imprecision from outliers, the remainder of the analysis is performed on the main sample of 258 that abstracts from issues related to measurement error and extreme values.

The coefficient estimates of β_{fs} in column 1–3.75 for the population-based instrument and 1.94 for the 9/11-based instrument–do not have a simple and intuitive interpretation. However, the magnitudes can be understood by considering the regression line fit between actual foreign graduate enrollment flows and predicted flows (see section A.IV and figures

[17]The standardization by total enrollment in the initial year can exacerbate heteroskedasticity, especially if universities vary widely in the size of their graduate programs. Weighting by total graduate enrollment effectively mitigates this issue. A longer discussion of this issue is provided in section A.3 of the appendix.

A.2 and A.3 of the appendix). If the regression line through the data coincided with the 45 degree line, point estimates would be equal to 1, indicating that actual foreign graduate enrollment within universities grew at the same exact rate as the college-age population in sending countries over the boom, and fell at the rate of declines in student visas during the bust. The fact that the estimated regression line is steeper than the 45 degree line–first-stage coefficients are greater than one–reveals that actual international enrollment, on average, grew faster than the college age population in sending countries over the boom, and fell faster than declines in aggregate student visa issuance.

Specifying native and foreign enrollment in standardized first differences (see specification 2), as discussed earlier, removes potential biases from fixed university-specific factors that correlate with the level of foreign enrollment. However, differencing panel data can exacerbate measurement error (Angrist & Pischke 2008). In the first stage, such differencing may lead to measurement error in the dependent variable–foreign student flows. If such measurement error is classical, first stage estimates will suffer lower precision. While removing outliers from the analysis helps assuage this concern, it may not capture all sources of measurement error.

Columns 4-6 attempt to assess the extent of remaining measurement error in international student flows and check whether first stage power of the IV is substantially affected. Column 4 removes institutions that ever had their foreign enrollment counts imputed by IPEDS data administrators.[18] Although this check causes 10 universities to be dropped from the analysis, the point estimates and standard errors are nearly unchanged when compared to the main specification in column 1.

Only 201 of the 258 Research universities responded to the 1993 IIE survey used to construct the instruments. For missing institutions, recall I impute their 1993 foreign enrollment by country of origin (see section A.2). Column 5 examines whether these imputations affect first-stage results by removing universities whose 1993 enrollments were imputed. Reassuringly, the results do not depend on these imputations. Point estimates remain stable, while precision during the boom and bust periods falls slightly, likely due to the shrunken sample size. Nevertheless, the instruments have sufficient power for two-stage least squares analysis.

Column 6 removes all sources of imputations in IPEDS or IIE data as a final check to

[18]Survey response rates are generally high, as only 10 universities in the sample ever had imputed values in IPEDS data. IPEDS imputes values where possible, using a variety of different imputation schemes. See http://nces.ed.gov/statprog/2002/appendixb3.asp for a comprehensive overview of IPEDS imputation schemes.

ensure that measurement error does not affect the first stage results. This greatly reduces the number of universities from 258 to 193. Nonetheless, the first stage point estimates are virtually unchanged. Furthermore, the population- and 9/11-based predicted flows still have sufficient power as instrumental variables.

The instruments are strong predictors of international graduate enrollment flows. Weighting is important to reduce imprecision due to heteroskedasticity and achieve sufficient power for 2SLS analysis. The first-stage relationship between the instruments and actual foreign graduate student flows over the boom and bust is not affected by imputations in IPEDS or IIE data. Having established the power of the population- and 9/11-based instruments, the next section presents the main results on whether foreign students affect native enrollment in graduate programs.

5 The Impact of International Students on Native Enrollment

5.1 Main Results

To assess whether international students affect native graduate enrollment, I estimate 2SLS regressions of 2, separately for the boom and bust. The college age population-based prediction serves as an instrument for actual foreign enrollment flows over the boom, while the prediction based on post-9/11 declines in student visa issuance is used as an instrument for foreign enrollment flows during the bust. Standard errors are clustered at the university level to account for serial correlation in enrollment flows within universities.

Table 3 presents results from 2SLS regressions of 2. Panels A and B show results for the boom and bust periods, respectively. The first-stage F-statistics on the excluded instruments from table 1 are reprinted for reference. Column 1 of table 3 presents the main 2SLS estimates. The point estimate of 1.30 for the boom is statistically significant at the 5% level and indicates that foreign students crowd in natives. Interestingly, the coefficient of 1.59 for the bust is very similar and significant at the 10% level. Column 2 presents results from 2SLS regressions without weighting. Point estimates are nearly identical to the main specification in column 1, although precision and first stage F-statistics are greatly reduced in the bust period.

Because specification 2 is a simple transformation of the basic specification 1, and the dependent and independent variables are standardized by the same factor, these point estimates can be interpreted in terms of numbers of students. The main estimate for the boom suggests that 10 additional foreign graduate students increase native graduate enrollment by 13. The main estimate for the bust suggests 10 fewer foreign students lowers native enrollment by 16. A formal Wald test, however, does not indicate the point estimates to be statistically distinguishable from 1. Therefore, the main results indicate a 1-for-1 crowd in effect.

As stated earlier, first differencing panel data may exacerbate measurement error. Columns 3-5 attempt to mitigate any remaining sources of measurement error in surveys by removing various sources of imputations. Column 3 removes universities with imputations in the IPEDS surveys, column 4 removes universities with imputations in IIE data, and column 5 removes all universities with imputations in either IPEDS or IIE data. Notice that point estimates are remarkably stable in columns 3-5. Removing universities with imputations reduces the sample size which leads to a slight loss in precision–standard errors increase in columns 3, 4 and 5. While this has little effect on statistical significance during the boom, estimates for the bust become statistically insignificant at the 10% level.

Finally, column 6 presents OLS estimates corresponding to the main specification in column 1. Notice OLS estimates–0.41 for the boom and 0.33 for the bust–are also positive, but much smaller in magnitude than the main 2SLS estimates. The increase in point estimates when instrumenting may indicate that the IVs solve attenuation bias from classical measurement error. Alternatively, this may suggest the existence of endogenous shocks that negatively correlate with foreign enrollment flows within universities. The downward biased OLS estimates are not consistent with the presence of endogenous factors, such as university quality, that attract native and foreign students alike.

Overall the analysis revealed that foreign students crowd in natives on the order of 1-for-1. The instruments mitigate bias from negative confounding shocks and/or classical measurement error, and removing universities with imputated data does not change point estimates, although it does substantially reduce precision in the bust period due to smaller sample size. Interestingly, the effects on native graduate enrollment appear to be symmetric. During the boom period 2SLS regressions reveal that each additional international student increased native enrollment by approximately 1. Over the bust period a loss of 1 international student reduced native enrollment by 1.

5.2 Effects by Field of Study: STEM vs. Non-STEM

As shown in section 2, over 50% of all foreign graduate students were enrolled in STEM disciplines (see figure 4). The high proclivity of international students to study STEM fields suggests that, all else equal, supply shocks to international enrollment disproportionately affect graduate STEM programs. Additionally, recent studies provide some evidence that foreign students bolster research and patenting in STEM departments (Chelleraj et al. 2008; Maskus et al. 2012), and may be of very high quality when compared with native STEM students (Gaulé & Piacentini 2013). Therefore, the effect of foreign students on native enrollment may differ by field of study. This section examines whether the crowd in effects vary for natives in STEM and non-STEM fields.

Data on native enrollments by field of study from IPEDS Fall Enrollment surveys are only available biennially from 1994-2006. The surveys over this period consistently requested enrollment counts for only 9 of 52 fields of study under the Classification of Instructional Programs–these include Education, Law, Business, Dentistry, Medicine, Biological Sciences, Mathematics, and Physical Sciences. Various other STEM fields, such as Engineering Technologies and Computer Science, and many non-STEM fields, such as Social Sciences and History, are not reported. Lastly, only 209 of the 258 universities consistently responded to these surveys over the 1994-2006 period.

I use two definitions of STEM fields. The first is a wide grouping that includes native enrollments in Biological Sciences, Mathematics, Physical Sciences, Medicine and Dentistry. A second more narrow definition only includes enrollments in Biological Sciences, Mathematics, and Physical Sciences. The only non-STEM fields available are Education, Law, and Business. I combine these three disciplines to form non-STEM enrollment. Importantly, many prominent fields of study, such as Economics and Computer Science, are omitted from this analysis due to lack of available data.

To examine differences in native enrollment by field of study I replace the dependent variable in 2, with native STEM or non-STEM enrollment flows, standardized by total graduate enrollment. Since enrollments by field of study are available only every two years, I first calculate the standardized flow over two years ($\frac{N_{ut}-N_{ut-2}}{E_{ut-2}}$, for $t = 1996, \ldots, 2006$) and then annualize these flows to obtain standardized native STEM and non-STEM enrollment flows from 1995-2005.[19] The independent variables and instruments are identical to those used in the main analysis.

[19]The procedure for annualizing the two-year flows is described in section A.6.

Table 4 presents results when examining effects on native enrollments separately by field of study. Panel A reports results for the boom and panel B shows results for the bust. Column 1 shows results for native STEM enrollment, using the wider definition of STEM fields. Column 2 shows results using the stricter definition of STEM. Lastly, column 3 presents results for the three available non-STEM fields. The first row in each panel presents results using the main 2SLS specification and the second row removes universities with imputations in either IPEDS or IIE data. OLS estimates are reported in the third row.

The results for the boom show that the crowd in effects appear largely concentrated in STEM fields. Using either the wide or narrow definition of STEM reveals that each additional international student increases the native enrollment STEM by approximately 1. The estimated effects are statistically significant, and robust to the removal of universities with imputed data. Interestingly, while the point estimates on natives in the three non-STEM fields are not statistically significant, they are positive. Because the number of universities responding to the field of study surveys falls dramatically from 258 to 209, it is important to emphasize that the IV have sufficient first-stage power for the boom. The F-statistics on the excluded instrument from first-stage regressions, reported in the fourth column, are well above 10.

The effects on natives in STEM or non-STEM fields during the bust are not statistically significant. The F-statistic from the first-stage regressions suggest the 9/11-based instrument is at risk of weak instrument bias, especially in the specification that removes universities with imputed data. For native STEM and non-STEM enrollments, 2SLS point estimates are positive, but statistically indistinguishable from zero. Notice that in all cases, OLS estimates appear to be biased downward, mimicking the pattern from the main results in table 3.

The imprecise findings in panel B may indicate that decreases in foreign students over the bust did not have a strong impact on native enrollment in the available STEM or non-STEM fields. Alternatively, the weak results for the bust may also reflect a lack of sufficient data. Because enrollments by field of study are biennial, the data underlying come from only two periods: 2002-2004 and 2004-2006. Annualizing the two-year flows fails to add any new data/variation. Without better data, it is difficult to assess whether the overall positive effects during the bust, shown in table 3, were concentrated in other STEM or non-STEM fields (e.g. Computer Science, Social Sciences, History, etc.).

The analysis thus far has revealed that international students do not crowd out natives from graduate school, but rather crowd in natives. One additional/fewer foreign student leads to one additional/fewer native. This one-for-one crowd in is evident in both the boom and bust, and appears to be stronger for natives in STEM fields during the boom compared with some non-STEM fields like education, law, and business. The next section examines whether the instruments satisfy their exclusion restrictions, and shows the robustness of the main results to various checks.

6 Instrument Validity & Robustness

My empirical strategy hinges crucially on whether the population- and 9/11-based predictions meet the criterion for viable instrumental variables. While section 4.1 demonstrated that these variables have strong first-stage power, it is also necessary that they satisfy the exclusion restriction–the instruments must only predict actual international enrollment flows and cannot be correlated with any other factors that also affect native enrollment flows within universities. Recall that the instruments are derived from the interaction of two separate pieces–the nationality distribution of foreign graduate enrollment in 1993, and the nationality-specific supply shifters (college age population for the boom, and declines in student visa issuance for the bust). Therefore, to satisfy the exclusion restriction it is necessary that each piece is unrelated to other factors that also affect native graduate enrollment. Because I only use one instrument for actual foreign enrollment flows in each period, it is not possible to directly test the exclusion restriction. Nevertheless I examine and rule out several issues of first order concern.

Using the nationality distribution of foreign graduate students in 1993 is of concern if initial features or shocks to Research universities had persistent influence on future foreign and native flows. For example, the prestige of a university in 1993 may and have persisted to attract native and foreign students in later years. Such endogenous initial factors that are time-invariant are removed in the first differencing of enrollment. Initial shocks that persist or grow at linear rates are captured by university fixed effects. Unaccounted for are initial shocks or features that evolve non-linearly. Further, this issue is a larger concern for the boom period than the bust period, because the start of the boom period (1995) is only 2 years after the initial 1993 distribution.

One solution in studies that rely on similar shift share-style instruments has been to use long lags of the initial distribution to reduce the possibility of endogenous serially correlated shocks persisting into the sample period. Unfortunately, the IIE does not have data on enrollments by country of origin prior to 1993. However, the 1993 survey contains undergraduate enrollment by country of origin which I exploit to examine the potential endogeneity of foreign graduate enrollments in 1993 to native outcomes in later periods. Specifically, I construct falsified-predictions of foreign flows over the boom and bust that are nearly identical to the main instruments, with the only difference being that foreign undergraduate enrollment in 1993 are used instead of foreign graduate enrollment. I then run first-stage specification 11 with the falsified-predictions to check whether these shocks are also predictive of foreign graduate flows over the boom and bust, and thus a concern.

The intuition behind this procedure derives from the fact that foreign graduate enrollment by country of origin in 1993 helps form a powerful instrument because it captures the strength of networks between graduate students from the same countries. However, endogenous shocks to universities in 1993 may also drive the power of the instrument if they have persistent impacts on foreign graduate enrollment in future periods. Using foreign undergraduate enrollment in 1993 helps disentangle the endogenous source of power (i.e. persistent initial shocks) from the exogenous source of power (i.e. foreign networks) of the instruments because the cross-university distribution of foreign undergraduates by country of origin in 1993 is very different from that of foreign graduates.[20] However, initial shocks to universities in 1993 were also likely to have affected initial undergraduate enrollments. The falsified-predictions reduce the exogenous source of power while retaining the endogenous source of power.

Row 1 of table 5 performs this check and reveals that falsified-predictions based on initial foreign undergraduates have no predictive power over foreign graduate flows over the boom or bust. Thus, any unobserved initial shocks not captured by the first differencing or the fixed-effects are likely unrelated to foreign graduate enrollment flows over the boom and bust. It is important to recognize, however, that this test does not account for initial shocks that had no impact on undergraduates in 1993 and only affected the graduate programs within universities.

While the initial foreign graduate distribution in 1993 appears plausibly exogenous to native enrollment over the boom and bust, the nationality-specific supply shifters may introduce other concerns. College age population growth and aggregate declines in student visa issuance may lead to violations of the exclusion restriction if they correlate with other phenomena that also altered foreign and native enrollments within universities. A rather important issue is whether fluctuations to the college age populations of foreign nations and the post-9/11 tightening of student visa policy also altered the composition of undergraduate

[20]The cross-university correlation between foreign graduates by country of origin and foreign undergraduates by country of origin in 1993 is 0.23.

enrollment. Changes to the undergraduate population may also impact native graduate enrollment. For example, increases in undergraduates from abroad might require more teaching assistants, and therefore more native graduate students.

To examine whether the instruments predict foreign or native undergraduate flows, I gather data on undergraduate enrollments from the IPEDS Fall Enrollment surveys. I estimate first-stage specification 11, replacing the dependent variable with the yearly change in foreign undergraduate enrollment divided by total undergraduate enrollment in the initial year ($\frac{\Delta F^{UG}_{ut}}{E^{UG}_{ut-1}} = \frac{F^{UG}_{ut} - F^{UG}_{ut-1}}{E^{UG}_{ut-1}}$). The results, presented in row 2 of table 5, show no relationship between the 9/11-based IV and foreign undergraduate flows during the bust (columns 3 and 4). During the boom there appears to be a very slight positive correlation between the college age population-based instrument and foreign undergraduate flows (column 1). Removing imputed data, in column 2, however shows no statistically significant relationship. I also examine whether the instruments have any correlation with native undergraduate flows in row 3 of table 5. Reassuringly, the instruments do not appear to have any statistically significant relationship with native enrollment flows over either the boom or bust. Note the F-statistics on the excluded instruments in rows 2 and 3 are between 0 and 3–far too low to be considered viable instruments for actual foreign or native undergraduate flows.

Because a slight positive correlation appears between the population-based IV and foreign undergraduate flows during the boom (column 1), I present a robustness check that controls for foreign undergraduate flows in the main 2SLS regressions. While directly including foreign undergraduate flows as a control would introduce further endogeneity, the falsified-predictions used in row 1 can be used as exogenous controls that account for changes to foreign undergraduate flows that were attributable to college age population growth or post-9/11 foreign student policy. Row 4 of table 5 includes these falsified-predictions as a control variable in 2SLS regressions. Reassuringly, the findings are very similar to the main results, reprinted for reference in the last row of table 5.

Another concern regarding the supply-shifting components of the instruments is that they may be related with the Dot Com boom and bust or the raising and lowering of H-1B visa caps, which in turn may have affected U.S. graduate education. To mitigate any bias from these other factors, I develop measures of H-1B and Dot Com-driven predictions of international flows and include these as controls in 2SLS regressions. These predictions are constructed in a similar fashion as the main instruments. Instead of college age population growth and declines in student visas, however, I use growth in H-1B visas or growth in the Nasdaq Composite Index (see section A.7).

Table 5 shows 2SLS results after controlling for H-1B policy (row 5) or the Dot Com boom and bust (row 6). Reassuringly, the estimates for both the boom and bust period are generally robust to the inclusion of these controls. Note that the Dot Com bust coincided strongly with the declines in student visa issuance after 9/11, and thus including the Dot Com control absorbs much variation and substantially reduces the first-stage power. F-statistics from first-stage regressions in columns 3 and 4 of row 6 reveal slightly weak instruments, possibly contributing to the inflation of point estimates (2.40 and 2.09 in columns 3 and 4 of row 6, respectively).

Table 6 provides further robustness checks of the instrumental variables and main results. Another concern is whether the supply-shifters used to construct the instruments are themselves driven by endogenous changes within a few large universities. For example, rather than capturing the impact of post-9/11 visa policies, declines in student visa issuance might be driven by falling performance of a few universities that host large numbers of international students. Though this issue is less of a concern for the boom period–it is unlikely that changes to the performance of U.S. universities drove college population growth rates abroad–I exclude large universities in both periods as a robustness check.

I remove 8 universities that are consistently ranked in the top 10 in terms of international graduate enrollment in each year from 1995-2005. I then rerun the 2SLS analysis after dropping these top 8 universities. The results, reported in row 1 of table 6, are very similar to the main estimates. Coefficients during the boom and bust remain nearly identical to the main results. It is worth noting that the loss of 8 universities further reduces the sample size and leads to larger standard errors than those from the main estimates (row 7 of table 5). While the estimates for the boom period remain statistically significant, the loss in precision leads to insignificant estimates during the bust.

A similar concern is whether the nationality dimension of the aggregate supply-shifters reflect the performance of universities that host large numbers of students from those nationalities. For example, falls in student visas issued to individuals from India may be a result of decreases in the quality of the top universities that host Indian students. A simple test of this concern would be to see if 2SLS results are robust to the exclusion of the largest nationality groups from the explanatory variable and instrument. Unfortunately, the available data from IPEDS only has total foreign student counts, and does not allow provide information on particular nationality groups. Nonetheless, I provide a partial check by only removing top nationality groups from the instruments.

I reconstruct the instruments without Chinese students, the largest nationality group, and estimate the main 2SLS specification. I also reconstruct the instruments without Indian students, the second largest nationality group, and perform 2SLS regressions. Note that this procedure will reduce the power of the instruments, as a large source of variation (i.e. variation from Chinese or Indian students) has been purged from the IV, yet still remains in the endogenous explanatory variable.

Rows 2 and 3 of table 6 show the results from this check. Row 2 removes Chinese graduate students from the construction of the IV, and row 3 removes Indian graduate students. Overall the results are very similar to the main findings. The estimates range from 0.98 to 1.84 and support the main finding of 1-for-1 crowd in effects. Notice the first-stage power and precision of estimates is greatly reduced by not being able to also eliminate these nationality groups from actual foreign enrollment counts.

The final three rows table 6 address three concerns specific to the period under study. College age population growth rates used to construct the instrument for the boom period may be tied to rising living standards. Rising living standards abroad may be endogenously related to native enrollment. For example, externalities from U.S. graduate education may spillover to other nations. I abstract college age population growth from changes in living standards by developing a control variable formed almost identically to the instrument, except that college age population growth rates are replaced by growth in real income per capita in sending nations. The results in row 4 include this control for living standards in 2SLS regressions for the boom. Additionally, I also show results for the bust using this control. Results are robust to controlling for income per capita growth in sending countries. Note that weak first-stage power leads to slight inflation of point estimates during the bust.

A final concern is whether students from Muslim countries drove the effects during the bust period. Even though students from Muslim nations do not represent a large fraction of total international enrollment, the post-9/11 policies may have had an especially large effect on the entry of students from predominantly-Muslim nations. Since removing students from Muslim nations from the explanatory variable is not possible, I provide a partial check by only removing students from Muslim nations from the instrument. Results from 2SLS regressions using this instrument are presented in row 5 of table 6, and for completeness I show results for both the boom and bust. Results over the boom period are nearly identical to the main findings. While the point estimates from the bust are positive and qualitatively similar to the main results, the power of the instrument is drastically reduced. This is because the decline in student visa issuance to nationals of Muslim countries was quite large, making variation in Muslim students an important part of the instrument. As a result, the instrument is weak and 2SLS estimates appear inflated. The qualitative similarity of results from this partial check, however, suggests results are not entirely driven by students from Muslim nations.

Overall the instruments are strong predictors of actual graduate enrollment flows from abroad, and results do not change when controlling for foreign undergraduate flows. Additionally, after first differencing and controlling for further university fixed-effects, the 1993 distribution of foreign graduate students by nationality appears plausibly exogenous to native outcomes in during the boom and bust cycle. Results are also robust when accounting for the boom and bust cycles in H-1B visas and in the Dot Com sector, which also occurred over the 1995-2005 decade. Finally, results do not appear to be driven by the largest universities that host foreign students, or the largest nationality groups. Having established the robustness of the results, the next section explores various mechanisms which elucidate how foreign students expand native enrollment in graduate schools.

7 Mechanisms

7.1 Peer Effects

Given a perfectly elastic supply of graduate education, crowd in of natives would only be observed if exogenous increases in foreign enrollment also bolstered native demand for graduate education. Many studies have found that high ability individuals often generate positive effects that spillover to their peers (e.g. Mas & Moretti 2009; Carrell, Fullerton, & West 2009; Sacerdote 2011). While evidence is still limited, several studies support the notion that foreign graduate students in the U.S. on average are of very high quality. Gaulé & Piacentini (2013) show that Chinese Ph.D. students in Chemistry perform as well as NSF doctoral fellowship recipients. Black & Stephan (2010) examine a sample of publications in Science and find that over 50% had a foreign graduate student or postdoctoral researcher as a coauthor, and that around 60% of all graduate student coauthors are from abroad. Thus, foreign students may generate peer effects through increased opportunities for collaboration, diversifying knowledge, or raising the quality of research which, in turn, may raise native demand.

To examine whether crowd in effects operate through peer effects, I identify groups of natives that are more likely to interact with foreign students by exploiting information on the fields of study of foreign students and different groups of native students. Natives of different race and gender groups vary tremendously in their chosen fields of study, and I utilize this fact to measure the similarity of natives by race and gender to foreign students. Estimating 2SLS regressions on these different native groups sheds light on whether crowd in effects are stronger for native groups that are more likely to socialize, interact, and take the same courses as foreign students.

While data on native enrollments by field of study is extremely limited, as stated earlier, IPEDS has very detailed data on completions by race, gender, and field of study. I divide natives into eight race (White/Asian/Black/Hispanic) by gender (male/female) groups and use the IPEDS Completions surveys from 1990-1994, just prior to the boom and bust cycle, to develop an index of similarity to international students for each native group. The index of similarity is constructed by first calculating the distribution of graduate degrees awarded across each of 33 fields of study for foreign students, and for each of the native groups. Each native groups distribution is compared with that of international students by calculating a chi-squared statistic goodness-of-fit statistic:

$$\chi^2_{G,32} = \sum_{m=1}^{33} \frac{\left(p_m^G - p_m^f\right)^2}{p_m^f} \tag{12}$$

The chi-squared statistic is formed, as shown in 12, by taking deviations in the percentage of all graduate degrees awarded to native group G in a field m (p_m^G) from the same percentage for foreign students (p_m^f). These deviations are then squared and standardized by the percentage of foreign students awarded degrees in that field. Summing over all fields yields the chi-squared statistic ($\chi^2_{G,32}$)–an index of each groups similarity to international students in terms of their fields of study. A chi-squared value for group G of 0 indicates that natives are identical international students in terms of what they study. Larger values indicate higher dissimilarity with international students.

Figure 7 plots, for each native group, the point estimate and 90% confidence interval from 2SLS regressions of the main specification, against the index of similarity with international students. Point estimates are standardized due to the fact that native groups vary widely in terms of their yearly flows. Panel A shows the effects for the boom period, and plots the standardized effect on native enrollment for a 1 standard deviation increase in foreign students on the vertical axis. Panel B displays the results for the bust and the vertical axis indicates the standardized effect on native enrollment for a 1 standard deviation decrease in foreign students. The horizontal axis measures the index of similarity, with smaller values indicating more similarity towards foreign students.

A clear pattern emerges during both the boom and bust periods. The impact on natives grows with their similarity to international students. During the boom, the effect of a 1 standard deviation increase in international students raised the enrollment of the most similar groups (e.g. Asian and White men) by between a quarter to a sixth of a standard deviation. In contrast the most dissimilar groups (Black and Hispanic women) saw no effect from increased foreign enrollment. Over the bust a similar pattern appears. A 1 standard deviation decrease in foreign enrollment is associated with larger declines in native enrollment for more similar groups–approximately around more than of a standard deviation for White and Asian males compared with almost no effect for Black women. It is important to note that many of the point estimates are imprecisely estimated, and some groups with that rank in the middle in terms of similarity towards foreign students, such as Hispanic men and Asian women, see some strong effects. Nonetheless, the overall pattern suggests that the estimated crowd in effects may be partly due to the possibility that foreign students bring positive externalities that attract natives whom are most likely to interact with foreign students.

7.2 Complementarity with Faculty

Consider the case where the supply of graduate education is fixed or very inelastic. Crowd in of natives would only be possible if foreign students also induce expansions in the supply of graduate education. Prior research suggests that foreign graduate students, especially those in STEM fields, strongly complement faculty in research production. This section checks whether foreign graduate students expand the number of faculty, thereby alleviating supply constraints.

Data on faculty is available from IPEDS Instructional Staff/Salary surveys. I collect data on tenure-track (assistant, associate, and full professors) and instructional (non-tenure track) faculty from 254 of the 258 sample Research universities that consistently responded to this survey over the 1995-2005 period. I estimate main specification 2, replacing the dependent variable with the yearly change in faculty divided by total graduate enrollment in the initial year (i.e. the dependent variable is $(\frac{\Delta Faculty^T_{ut}}{E_{ut-1}})$, where T indicates whether the faculty are tenure-track or instructional). Standardizing in this fashion allows the estimates to be directly interpreted in terms of the number of additional faculty associated with an increase in foreign enrollment.

The results of this exercise are shown in table 7. Columns 1 and 2 report results for tenure-track and instructional faculty, respectively, for the boom. Estimates using the main specification are reported in the top panel, and results after removing universities with imputed data are reported in the lower panel. Results for the boom show an extra 10 international students is associated with approximately 3 additional tenure-track faculty, and 1-2 instructional faculty. While the results for tenure-track faculty are statistically significant, the estimates for instructional faculty are less precise. Interestingly, the same positive relationship is not found for the bust period. Decreases in international enrollment did not lead to declines in faculty. The temporary nature of the bust and downward rigidity in faculty emploment may contribute to the results for the bust.

7.3 Cross-subsidization

Because international students often pay full sticker-price tuition, they may cross-subsidize the cost of educating natives, who often are offered discounted tuition. In response to exogenous increases in foreign students, universities may experience higher revenues, which allow them to expand the supply of seats. Alternatively, universities may offer tuition discounts to natives, while raising tuition for foreign students. Analysis of these two channels, detailed in section A.8, show that international students have little impact on revenues or resources per student or tuition price. At the graduate level, it is likely that international students may be able to secure funding which would limit the cross-subsidization of natives. Additionally, rigidities in tuition price for many universities may make changing tuition in response to exogenous changes in international enrollment difficult in the short-run.

8 Conclusion

For decades, international students have maintained a large and growing presence in U.S. graduate education. While U.S. immigration policy places no numerical constraints on the number of international students that may study in the states, little is known regarding how this open door policy has affected higher education. This paper provides insight into this issue by assessing the impact foreign students have on their native peers.

I examine whether foreign students affect native enrollment in graduate schools, focusing on an unusual boom and bust in foreign graduate enrollment that took place at Research universities over the 1995-2005 decade. I mitigate endogenous factors by developing an instrument based exogenous, supply-push factors that contributed to the boom (1995-2001) and bust (2002-2005). In particular, growth in the college age (18-30) population in sending countries helped sustain the tremendous growth in foreign graduate enrollment over the boom. Flaws in the implementation of post-9/11 security policies targeted towards foreign students interrupted the boom, and led to declines in foreign graduate enrollment that lasted until 2005. Interacting the nationality distribution of foreign graduate students across Research universities in 1993 with growth in the college age population by nationality, and declines in student visas due to post-9/11 policies, forms instruments for the boom and bust, respectively.

Instrumental variables regressions show that foreign students do not crowd out, and actually crowd in native students. Point estimates suggest that native enrollment increases one-for-one with foreign graduate enrollment over the boom. Similarly, over the bust a decline in one foreign graduate student is associated with a loss of one native graduate student. Nearly 50% of foreign graduate students study STEM fields, and I find evidence that the crowd in effects were stronger for natives in STEM fields relative to some non-STEM fields (Business, Education, and Law).

Importantly, the instrumental variable strategy is robust to various checks and falsification tests. While the foreign graduate student boom and bust over 1995-2005 also coincided with expansions and contractions of H-1B visa policy, and the Dot Com boom and bust, robustness checks show that results are unchanged when controlling for these other phenomena. Additionally, the 1993 distribution of foreign graduates used to construct the instrument appears to be unrelated to future native enrollments. Lastly, results are robust to removing top universities, top nationality groups, and abstracting from endogenous changes to income per capita abroad.

Exploration of various mechanisms suggests that foreign students may positively affect native demand for graduate education through peer effects. The estimated effect of foreign students is larger for native groups (White and Asian males) who are distributed across fields of study almost identically as foreign students, and hence are more likely to socialize and interact with them in courses. The estimated impact is lower for those native groups who are very different from foreign students in terms of their fields of study (Black and Hispanic females). Additionally, increases in graduate enrollment from abroad are associated with increases in faculty, suggesting that complementarities in research production allow for expansions in the supply of higher education.

Concerns over deteriorating educational quality, combined with unprecedented recent inflows of foreign students from China, raise the importance of understanding how foreign students affect U.S. higher education. Further research more closely examining how natives respond to foreign students, and analyzing other native outcomes such as degree completion and switching across fields of study would help complete the picture of how international students affect the education of natives in higher education.

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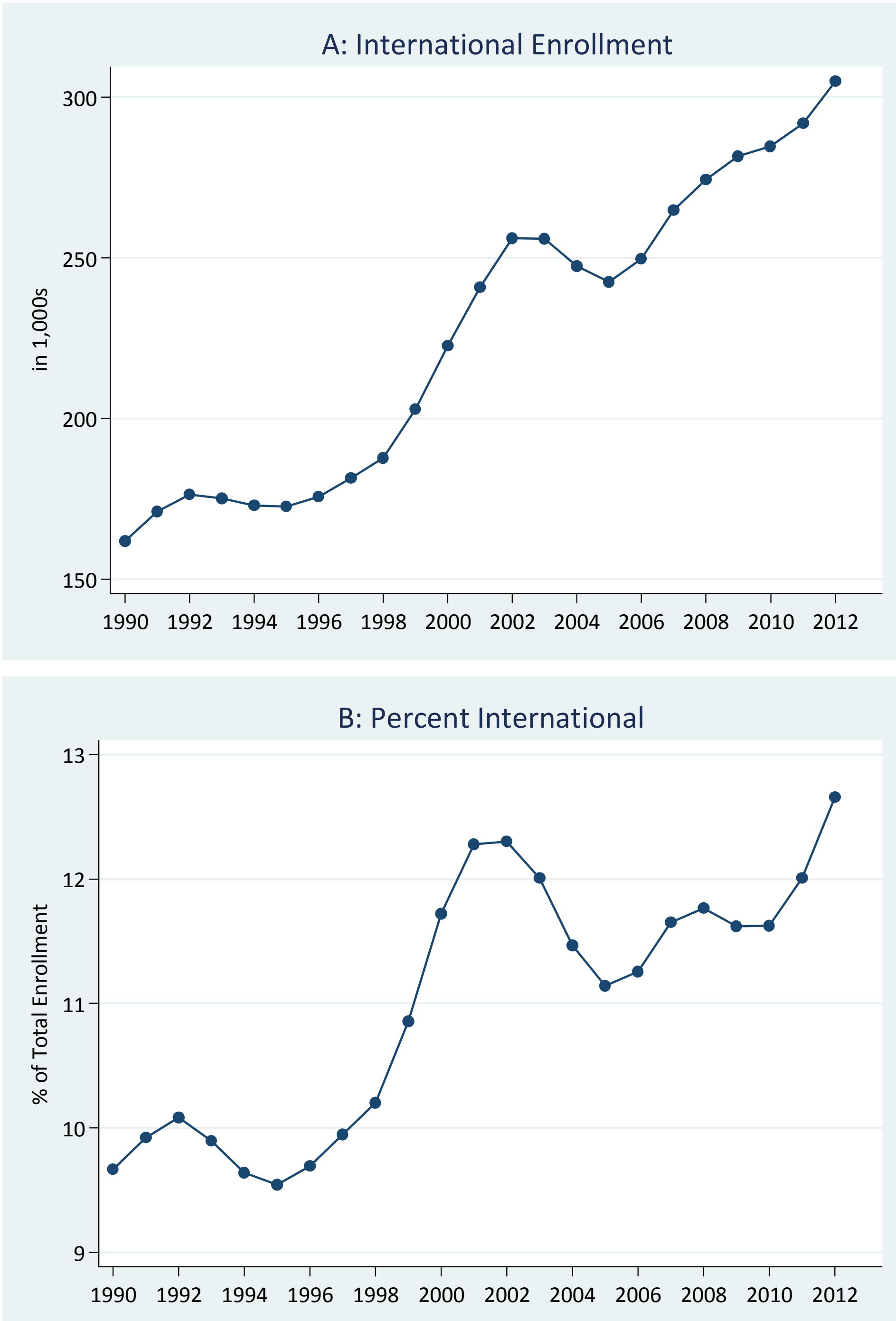
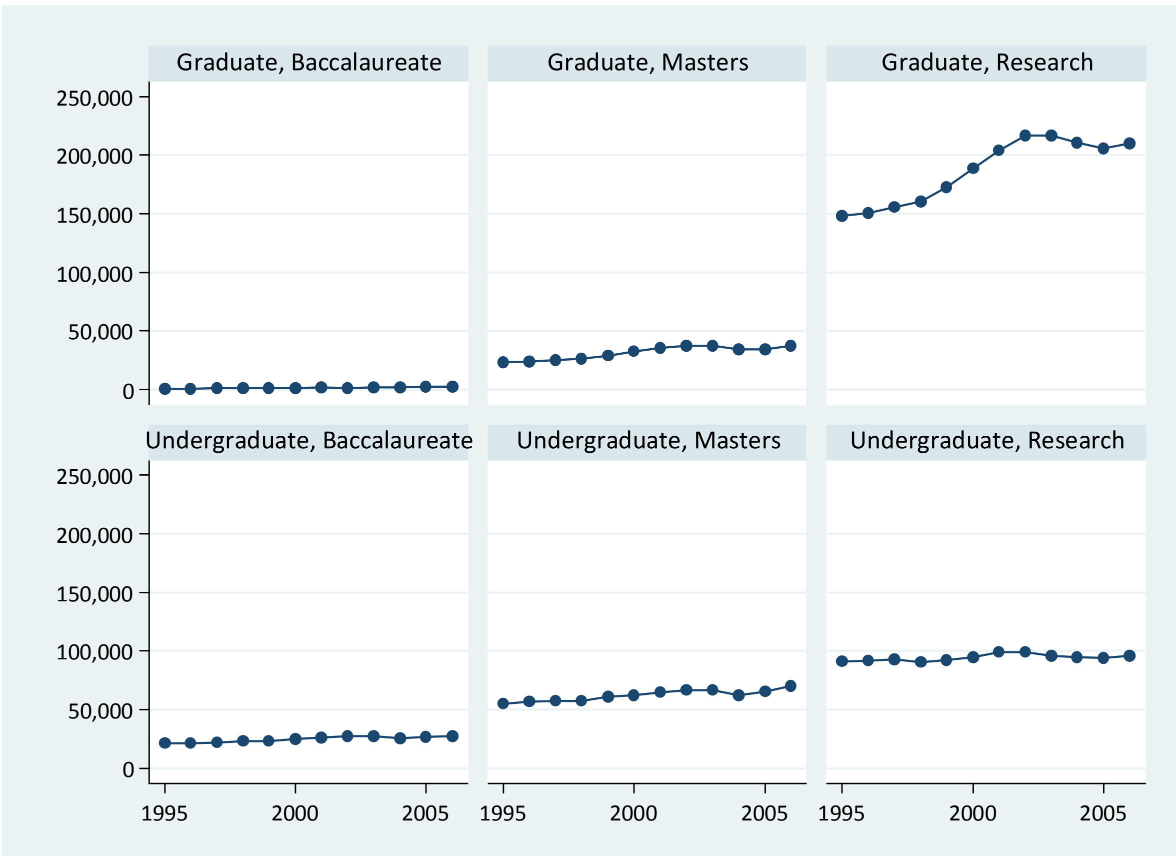
Figure 1: Trends in International Graduate Enrollment in the US, 1990-2013



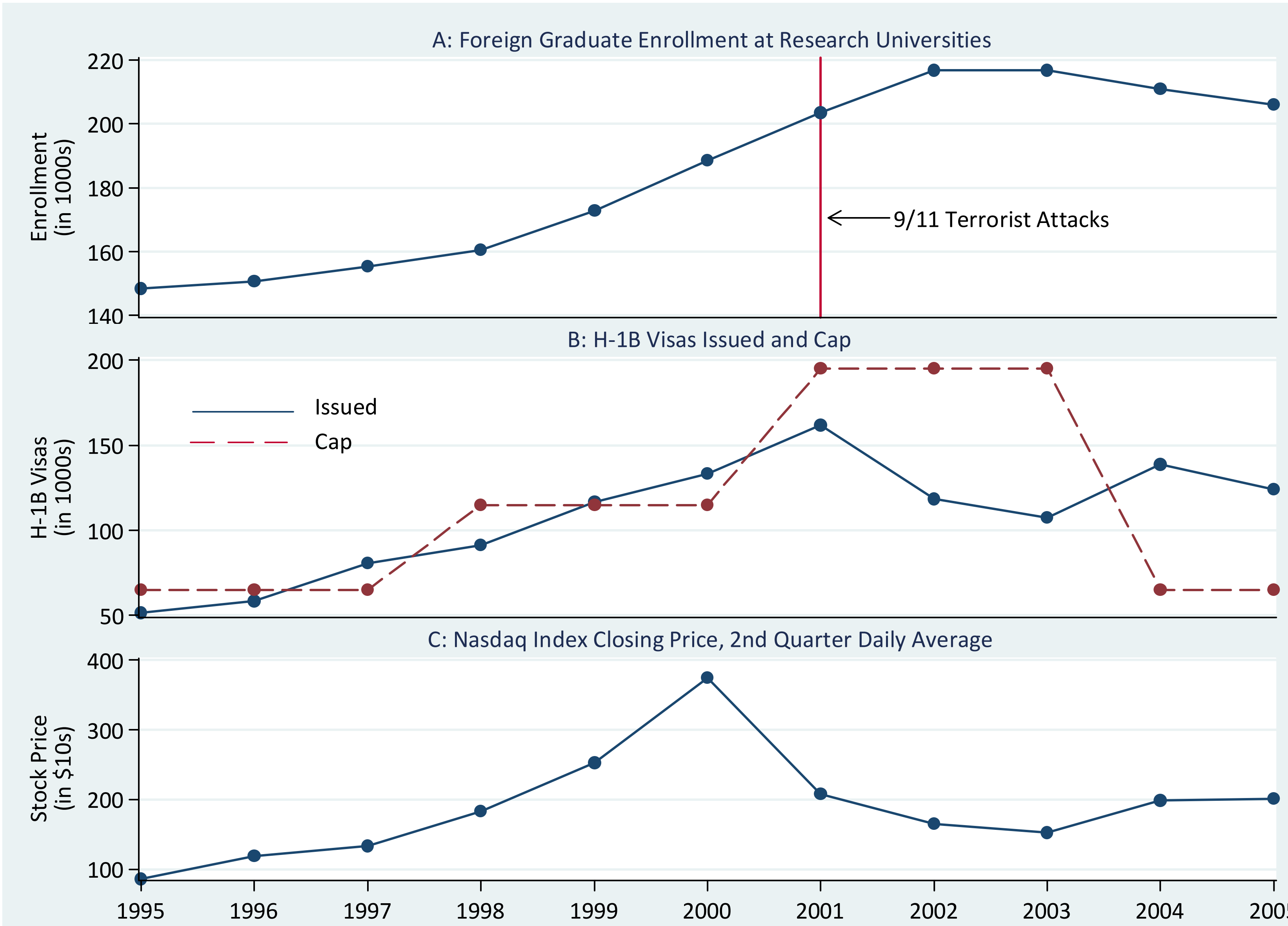
Note: Series constructed from IPEDS Fall Enrollment Surveys, 1990-2013. Figures above include total international graduate enrollment (in Panel A) and international graduate enrollment as a percent of total graduate enrollment in Baccalaureate, Masters, and Research/Doctoral Universities as defined by the 2000 Carnegie Classification. Data reflect enrollment for the Fall of the corresponding year.

Figure 2: International Enrollment by Academic Level and University Type, 1995-2005



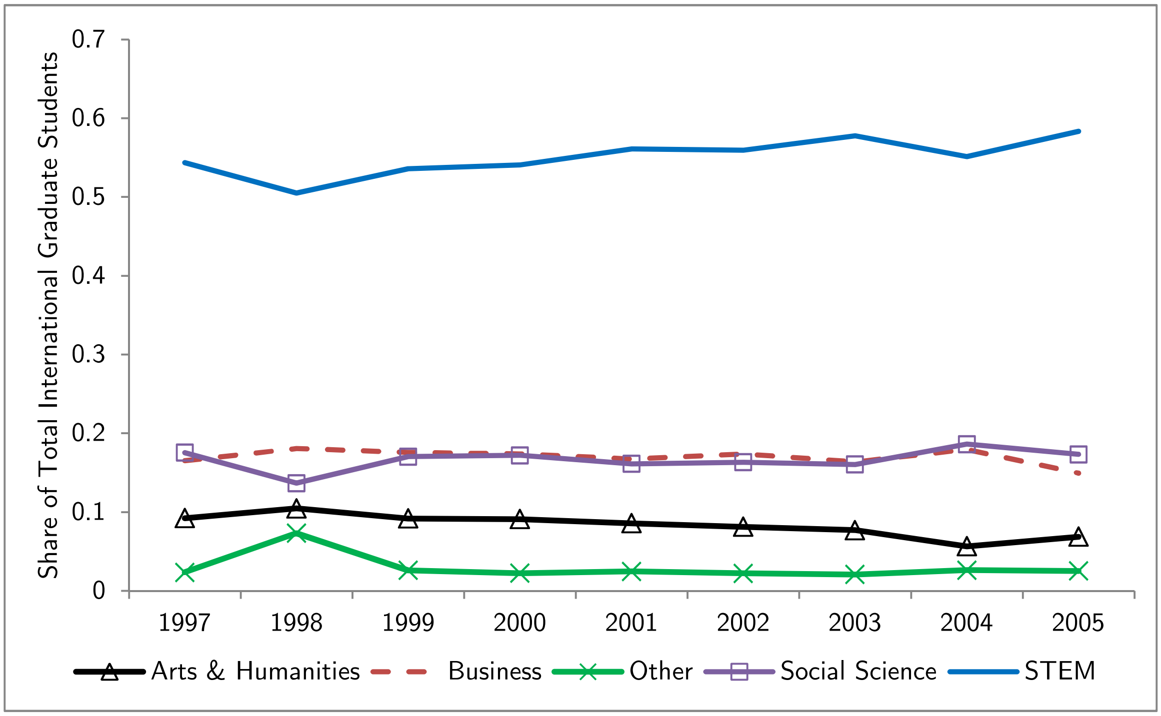
Note: Series constructed from IPEDS Fall Enrollment Surveys, 1995-2006. Figures above include total undergraduate and graduate enrollment of non-resident aliens in Baccalaureate, Masters, and Research/Doctoral Universities as defined by the 2000 Carnegie Classification. Data reflect enrollment for Fall of the corresponding academic year.

Figure 3: International Graduate Student Boom and Bust, Research Universities, 1995-2005



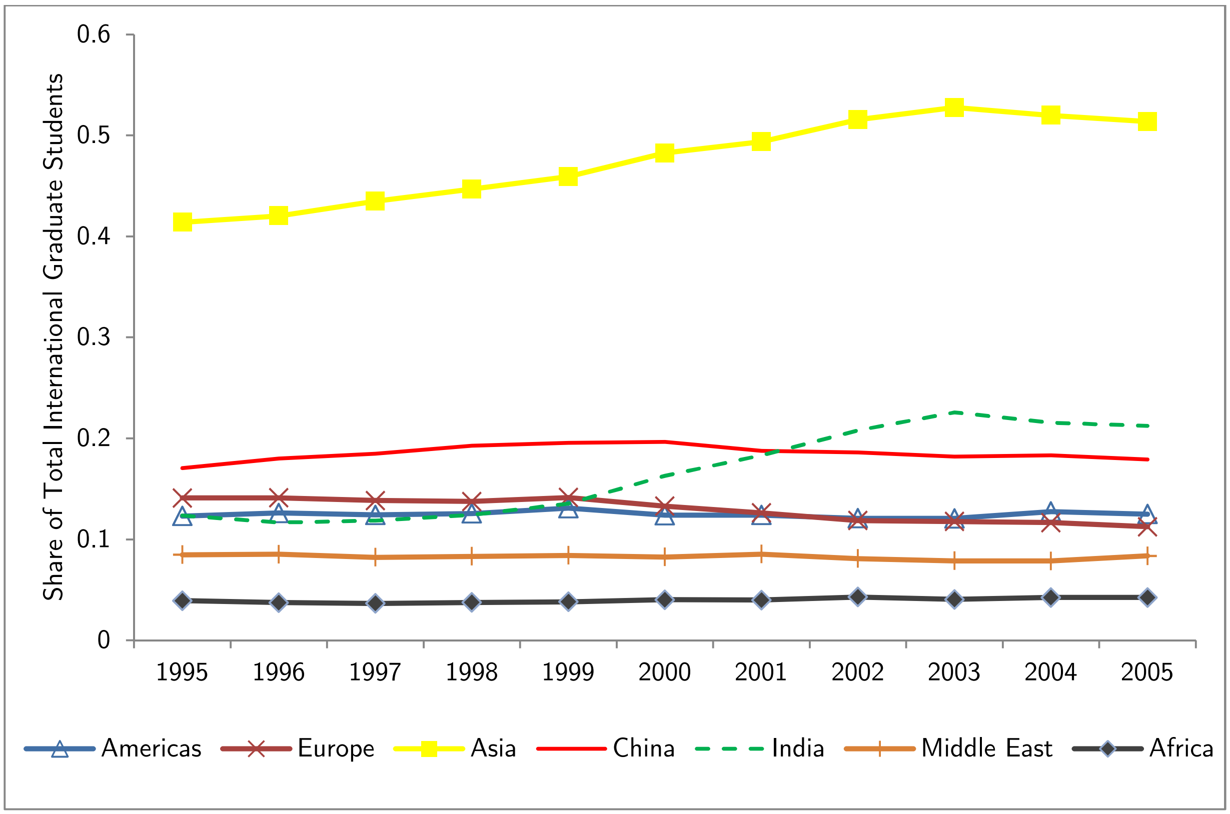
Note: Data on foreign enrollment from IPEDS fall enrollment surveys. Fall enrollment figures reflect the number of international students enrolled in the fall of the corresponding year. Data on H-1B visas issued are from the Department of States Non-immigrant Visa Statistics (Department of State 2012). Data on Nasdaq Index stock prices are from Yahoo Finance Historical Prices. Figures reflect the average of the daily closing price of the Nasdaq Composite Index (IXIC) over the 2nd quarter of each year, when graduate students generally make enrollment decisions.

Figure 4: International Graduate Students by Field of Study, 1997-2005



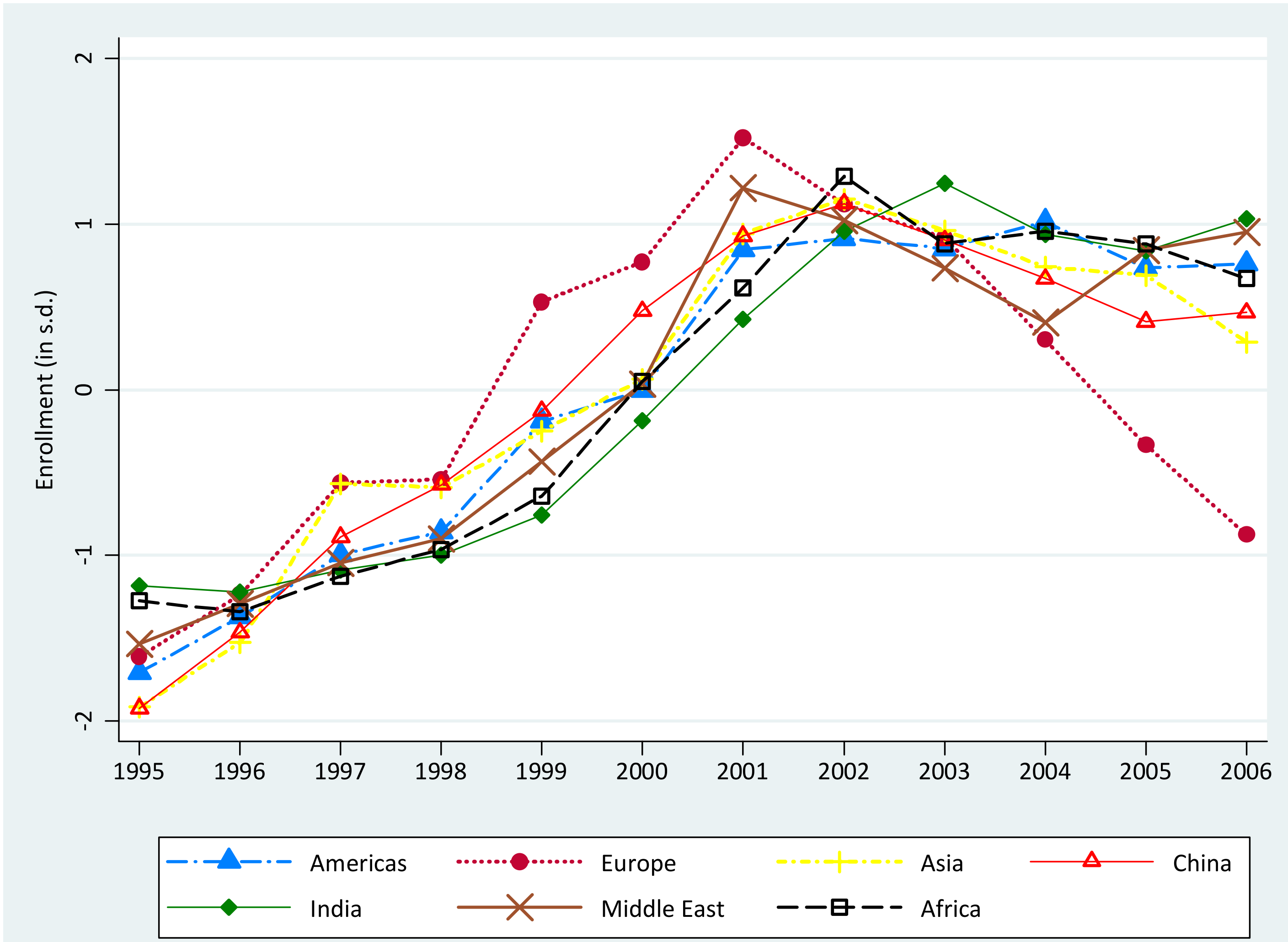
Note: Data is from IIEs Open Doors reports 1997-2005. Each series presents the share of total foreign graduate students studying in that field. Data prior to 1997 was unavailable.

Figure 5: International Graduate Students by Region-of-Origin, 1995-2005



Note: Data is from IIEs Open Doors reports 1995-2005. Each series presents the share of total foreign graduate students from the corresponding country/region of origin. China and India are included in the figures for Asia, but are also reported separately since they are the two largest sending countries.

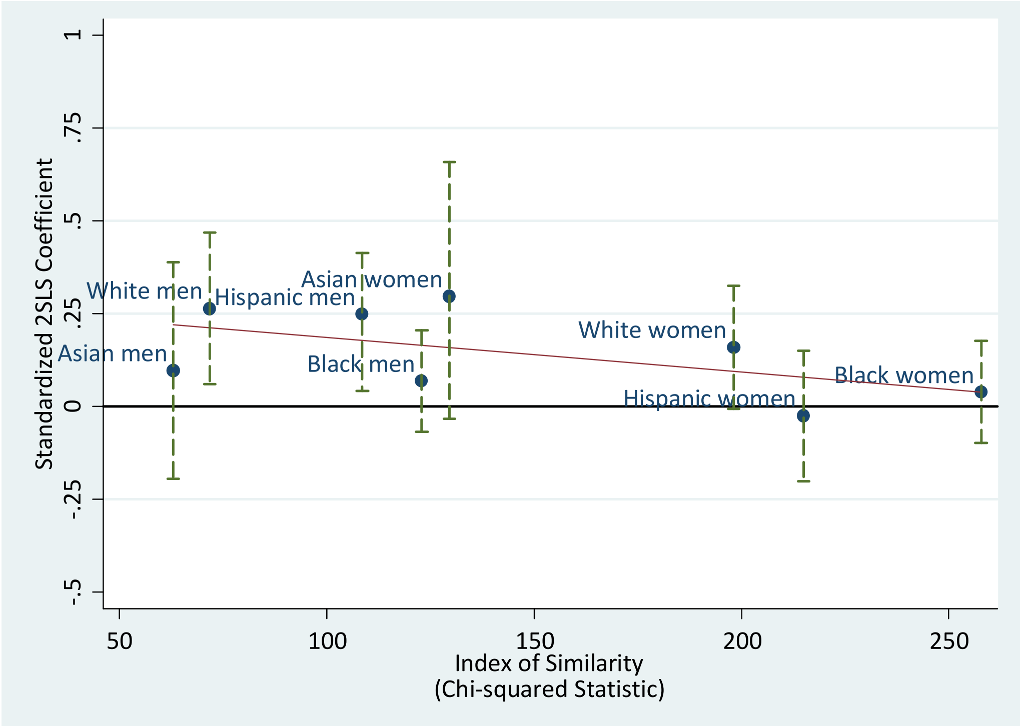
Figure 6: Foreign Graduate Student Boom and Bust in the U.S. by Country/Region-of-Origin, 1995-2006



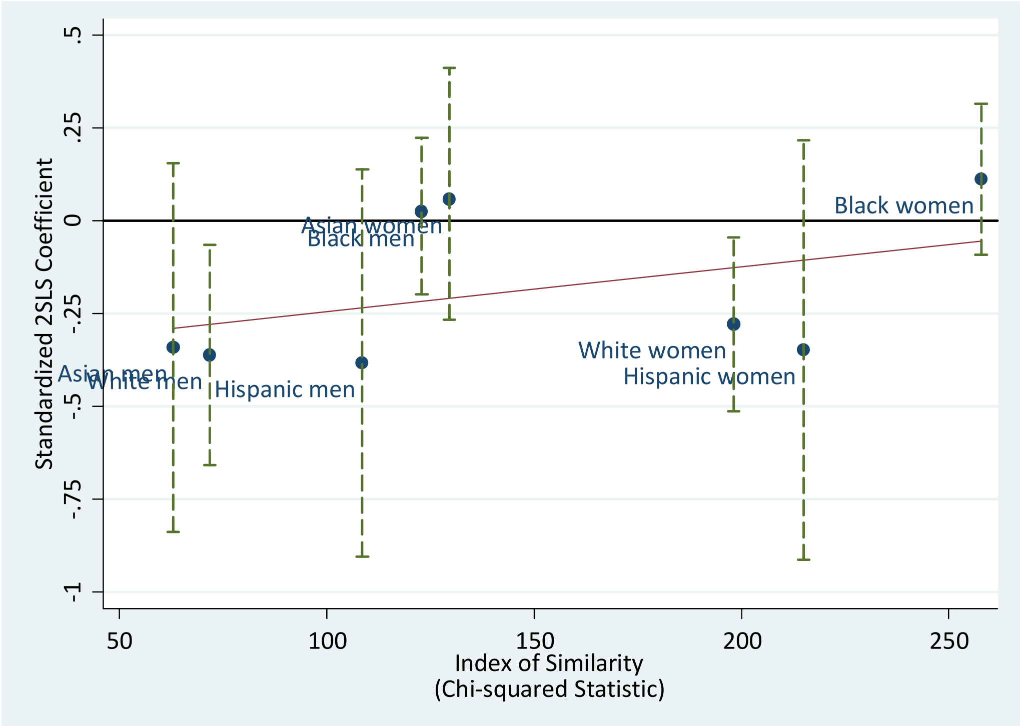
Note: Data is from IIE Open Door Reports 1995-2006. Graduate enrollments have been standardized within-countries. That is, enrollment figures for each country-year are standardized by the mean and standard deviation of enrollments for that country over the entire 1995-2006 period. Enrollment from China and India are also included in the enrollment counts for Asia, but are also plotted separately since they are the top sending countries.

Figure 7: Test for Peer Effects: 2SLS Effect vs. Index of Similarity

A: Boom, Effect of 1 sd *increase* in international students (90% CI)



B: Bust, Effect of 1 sd *decrease* in international students (90% CI)



Note: The above graphs plot the standardized 2SLS effect of foreign enrollment flows on native enrollment flows against the index of similarity to foreign students for 8 race by gender native groups. Reported 2SLS effects, on the vertical axis, measure the effect, in standard deviations, of a 1 standard deviation increase (Panel A) or decrease (Panel B) in foreign enrollment. The index of similarity measures how similar each native group is in their distribution across fields of study to that of international students. Lower values indicate higher similarity, and an index of 0 indicates identical distributions. 90% Confidence intervals are represented by dashed vertical green bars.

Table 1: Baseline (1995) Summary Statistics of IPEDS Higher Education Institutions

Academic Level	**Non-Research**		**Research (292)**		**Sample (258)**	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Undergraduate Enrollment						
Total	1,570	2,617	10,700	7,920	11,184	8,017
International	4%	9%	4%	4%	3%	4%
U.S. Native	94%	13%	93%	8%	93%	8%
Graduate Enrollment						
Total	340	688	4,291	3,212	4,490	3,219
International	6%	12%	11%	8%	11%	8%
U.S. Native	90%	19%	84%	10%	85%	10%
White	73%	26%	68%	15%	69%	15%
Asian	4%	10%	4%	5%	4%	5%
Minority	12%	19%	11%	13%	11%	12%
1st Professional Degrees						
Total	15	54	150	194	157	198
International	5%	13%	2%	4%	2%	4%
U.S. Native	93%	16%	96%	7%	96%	6%
Masters Degrees						
Total	69	167	858	697	903	709
International	8%	16%	14%	9%	13%	8%
U.S. Native	88%	20%	82%	12%	83%	11%
Ph.D. Degrees						
Total	2	12	139	167	146	174
International	12%	22%	22%	16%	21%	14%
U.S. Native	83%	27%	75%	17%	76%	15%
# of Universities	2,448		292		258	
Type of University						
Public	18%		61%		62%	
Private (non-profit)	74%		39%		38%	
For Profit	7%		0%		0%	
Share of Total:						
Foreign Graduates	20%		80%		73%	
Graduate Enrollment	40%		60%		56%	
1st Professional Degrees	43%		57%		52%	
Masters Degrees	38%		62%		58%	
Ph.D. Degrees	10%		90%		83%	

Note: Statistics calculated from IPEDS 1995 Fall Enrollment, Completions, and Institutional Characteristics surveys. Sample includes institutions that are of the Baccalaureate level or higher. Universities are defined as Research if they are ever classified as a Doctoral/Research university in the 1994, 2000, 2005, or 2010 Carnegie Classifications.

Table 2: First Stage Power of the Instruments

	(1) Main	(2) Main (unwtd.)	(3) W/ Outliers (unwtd.)	(4) No Imputed (IPEDS)	(5) No Imputed (IIE)	(6) No Imputed (IPEDS/IIE)
Panel A Boom 1995-2001						
IV - Coll. Pop	3.75***	3.82***	3.31***	3.70***	3.91***	3.85***
	(0.55)	(0.55)	(1.09)	(0.57)	(0.60)	(0.62)
F - Statistic	46.6	48.9	9.2	42.5	42.4	38.4
N	1,548	1,548	1,752	1,488	1,206	1,158
Panel B Bust 2002-2005						
IV - 9/11	1.94***	1.23***	2.13*	1.98***	2.03***	2.08***
	(0.42)	(0.46)	(1.12)	(0.43)	(0.51)	(0.51)
F - Statistic	20.8	7.1	3.6	21.2	16.1	16.5
N	774	774	876	744	603	579
# of Univ.	258	258	292	248	201	193

Note: The above displays first-stage results from regressions of actual foreign enrollment flows on the IV, controlling for fixed-effects and year effects. The IV for the boom period are predicted foreign flows based on the college age (18-30) population growth in sending countries. For the bust period the IV is based on aggregate declines in student visa issuance due to post-9/11 security policies. Standard errors clustered at the university level. All regressions control for time-period effects and university fixed effects., using the panel fixed effects estimator. Columns (1)-(5) weight regressions by total graduate enrollment in the initial year. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3: 2SLS Results, Native Enrollment

	(1) Main	(2) Main (unwtd.)	(3) No Imputed (IPEDS)	(4) No Imputed (IIE)	(5) No Imputed (IPEDS/IIE)	(6) OLS (Main)
Panel A Boom 1995-2001						
Int'l Graduate Flow	1.30**	1.71**	1.17*	1.83***	1.80***	0.41**
	(0.59)	(0.85)	(0.62)	(0.63)	(0.67)	(0.16)
1st Stage F-statistic	46.6	48.9	42.5	42.4	38.4	
N	1,548	1,548	1,488	1,206	1,158	1,548
Panel B Bust 2002-2005						
Int'l Graduate Flow	1.59*	1.09	1.55*	1.39	1.38	0.33
	(0.85)	(1.52)	(0.85)	(0.90)	(0.91)	(0.34)
1st Stage F-statistic	20.8	7.1	21.2	16.1	16.5	
N	774	774	744	603	579	774
# of Univ.	258	258	248	201	193	258

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using the panel fixed effects estimator. All regressions are weighted by total graduate enrollment in the prior year, unless otherwise specified.

Table 4: 2SLS Results, Native Enrollment by Field of Study

	(1) STEM (wide)	(2) STEM (strict)	(3) Non STEM (Business & Education)	1st Stage F-statistic	# of Univ.	N
Panel A Boom 1995-2001						
Main	1.30***	0.86***	0.50	34	209	1,254
	(0.29)	(0.18)	(0.57)			
No Imputed (IPEDS/IIE)	1.28***	0.85***	0.56	30	160	960
	(0.28)	(0.19)	(0.63)			
OLS	0.07	0.08**	0.17		209	1,254
	(0.05)	(0.04)	(0.13)			
Panel B Bust 2002-2005						
Main	0.25	0.12	0.43	13	209	627
	(0.18)	(0.12)	(0.76)			
No Imputed (IPEDS/IIE)	0.20	0.15	0.67	9	160	480
	(0.20)	(0.15)	(0.99)			
OLS	-0.02	-0.02	0.03		209	627
	(0.04)	(0.03)	(0.12)			

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using 2SLS. All regressions are weighted by total graduate enrollment in the prior year, unless otherwise specified.

Table 5: Instrument Validity

		Boom 1995-2001				Bust 2002-2005			
Estimation	Specification	**(1) Main**	1st Stage F-statistic	**(2) No Imputed (IPEDS/IIE)**	1st Stage F-statistic	**(3) Main**	1st Stage F-statistic	**(4) No Imputed (IPEDS/IIE)**	1st Stage F-statistic
1st Stage	IV - 1993 Int'l Undergrad.	0.02 (1.62)	0.0	-2.07 (2.42)	0.7	1.12 (1.25)	0.8	2.05 (1.88)	1.2
1st Stage	Int'l Undergrad.	0.44* (0.26)	2.9	0.40 (0.30)	1.8	0.01 (0.15)	0.0	0.01 (0.16)	0.0
1st Stage	Native Undergrad.	0.79 (2.44)	0.1	3.17 (2.84)	1.3	1.49 (1.36)	1.2	1.53 (1.70)	0.8
2SLS	Control for int'l undergrad.	1.32** (0.55)	49.8	1.64*** (0.60)	45.8	1.39* (0.81)	20.7	1.17 (0.89)	15.8
2SLS	Control for H-1B Policy	1.15* (0.67)	39.0	1.75** (0.75)	31.9	1.75** (0.89)	19.1	1.51* (0.87)	17.1
2SLS	Control for Dot Com Sector	1.24** (0.59)	55.6	1.49** (0.64)	50.3	2.40* (1.33)	10.6	2.09 (1.42)	8.5
2SLS	Main (from Table 3)	1.30** (0.59)	46.6	1.80*** (0.67)	38.5	1.59* (0.85)	20.8	1.38 (0.91)	16.5

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using the panel fixed effects estimator. All regressions are weighted by total graduate enrollment in the prior year, unless otherwise specified.

Table 6: Further Robustness Checks

	Boom 1995-2001				Bust 2002-2005			
Specification	**(1)** **Main**	1st Stage F-statistic	**(2)** **No Imputed** **(IPEDS/IIE)**	1st Stage F-statistic	**(3)** **Main**	1st Stage F-statistic	**(4)** **No Imputed** **(IPEDS/IIE)**	1st Stage F-statistic
Remove Top 8 Univ.	1.28** (0.62)	47.6	1.86*** (0.68)	43.0	1.60 (0.99)	17.1	1.35 (1.1)	12.3
Remove China	0.98 (0.77)	23.7	1.67* (0.93)	16.4	1.84** (0.91)	19.5	1.58* (0.95)	16.5
Remove India	1.26** (0.59)	47.6	1.74*** (0.66)	40.2	1.28 (1.05)	10.0	1.34 (1.07)	10.1
Control for Income	1.28** (0.61)	48.0	1.73** (0.69)	40.2	3.17** (1.54)	9.8	2.28** (1.15)	13.7
Remove Muslim Nations	1.28** (0.60)	45.4	1.80*** (0.67)	37.5	2.28 (2.30)	3.0	2.26 (1.99)	4.2

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using the panel fixed effects estimator. All regressions are weighted by total graduate enrollment in the prior year, unless otherwise specified.

Table 7: 2SLS Results, Faculty

	Boom 1995-2001		**Bust 2002-2005**	
	(1) Tenure-Track	(2) Instructional	(3) Tenure-Track	(4) Instructional
Main	0.34**	0.14	0.01	-0.19
	(0.16)	(0.09)	(0.16)	(0.16)
1st stage F-statistic	46	41	20	22
# Universities	254	228	254	228
N	1524	1368	762	684
No Imputed (IPEDS/IIE)	0.28*	0.15*	0.08	-0.29
	(0.16)	(0.09)	(0.19)	(0.18)
1st stage F-statistic	42	38	16	16
# Universities	200	183	200	183
N	1,200	1,098	600	549

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using 2SLS. All regressions are weighted by total graduate enrollment in the initial period, unless otherwise specified.

A Appendix

A.1 Defining Research Universities

I use the Basic Carnegie Classification to identify Research universities. The Carnegie Classification is revised every few years, and revisions are based on thresholds in the numbers of degrees awarded from recent IPEDS data. For example, the 2005 Carnegie Classification labeled universities under the "Doctorate-granting" category if they awarded at least 20 doctorates in the 2003-04 academic year, measured from the IPEDS Completions survey. As such, some universities that failed to respond to an IPEDS survey in a given year, or those are on the margin of such cutoffs in degrees awarded tend to fall in and out of the classification.

I create a time-consistent definition of Research universities by considering all universities that were ever classified as "Doctorate-granting" in the 1994, 2000, 2005, and 2010 Basic classifications. From the 1994 classification I include institutions categorized as "Doctoral I", "Doctoral II", "Research I", or "Research II". The 2000 classification only divided Doctorate-granting institutions into two categories–" Doctoral/Research Universities Extensive" and "Doctoral/Research Universities, Intensive", and thus I include universities classified as such. The 2005 classification yet again changed the classification of Doctorate-granting institutions to include three categories, and thus I include any university classified as "Research Universities with very high research activity", "Research Universities with high research activity", or "Doctoral/Research Universities". Finally, the 2010 classification kept the three category labels as in 2005, and I include any universities classified as such. This process results in a list of 300 universities, 292 of which consistently responded to IPEDS Fall Enrollment surveys from 1995-2005.

A.2 Imputations to 1993 IIE Data

Only 201 of the main sample of 258 Research universities responded to the 1993 IIE survey on enrollments by country of origin and academic level. I impute graduate and undergraduate enrollments for the 57 universities that did not respond. I do this by taking advantage of a large amount of non-Research universities that did respond to the survey. These include Masters and Baccalaureate level institutions, and also community colleges and vocational colleges. In what follows, I describe the imputation procedure for graduate enrollments by country of origin. The procedure for undergraduate enrollments is identical, the only difference being that I use available data on undergraduate enrollments rather than graduate enrollments.

To impute graduate enrollment by country of origin, I obtain total graduate enrollment in 1993 from the IPEDS Fall Enrollment survey for each of the 57 missing universities. Using only non-Research universities in the 1993 IIE data I calculate the share of graduate enrollment from each country of origin by state. This procedure involves first aggregating graduate enrollment by country of origin (c) for all non-Research universities (i) within the same state (s),

$$F^c_{s1993} = \sum_i F^c_{is1993} \tag{A.1}$$

Hence I obtain for each state total enrollment by country of origin in non-Research universities. Next, enrollments by country of origin for each state are then aggregated across all countries of origin,

$$F_{s1993} = \sum_s F^c_{s1993} = \sum_s \sum_i F^c_{is1993}$$

Dividing the state level country of origin enrollment by total state enrollment yields the share of students from country c in each state in 1993,

$$sh^c_{s1993} = \frac{F^c_{s1993}}{F_{s1993}}$$

To impute graduate enrollment from each country of origin for the 57 missing Research universities, I then multiply total enrollment in 1993, measured from IPEDS, with the share of students by country of origin in the corresponding state.

$$\widehat{F^c_{u1993}} = F_{u1993} * sh^c_{s1993}$$

To be precise, the state share assigned to the university is that of the state in which the university is located. Lastly, I further aggregate the country of origin imputations to one of 17 nationalities in order to construct the instruments.

A.3 Weighting to correct for heteroskedasticity

Suppose the true model governing native enrollment is given as follows:

$$N_{ut} = \alpha + \beta F_{ut} + \Psi_{ut} \tag{A.2}$$

In A.2, native enrollments are a function of foreign enrollment and a random, zero-mean error term. Further, suppose the residual is homoskedastic, normally distributed with constant variance σ^2_Ψ. Recall that the main specification used in this paper (see equation 2) first differences native and foreign enrollments and then standardizes both sides of the equation by total graduate enrollment in the prior year. This simple transformation applied to A.2 yields exactly the main estimating equation 2, ignoring the inclusion of a constant term, university fixed effects and year effects for simplicity:

$$\frac{\Delta N_{ut}}{E_{ut-1}} = \beta \frac{\Delta F_{ut}}{E_{ut-1}} + \frac{\Delta \Psi_{ut}}{E_{ut-1}} = \beta \frac{\Delta F_{ut}}{E_{ut-1}} + \varepsilon_{ut}$$

This transformation induces heteroskedasticity in the residual, as $\varepsilon_{ut} = \frac{\Delta \Psi_{ut}}{E_{ut-1}}$. The variance of the error term will vary based on differences in total graduate enrollment across universities. In regression analysis, this heteroskedasticty reduces the precision of estimates.

Heteroskedasticity induced by such transformations has been well documented. Since the factor that induces heteroskedasticity is known (i.e. standardizing by E_{ut-1}), the loss of precision can be corrected by weighting by the inverse square root of the standardizing factor ($\frac{1}{\sqrt{E_{ut-1}}}$). Solon, Haider, & Wooldridge (2013) provide a nice overview of this issue and suggest testing explicitly for the presence of heteroskedasticity before assuming weights are necessary. Breusch-Pagan tests and White tests for heteroskedasticity (available upon request) indeed strongly reject the hypothesis of no heteroskedasticity. Further, they recommend reporting unweighted results, which I do in column 2 of table 2.

Finally, further tests for heteroskedasticity after weighting (not reported but available upon request) suggest substantial heteroskedasticity remains. This suggests that the assumption of homoskedastic errors in A.2 is likely invalid. Thus, I use cluster robust standard errors to account for any remaining heteroskedasticity and/or serial correlation in residuals within universities.

A.4 Interpreting first-stage point estimates

The first-stage coefficients in table 2 are greater than one. For the boom the point estimates are roughly around 3.6, while for the bust they are around 2. Interpreted literally, the coefficients indicate that a one percentage point increase in predicted foreign graduate enrollment flows based on college age population growth is associated with a 3.6 increase in actual foreign enrollment flows over the boom. During the bust, a one percentage point decrease in predicted flows is based on 9/11 policies is associated with a two percentage point decrease in actual flows.

While these interpretations have little substantive meaning, fortunately, a more intuitive understanding of the point estimates can be clarified when considering the scatterplot underlying the first-stage regression line. After partialling out fixed effects and year effects from both actual foreign flows and the instrument, the best fit line between the points is the estimated regression line. I plot this regression line in figure A.2, omitting the underlying scatterplot for clarity. The vertical axis measures foreign graduate flows after partialling out university fixed-effects and year effects. The horizontal axis represents the predicted flows, also after partialling out university fixed-effects and year effects. The solid green line represents the regression line from the main specification during the boom, corresponding to column 1 of table 2. The slope of the line is equal to the point estimate of 3.64.

Now consider the 45 degree line, indicated by the dashed navy line. If the regression line was the 45 degree line, instead of the solid green line, the first-stage coefficient would be equal to 1 and indicate that actual foreign enrollment grew at the same rate as predicted foreign enrollment. Since predicted foreign enrollment is based off of college age population growth, this would indicate that foreign enrollment on average grew at the exact same rate as college population in sending countries. Because the actual regression line is much steeper, this means that actual enrollment grew, on average, faster than the college population abroad.

This is verified in figure A.3 which plots college age population growth and actual graduate enrollment growth factors in the U.S. over the boom period for each nationality group. These growth factors are calculated from 1993, thus the value for 1993 is 1. A value of 3 in 1998, for example, suggests that in 1998 the college population was 3 times larger than its 1993 level. Nationality groups are plotted in order of their foreign enrollment in the U.S., with China being the largest supplier of foreign graduate students and Indonesia the smallest.

As can be seen in the graphs, college age population growth factors indeed were much smaller than actual graduate enrollment growth rates in the U.S., for most of the nationalities. The turn of the millennium saw large growth in Chinese and Indian graduate students, while college age population growth was much more moderate–for China the college age population actually was in decline.

A.5 Measurement Error

My empirical strategy relies on transformations of panel data on native and foreign graduate enrollments. In particular, I first difference the yearly enrollments and standardize by total graduate enrollment. Such transformations are known to exacerbate measurement error (e.g. Angrist & Pischke 2008). Since the outcome and main explanatory variable are transformed, this likely means that measurement error is exacerbated in both the dependent and independent variable. While instrumental variables can solve classical measurement error, such error in the independent variable threatens the power of instruments. This is especially true in the bust period, where power is much lower than in the boom.

Given strong enough power, the IV strategy will fail as a panacea for measurement error, however, if such errors are nonclassical. Several studies have shown that IV estimators yield inconsistent estimates in the presence of nonclassical measurement error (Kim & Solon 2005; Hu & Schennach 2008). Measurement errors are nonclassical if they are correlated with observables or unobservables, or if the errors in outcome and explanatory variables are correlated with each other. This is a large concern during the bust period, in which universities experienced an overhaul of their data management systems to track international students. University administrators were mandated to switch to SEVISs online platform, which was riddled with technical glitches. This could have severely affected data reporting to surveys like IPEDS.

To assess whether measurement errors appear classical, I provide some descriptive statistics of the data. From the full group of 292 Research universities I examine universities with extreme observations (outliers), which I define as reported international flows above the 99th percentile or below the 1st percentile in all international flows over the 1995-2005 decade. Table A.1 compares the summary statistics of universities with outliers against the entire sample, measured in 1995. Indeed, universities with outliers appear to be different from the average university in the sample. Outlier universities are much smaller in terms of both undergraduate and graduate enrollment, but have a larger share of international students. Outlier universities award nearly half the number of Ph.D. degrees, and as many Masters degrees as the sample universities.

Additionally, there appear to be differences in measurement error over the boom and bust. Panel A of Figure A.4 (top graph) shows the distribution of native graduate enrollment flows across universities during the boom period. These flows appear approximately normally distributed and are roughly centered around 0. The bottom graph in panel A shows the distribution of native flows only for those observations classified as outliers–i.e. those observations for which foreign flows are beyond the 99th percentile or below the 1st percentile. Interestingly, during the boom period, native enrollment flows of outliers seem to be also fairly normally distributed.

Panel B presents the same two distributions during the bust. The top figure represents the distribution of native enrollment flows during the bust. Native enrollment flows again appear normally distributed around 0. Differently, however, native enrollment flows of outlier observations are skewed. During the bust there were few negative native enrollment flows, and mostly positive enrollment flows. Moreover, there are masses at the right tail of the native enrollment flow distribution. This reveals a potential correlation in measurement errors in the outcome and explanatory variables. Outlier observations appear likely to have extremely high values of native enrollment flows.

To summarize, it appears that measurement error in the outcome variable (native flows) during the bust was relatively unrelated to measurement error in the explanatory variable (foreign flows). In contrast, during the bust period, universities that report extreme foreign flows appear to also report extreme, positive native flows. Because of this apparent non-classical measurement error, I drop extreme outliers entirely from the analysis, focusing on the main sample of 258 research universities. The removal of outliers helps assuage issues arising from measurement error.

A.6 Annualizing native flows by field of study

Since data on native enrollment by field of study is available every two years, I cannot directly calculate yearly changes standardized by initial enrollment. Thus, I calculate changes over two year periods, standardizing by total enrollment in the initial period: $\frac{\Delta_2 N_{ut}}{E_{ut-2}} = \frac{N_{ut}-N_{ut-2}}{E_{ut-2}}$. I then approximate the actual annual growth rate as follows:

$$\frac{\widehat{N_{ut} - N_{ut-1}}}{E_{ut-1}} = \sqrt{1 + \frac{\Delta_2 N_{ut}}{E_{ut-2}}} \approx \frac{N_{ut} - N_{ut-1}}{E_{ut-1}}$$

A.7 Construction of control variables

This section describes, in further detail, the construction of the various different control variables used in the analysis. Since the control variables all are formed using a common basic structure, I first present the generalized construction and then discuss where each control variable differs.

For the analysis I develop control variables for three other phenomena that may violate the exclusion restriction. In particular, the loosening and contracting of H-1B visa policy, the Dot Com boom and bust, and changes in living standards in sending countries may have endogenously affected native enrollment in the U.S. The basic control variables can are formed in a manner very similar to the main IVs. Equations A.3-A.5 detail the general construction of the control variables for each of the different factors (H-1B policy, Dot Com boom and bust, and foreign income per capita) that may hinder causal inference.

$$\hat{F}^w_{nut} = F_{nu1993} * g^w_{nt} \tag{A.3}$$

$$\hat{F}^w_{ut} = \sum_{n=1}^{17} \hat{F}^w_{nut} \tag{A.4}$$

$$\frac{\Delta \hat{F}^w_{ut}}{\hat{E}^w_{ut}} = \frac{\hat{F}^w_{ut} - \hat{F}^w_{ut-1}}{\hat{E}^w_{ut}} \tag{A.5}$$

Equation A.3 interacts the number of foreign graduate students by nationality and university in 1993 with the nationality-specific growth pertaining to the factor of concern (g^w_{nt}). For each university, these predictions are then aggregated over all nationality groups in A.2, forming imputations that capture how the evolution of foreign graduate enrollment was influenced by each factor. Finally yearly differences are taken and standardized by total imputed graduate enrollment A.3. In what follows I describe the construction of the growth factor g^w_{nt} and the construction of total imputed graduate enrollment ($\hat{E}^w_{ut}$) pertaining to each factor of concern.

A.7.1 H-1B Control

The H-1B-driven control accounts for the possible influence that national changes to H-1B visa policy may have had on both international student entry and native enrollment. To form the control variable I first predict how international enrollment would have evolved if all nationality groups had grown at the rate of H-1B workers of that nationality from 1993 to each of the sample years (1995-2005).

The first step in forming this prediction requires calculating the stock of H-1B workers from each nationality for the base year 1993 and subsequent sample years 1995-2005. Data on H-1B visa issued by country of origin is available from 1997-2005 from the Department of State. An immediate issue, however, is that data from prior to 1997 are not available. However, yearly data on the total number of H-1B visas issued from 1990-2005 are available. This allows imputation of H-1B visas issued by country of origin in the missing years, as follows:

$$S^n_{97-05} = \frac{\sum_{t=1997}^{2005} H1B^n_t}{\sum_{t=1997}^{2005} H1B_t}$$

$$\widetilde{H1B}^n_\tau = S^n_{97-05} * H1B^n_\tau \qquad for\ \tau = 1990, 1991, \ldots, 1996$$

I first calculate the share of all H-1B visas awarded to each nationality group n from 1997 to 2005 (S^n_{97-05}). This is done by cumulating all visas issued to that nationality group ($H1B^n_t$) and dividing by the total H-1B visas awarded over the 1997-2005 period. The second step imputes the number of H-1B visas issued to each nationality group in the years prior to 1997 ($\widetilde{H1B}^n_\tau$) by interacting the share of all H-1B visas awarded to that nationality group over the 1997-2005 period with the total number of H-1B visas in each of those years (i.e. 1990, 19911996).

A second challenge is that visa issuances measure flows not stocks, and to transform issuances to stocks I use the fact that H-1B visas are 3-year work permits. Thus, I form estimates of the stock of H-1B workers in each year by cumulating H-1B visas issued over the past 3 years. For example, the total number of H-1B workers in 2000 is the sum of the number of H-1B visas issued in 2000, 1999, and 1998. More formally, I predict the stock as follows:

$$\widehat{H1B}^n_t = \sum_{s=0}^{2} H1B^n_{t-s} = H1B^n_t + H1B^n_{t-1} + H1B^n_{t-2} \quad for\ t = 1993, 1995, \ldots, 2005$$

I aggregate the country of origin data on H-1B visas issued to the 17 nationality groups used in the analysis to obtain the number of visas issued by nationality group in each year ($H1B^n_t$). For each year, I then cumulate the number of H-1B visas issued over the past three years to obtain predictions of the stock of H-1B workers ($\widehat{H1B}^n_t$) of each nationality in the U.S.

After estimating the stock of H-1B workers of each nationality group in each year, I calculate the aggregate growth rates of H-1B workers by nationality from 1993 to each of the sample years.

$$g_{93-t}^{H1B^n} = \frac{\widehat{H1B}_t^n}{\widehat{H1B}_{1993}^n}$$

This growth factor is used in equations A.3-A.5 to construct the control variable for H-1B policy fluctuations over the 1995-2005 decade.

A.7.2 The Dot Com Boom and Bust

The Nasdaq Composite Index (NCI) is a stock market index consisting of over 3,000 actively traded securities listed on the Nasdaq stock exchange, generally used to track the performance of technology-based companies. The performance of NCI has often been used to characterize the Dot Com boom and bust. Similarly, I capture the aggregate impacts of the Dot Com boom and bust by measuring growth in the NCI.

I compute a simple average of the NCI daily closing price over the 2nd quarter of each year, around the time when students make enrollment decisions. I correct these values for inflation, and calculate growth in the average NCI values from 1993 to each of the years in the sample (1995-2005),

$$g_{93-t}^{NCI} = \frac{NCI_t}{NCI_{1993}}$$

This growth factor is used in equations A.3-A.5 to construct the control for the Dot Com boom and bust.

A.7.3 Income per capita in sending countries

To construct growth rates in living standards in sending countries I collect data on real GDP and population by country from 1993-2005 from the Penn World Table version 8.0. I then aggregate country-level real GDP and population counts to the 17 nationality groups. For each nationality group I then calculate the real GDP per capita by dividing total real GDP of the nationality group by total population of the nationality. Then for each year from 1995-2005 I calculate growth factors in real GDP per capita of the nationality group by dividing that nationality groups real GDP per capita in that year by the 1993 level.

A.8 Effect of foreign students on university resources and tuition

International students may bolster the enrollment of natives through increased tuition revenue. International students often pay full-sticker price tuition and their contributions may cross-subsidize natives. This may materialize in increased resources and university revenues. This may also show up in price reductions for natives.

I check whether these are plausible mechanisms by using university level data on revenues and tuitions from the IPEDS Delta Cost Project database (Lenihan 2012). Specifically, for each university I compute real inflation-adjusted tuition revenues per student, grant revenue per student, in-state average tuition, and out-of-state average tuition. These measures are not separately reported for graduates and undergraduates, and thus reflect figures for the university as a whole.

To assess the impact of foreign students on these measures, I run 2SLS regressions on specification A.6, separately for the boom and the bust using the same instruments as in the main analysis:

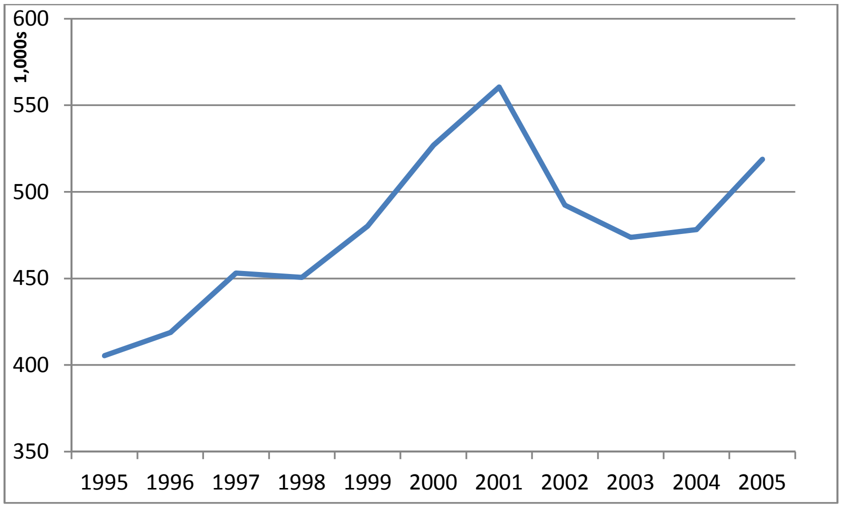
$$\frac{\Delta R_{ut}}{E_{ut-1}} = \alpha + \beta_R \frac{\Delta F_{ut}}{E_{ut-1}} + \gamma_u + \gamma_t + \psi_{ut} \tag{A.6}$$

In A.6 the outcome variable represents the yearly change in financial measure R (=tuition revenue per student, grant revenue per student, in-state tuition, or out-of-state tuition), standardized by total graduate enrollment in the initial period. This standardization allows the estimated coefficients to be interpreted directly in dollar amounts. The outcomes are then regressed on foreign flows, university fixed effects, and year effects, similar to the main analysis.

The results are shown in table A.2. Odd numbered columns show results using the main specification (i.e. 2SLS regressions of A.6 weighted by total graduate enrollment in the initial period). Even numbered columns show results after removing outliers. Overall the results are generally statistically indistinguishable for zero, suggesting foreign students have little impact on tuition prices or on revenues. Although foreign graduate students pay higher tuition, they may be able to secure funding (teaching assistant or research assistant positions) that help offset the cost of education, and thereby limit the extent by which they may cross-subsidize natives.

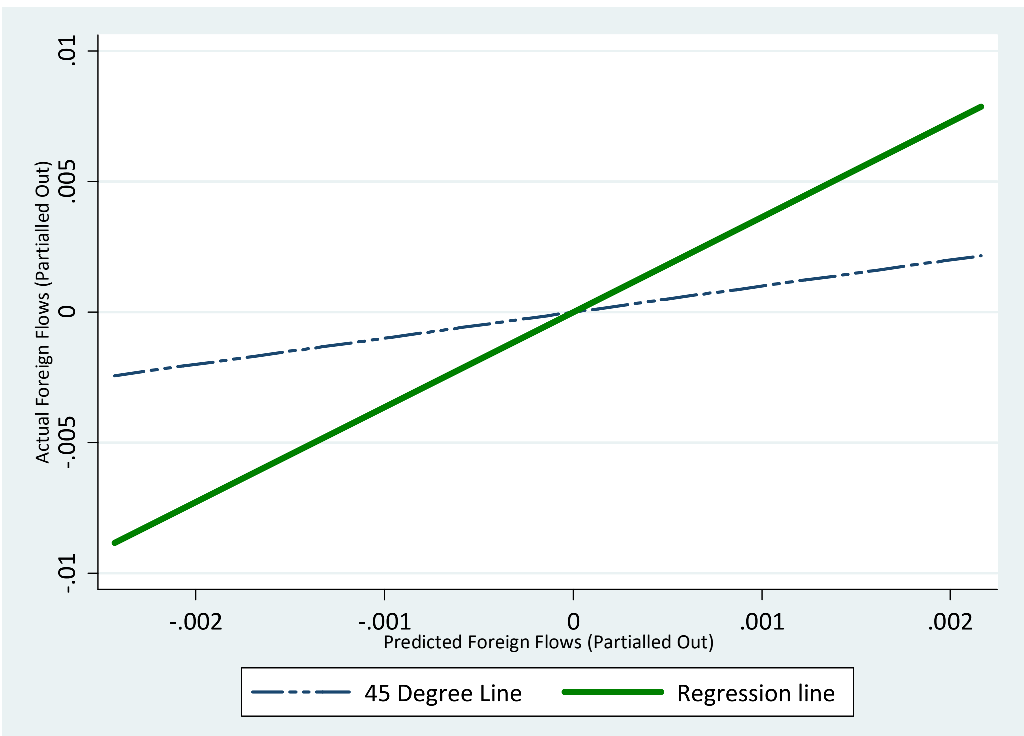
Interestingly, for the boom period international graduate students appear to lower tuition revenues per student. The coefficient in column 1 suggests that each additional foreign student lowers tuition revenues per student by almost $9. The suggests that many foreign students do not contribute to university resources through tuition payments, and universities are willing to lose tuition revenues in exchange for higher enrollments from abroad.

Figure A.1: Student Visa (F-1, J-1, M-1) Issuances, 1995-2005



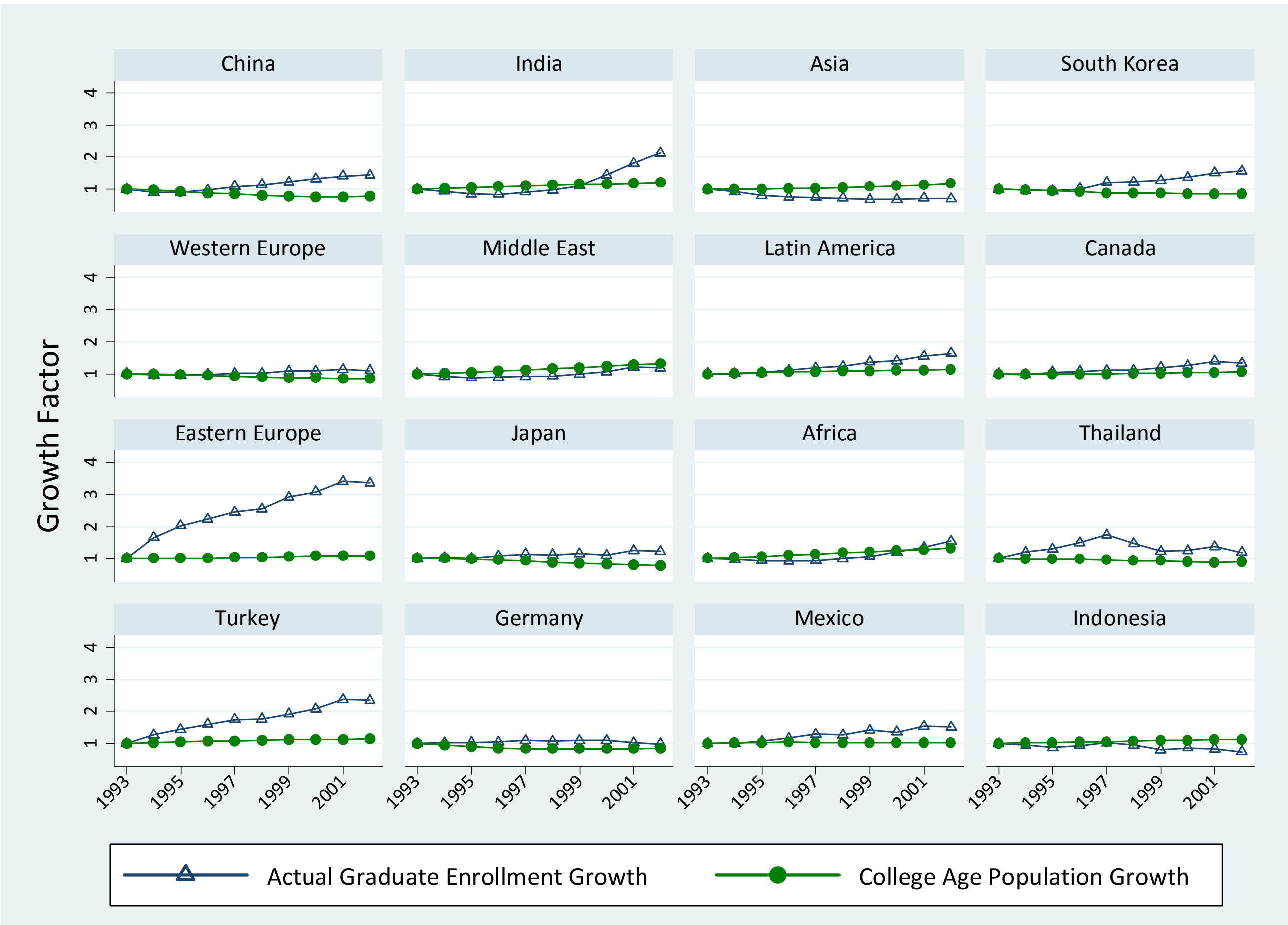
Note: The above series represents all classes of student visas issued in each fiscal year from 1995-2005. The student visas include F-1, J-1, and M-1 visas. Data come from the Department of States Non-immigrant Visa Issuances by Visa Class and Nationality FY 1997-2013, retrieved from: http://travel.state.gov/content/visas/english/law-and-policy/statistics/non-immigrant-visas.html.

Figure A.2: First-stage regression line vs. 45 degree line, boom



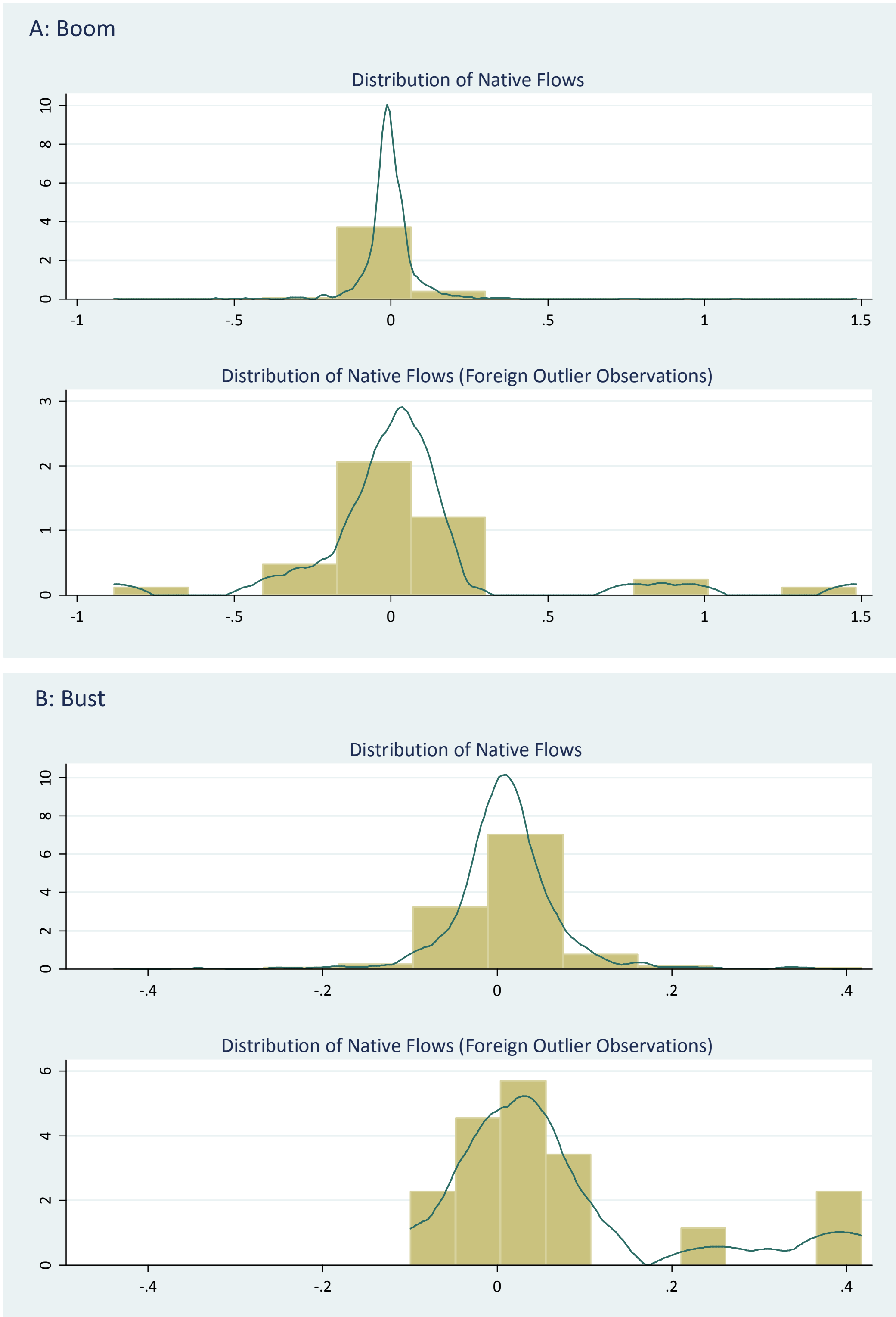
Note: The vertical and horizontal axes measure foreign graduate enrollment flows and predicted foreign flows based on college age population growth (i.e. the instrument for the boom period), after partialling out university fixed effects and year effects, respectively. The solid green line represents the regression line through the underlying data (scatterplot has been suppressed for visual clarity) of the first-stage main estimate for the boom period, reported in column 1 of table 2. The dashed-dotted navy line represents the 45 degree line–i.e. the case where actual foreign enrollments grew at exactly the rate of college age population in sending countries.

Figure A.3: College age population growth vs. Actual graduate enrollment growth



Note: The figure plots growth factors of graduate enrollment in the U.S. and college age population by nationality group. The nationality groups are presented in order of the number of graduate students in the U.S. China is the largest sending country of graduate students, and Indonesia the smallest. Growth factors are calculated from 1993, and hence the value in 1993 is 1 for all nationalities. A college age population growth factor of 3 in 1998 means that the 1998 college age population is 3 times the 1993 level.

Figure A.4: Potential Nonclassical Measurement Error



Note: For each panel the top figure displays the distribution of native enrollment flows–i.e. the outcome variable–for the 292 Research universities. The bottom figure represents the conditional distribution for observations which are outliers in foreign enrollment flows–i.e. the explanatory variable. Outliers are defined as observations that are above the 99th percentile or below the 1st percentile of all international flows from 1995-2005. Panel A presents results for the boom (1995-2001) and panel B for the bust (2002-2005).

Table A.1: Baseline (1995) Summary Statistics of Universities with Outliers vs. 292 Research Universities

Academic Level	292 Research Universities		34 Universities w/ Outliers		
	(1)		(2)		(3)
	Mean	Std. Dev.	Mean	Std. Dev.	Diff. (1) - (2)
Undergraduate Enrollment					
Total	10,700	7,920	7,020	6,071	3,680***
International	4%	4%	5%	7%	-2%**
U.S. Native	93%	8%	91%	10%	1%
Graduate Enrollment					
Total	4,291	3,212	2,779	2,760	1,511***
International	11%	8%	16%	10%	-5%***
U.S. Native	84%	10%	80%	10%	4%**
White	68%	15%	63%	18%	5%*
Asian	4%	5%	5%	4%	-1%
Minority	11%	13%	12%	19%	-1%
1st Professional Degrees					
Total	150	194	98	154	53*
International	2%	4%	4%	5%	2%***
U.S. Native	96%	7%	92%	11%	4%***
Masters Degrees					
Total	858	697	514	482	343***
International	14%	9%	21%	12%	-7%***
U.S. Native	82%	12%	75%	14%	7%***
Ph.D. Degrees					
Total	139	167	89	85	51*
International	22%	16%	32%	23%	-9%***
U.S. Native	75%	17%	65%	23%	9%***
Type of University					
Public	61%		50%		
Private (non-profit)	39%		50%		

Note: Statistics calculated from IPEDS 1995 Fall Enrollment,Completions, and Institutional Characteristics surveys. Sample includes institutions that are of the Baccalaureate level or higher. Universities are defined as "Research" if they are ever classified as a Doctoral/Research university in the 1994, 2000, 2005, or 2010 Carnegie Classifications. Outliers are those that report standardized international flows (the key independent variable in the analysis) above the 99th percentile or below the 1st percentile.

Table A.2: 2SLS Results, University Revenues and Tuition

Outcome Variable	Tuition Revenue Per Student		Grant Revenue Per Student		In-State Average Tuition		Out-of-state Average Tuition	
Specification	(1) Main	(2) No Imputed (IPEDS/IIE)	(3) Main	(4) No Imputed (IPEDS/IIE)	(5) Main	(6) No Imputed (IPEDS/IIE)	(7) Main	(8) No Imputed (IPEDS/IIE)
Boom	-7.66**	-4.10	3.77	-1.35	0.86	3.12	0.96	3.19
	(3.90)	(3.05)	(29.91)	(35.77)	(2.53)	(2.30)	(2.53)	(2.30)
1st-stage F-statistic	47.04	39.24	46.22	36.68	49.9	42.68	49.9	42.68
N	1,464	1,116	1,314	1,038	1,374	1,050	1,374	1,050
Bust	3.52	4.23	-21.00	-21.12	-0.96	3.03	-1.24	2.63
	(2.52)	(2.81)	(14.88)	(17.81)	(7.65)	(3.90)	(7.69)	(4.09)
1st-stage F-statistic	21.33	16.37	17.74	13.82	23.15	15.84	23.15	15.84
N	732	558	657	519	687	525	687	525
# Univ.	244	186	219	173	229	175	229	175

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Standard errors are clustered at the university level. All regressions include period effects and university fixed effects. Models are estimated using 2SLS. All regressions are weighted by total graduate enrollment in the prior year unless otherwise specified.