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Crowd Out or Opt Out: The Changing Landscape of Doctorate Production in American Universities

Liang Zhang
Cornell University

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Abstract

This paper addresses two issues arising from the changing pattern of doctorate production in American universities in last forty years. First, there has been a large increase in the number of doctorates awarded to foreign students. This leads to the concern that foreign doctorates have crowded out native doctorates especially certain groups of native doctorates such as native male and minorities. Second, graduate programs are increasingly becoming "feminine," and some academic fields have already witnessed a ratcheting process toward female. This gives rise to concern about gender segregation among academic fields. Using data on the number of doctorates awarded in all academic fields from 1966 to 2002, this study examines the crowding-out effect and the tipping effect systematically. In science and engineering fields, there is no evidence of crowding-out between foreign doctorates and native doctorates. Outside of science and engineering, there is a strong negative correlation between the number of foreign doctorates and native male doctorates; however, non-science education accounts for almost all the negative association, suggesting the inappropriateness of aggregating fields in examining the crowding-out effect. Male students, especially native male students, exhibit strong "women-avoiding" behaviors in selecting academic fields of doctoral study, suggesting that native male students opt out of, instead of being crowded out of fields with a high proportion of female doctorates. As the gender composition of college graduates has started to stabilize in recent years, it is unlikely that those fields that already have a high proportion of female doctorates will be tipping toward all female.

Keywords

higher education, doctorate degrees, gender segregation

Comments

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Liang Zhang

Cornell University

Please address correspondence to Liang Zhang, 258 Ives Hall, School of Industrial and Labor Relations, Cornell University, Ithaca, NY 14853. Email: lz33@cornell.edu. I am grateful to the Andrew W. Mellon Foundation and the Atlantic Philanthropies (Inc.) USA for funding through the Cornell Higher Education Research Institute. I thank Ronald Ehrenberg, Robert Hutchens, and George Jakubson for helpful comments. All errors are my own.

Abstract: This paper addresses two issues arising from the changing pattern of doctorate production in American universities in last forty years. First, there has been a large increase in the number of doctorates awarded to foreign students. This leads to the concern that foreign doctorates have crowded out native doctorates especially certain groups of native doctorates such as native male and minorities. Second, graduate programs are increasingly becoming "feminine," and some academic fields have already witnessed a ratcheting process toward female. This gives rise to concern about gender segregation among academic fields. Using data on the number of doctorates awarded in all academic fields from 1966 to 2002, this study examines the crowding-out effect and the tipping effect systematically. In science and engineering fields, there is no evidence of crowding-out between foreign doctorates and native doctorates. Outside of science and engineering, there is a strong negative correlation between the number of foreign doctorates and native male doctorates; however, non-science education accounts for almost all the negative association, suggesting the inappropriateness of aggregating fields in examining the crowding-out effect. Male students, especially native male students, exhibit strong "women-avoiding" behaviors in selecting academic fields of doctoral study, suggesting that native male students opt out of, instead of being crowded out of fields with a high proportion of female doctorates. As the gender composition of college graduates has started to stabilize in recent years, it is unlikely that those fields that already have a high proportion of female doctorates will be tipping toward all female.

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I. Introduction

Many people believe the picture is clear. Foreign students are crowding out native students from graduate programs (especially doctoral programs) in American universities. Borjas (2004a) documented that the share of non-resident aliens enrolled in graduate programs in the United States rose from 5.5 percent in 1976 to 12.4 percent in 1999. In science and engineering (SE) fields, the increase was even more pronounced. In the 1999-2000 academic year, non-resident aliens received 38.2 percent of doctorates awarded in the physical sciences, 52.1 percent of doctorates in engineering, 26.6 percent in the life sciences, and 22.8 percent in the social sciences. Recent data show that in 2002 about 26 percent of all doctorates awarded in American universities went to temporary residents, and in SE fields more than 32 percent of doctorates were conferred on temporary residents (Hoffer et al., 2003).[1]

The increase in doctorates awarded to foreign students has raised several concerns among U.S. researchers and policy makers.[2] Doctoral education demands enormous intellectual and financial resources; thus an increase in the number of doctorates earned by foreign students limits educational opportunities for native students, unless additional financial resources can be gained by educating foreign students. This can be achieved only when the benefits (e.g., tuition revenue) outweigh the costs, a situation that is unlikely given the heavy subsidies at the doctoral level of study in both public and private institutions in the United States. For example, more than 90 percent of foreign doctorates in recent years received various forms of financial assistance from their universities during their graduate studies (Hoffer et al., 2003).

The influx of foreign doctorates has a tremendous impact on the U.S. economy. Stephan and Levin (2001) showed that individuals making exceptional contributions to science and engineering in the United States were disproportionately drawn from the foreign born. On the other hand, the influx of these highly educated workers could also have displaced natives from some professional positions and lowered wages. Borjas (2004b) found that a 10 percentage point immigration-induced increase in the supply of doctorates lowers the wage of competing doctorates by about 3 to 4 percentage points.

[1] Hoffer et al. (2003) include the social sciences in science and engineering fields. Excluding the social sciences would increase the proportion of doctorates awarded to foreign students in science and engineering fields to 38 percent (see Table 1). Also see the field classifications used in this study in Appendix Table 1. For simplicity, in this study I call temporary resident students foreign students, and I call U.S. citizens and permanent resident students native students.

[2] By the same token, throughout this paper I call foreign students who earned doctorates in the U.S. foreign doctorates, and I call U.S. citizens and permanent resident students who earned doctorates in the U.S. native doctorates.

One particular concern raised by the growing enrollment of foreign doctoral students is that they may contribute to the continued under-representation of minorities among the doctoral population in the U.S., either by directly replacing minority students in the admissions process or by discouraging minority students from pursuing doctoral studies because of the lowered salaries they induced. Although it is not clear that an increase in the number of doctorates awarded to foreign students hurts minorities more than it might hurt other native groups, that increase is usually an easy "scapegoat" for the continued under-representation of minorities in the doctoral population.[3]

The increase of foreign doctorates is but one aspect of the changing pattern of doctorate production in American universities. Another is that graduate programs are increasingly becoming "feminine"; and some academic fields have already witnessed a ratcheting process toward the female. Between 1967 and 2002, the proportion of female doctorate recipients increased from 11.6 percent to 45.4 percent for all fields in American universities. In non-SE fields, female doctorates comprise the majority of degrees conferred (see Table 1). For example, in 2002, 67 percent of doctorate recipients in psychology, 61 percent in sociology, 60 percent in foreign languages, 66 percent in education, 58 percent in communication and librarianship, 58 percent in anthropology, and 59 percent in linguistics were female.[4]

The gender shake-up among doctorate recipients has far-reaching social significance. On one hand, as women move into fields traditionally dominated by men, they elevate their positions in the labor market, thereby contributing to gender equality in general. On the other, as the proportion of women with doctorates in some fields goes up, male students may avoid these fields, anticipating that wages will go down when the fields are "too female." Bellas (1992) shows that academic salaries are lower in fields with a higher proportion of female faculty, especially when the proportion goes beyond a certain point. Furthermore, male students may find it socially stigmatizing to pursue fields of study with a preponderance of females (England et al., 2004). If this trend continues, segregation among academic fields is likely to occur, and a stable, integrated gender equilibrium will be at stake.

Somewhat surprisingly, very few studies have addressed whether more foreign doctorates have led to fewer native doctorates and why certain academic fields are becoming predominantly female.[5] Moreover, when examined at all, these two issues are often addressed separately. This study looks at these issues in a connected way by linking findings from both areas, thus enabling us to have a more complete picture of the changing pattern of doctorate production in American universities. In particular, I

[3] In fact, this claim has been partially debunked by the research community. For example, Attiyah and Attiyeh (1997) revealed that foreign students were "discriminated against" while under-represented minority students received preferential treatment in the doctoral admission process at 48 leading graduate schools.
[4] These numbers are computed directly from the 2002 *Survey of Earned Doctorates*.
[5] See Borjas (2004a) and England (2004) for two recent studies on these issues.

ask two questions: (1) Is there a crowding-out effect of foreign doctorates on native doctorates? If so, in what fields, and is there a difference by gender? (2) Do male students exhibit "women-avoiding" behaviors in pursuing doctoral studies? If so, in what fields, and is there a difference by citizenship?

The organization of this paper is as follows. In Section Two, I discuss two possible models to explain the trend of doctorate production in American universities during the last four decades or so. Several hypotheses are generated from these models. After describing data and estimation strategies in Section Three, in Section Four I estimate panel data models to examine the crowding-out effect and the "women-avoiding" behaviors. The final section concludes and provides some policy discussion.

II. Models of Doctorate Production

The *crowding-out effect* is a term used loosely by researchers to attribute the shrinkage of one group to the growth of others. For example, if foreign doctorates crowd out native doctorates, it means that a decrease in the number of native doctorates is due to an increase in the number of foreign doctorates. This crowding out may take several forms. One form is clear. In the short run, the total number of doctoral students who can be educated is relatively fixed, and one additional doctorate awarded to a foreign student may translate directly into one fewer awarded to native students. Another form is less clear, in that in the long run the number of degrees earned by both foreign students and native students could be rising, but the proportion of degrees earned by native students could be decreasing. In fact, a variety of "crowding-out" effects could be defined using different benchmarks. For example, the numbers of both foreign and native doctorates could be rising, and the proportion of native doctorates might also be rising. Still, the number of native doctorates could have increased more if the number of foreign students had not increased. In essence, all types of crowding-out effects depend on what is assumed to be neutral. To avoid ambiguity, the simplest form of crowding-out effect is used in this analysis. That is, a crowding-out effect exists if the number of doctorates awarded to native students actually falls as the number of doctorates awarded to foreign students rises.[6]

Doctorate recipients are often categorized according to demographic characteristics such as gender, race/ethnicity, and citizenship. Institutions have to make decisions regarding the number of students in each category to admit to their doctoral programs. Although preferences and missions may vary among institutions, a well-balanced and diversified cohort of graduates is generally a legitimate goal of doctorate production in American universities. Quality is probably the primary reason. Presumably, the average quality of doctorates in a particular category declines when the number of doctorates in that category increases. For example, if the distribution of talent is about the same for male and female

[6] A similar definition of crowding-out effect was used in Borjas (2004a).

students, universities may wish to produce about the same number of doctorates in these two groups, assuming their goal is to maximize the aggregated talent for a fixed number of doctorates.[7] Furthermore, diversity itself may be a reasonable goal, so universities may give preference to under-represented groups. In the recent Grutter v. Bollinger case challenging the University of Michigan's use of race as a factor in admissions policies, the Supreme Court ruled that universities can use race as a "plus factor" when looking at applications from minorities.

If diversity is a legitimate concern, then those fields with few doctorates awarded to women may have as a priority an increase in the number of female students. Similarly, those fields with few doctorates awarded by foreign students may wish to increase the number of foreign students. With regard to both gender and ethnicity, a division occurs between the SE and non-SE fields. The former includes physical sciences, life sciences, and engineering but not social sciences.[8]

Historically, the SE fields produced a small number of female doctorates while the non-SE fields usually had a small number of foreign doctorates. For example, in the later 1960s, women with doctorates made up less than 6 percent of the population in SE fields, but over 17 percent in non-SE fields. In contrast, foreign students earning doctorates made up about 15 percent of the population in SE fields in the later 1960s, but less than 6 percent in non-SE fields. Presumably, then, the SE fields had as a priority an increase in the numbers of female doctorates, while at the same time taking the native-foreign balance into consideration. In contrast, the non-SE fields probably placed a priority on attracting more foreign students, while at the same time keeping an eye on female representation. These differences lead to several hypotheses about the crowding-out effect of foreign doctorates on native doctorates.

Hypothesis 1 (H1): In SE fields, there has been little crowding-out effect of foreign students on native students because of institutions' interest in increasing native female doctorates. However, in non-SE fields, there has been a negative correlation between foreign students and native students.

Hypothesis 2 (H2): In SE fields, the crowding-out effect of foreign students on native male students should not be evident either. In non-SE fields, there is a negative correlation between foreign students and native male students.

Hypothesis 3 (H3): In both SE and non-SE fields, there is a crowding-out effect of foreign female students on native male students.

[7] A similar argument was made in Ehrenberg and Sherman (1984) in establishing a model of optimal financial aid and admissions policies for a selective university.

[8] This classification is slightly different from that used in *Survey of Earned Doctorates* where the social sciences are classified in the broad category of the SE fields. For this analysis, the social sciences are similar to the non-SE fields in term of the proportion of female and foreign doctorates.

Hypothesis 4 (H4): In both SE and non-SE fields, there is no crowding-out effect of foreign students on native minority students. (This is so because universities have as a priority an increase in the number of minority doctorates in both fields.)

In the above model, universities are decision-making entities, and an individual's decision has little impact on doctorate production. This model, however, seems incapable of explaining the ever-increasing share of female doctorates in some fields, unless universities wish to have a high proportion of female doctorates in these fields. Needless to say, institutional decisions about the representation of different categories of doctorates are influenced by other factors, such as the current pool of applicants in each category. For example, if universities wish to produce more female doctorates in SE fields, they first need enough qualified female applicants in these fields. Similarly, the relatively small number of minority college graduates makes it difficult for universities to have a large representation of minorities in the doctoral population. One factor that may contribute to the increasing share of female doctorates in some fields is male students' unwillingness to enter fields that have a high proportion of women. For example, the lower wages in those fields may discourage male students from studying in them.

Sociologists and economists have studied similar avoidance behaviors in other areas. Schelling's model of residential segregation suggested that whites' unwillingness to live in neighborhoods with a high proportion of blacks could lead neighborhoods to become all black. This "tipping effect" demonstrates the difficulty of forming racially diverse communities (Farley et al., 1993; Schelling, 1978). Similar trends were observed in other social phenomena. For example, Lieberson, Dumais, and Baumann (2000) examined the trends in unisex names, and found that as the proportion of girls with a particular unisex name increased, parents stopped giving that name to boys. Likewise, England et al. (2004) invoked the tipping model to study doctorate production in American universities. Their results suggested that the higher the proportion of females receiving degrees in a field in a given year, the smaller the number of males who enter the field 4-7 years later.

As the first researchers to examine gender segregation among doctoral fields using the tipping model, England et al. (2004) argued that men's "women-avoiding" behavior made it unlikely that academia could move toward gender equilibrium. However, their study raised several questions and suggested potential extensions that I hope to address in the current study. First, an important division among male doctorates—native versus foreign—was ignored. Native and foreign male students could have quite different patterns of "woman-avoiding" behavior. For example, because native male students have a better idea of the gender composition in a particular field in the U.S. through observing the gender of their junior professors, teaching assistants, and graduate students, it may be easier for them to exhibit "woman-avoiding" behaviors than for foreign male students to do so. On the monetary front, the relatively lower wage in fields with a high proportion of women might dampen the enthusiasm of native

male students to pursue doctorates in those fields more than it might for foreign male students, because the relatively lower wage might still be attractive to the them when compared to the wage in their home countries. In fact, aggregate level data suggest that the number of native and foreign male doctorates produced in American universities exhibited quite different trends over the past forty years or so (see Figure 1). For example, a decrease in the total number of doctorates occurred only for native males but not for foreign males. This difference is important because foreign doctorates now make up more than a quarter of the doctorate population. It seems essential, then, to separate these two groups of male doctorates if we are to understand the changing gender composition of doctorate production in American universities.

So too, there might be differences between the effect of native female students and the effect of foreign female students on the behaviors of male students. Most foreign graduate students completed their undergraduate in their home countries and thus were unable to observe the gender composition of the field they planned to study in the United States, although presumably they knew the gender composition of that field in their own countries. If that is the case, foreign male students might be sensitive to foreign female students, while native male students might be sensitive to females in both groups.

Finally, there are important differences among fields of study. In SE fields, the number of doctorates awarded to females is about half that awarded to males, while in non-SE fields, female doctorates outnumber male doctorates, and in some fields female doctorates have reached a substantial majority of all doctorates. Thus it is reasonable to expect that the "tipping effect" is more pronounced in non-SE fields than in SE fields. Practically speaking, even if a negative correlation is observed between the proportion of women receiving doctoral degrees in a given year and the number of men receiving doctorates several years later in SE fields, these fields are not tipping toward the female; instead, they are moving toward gender equilibrium.

Hypothesis 5 (H5): There is no tipping effect toward the female in SE fields. And male students may exhibit "women-avoiding" behavior in non-SE fields.

Hypothesis 6 (H6): Native male students are sensitive to the share of both native female and foreign female students, while foreign male students are sensitive only to the share of foreign female students.

III. Data and Methods

This analysis uses data drawn from the *Survey of Earned Doctorates* (SED), which provides a population census of all doctorate recipients from American universities each year. The National Science Foundation makes the data publicly available through the Webcaspar. I extract data on the number of doctorates in all fields of study from 1966 to 2002, a span of 37 years. The Webcaspar classifies

doctorates into 49 fields. (See Appendix Table 1 for a complete list of these fields.) For each field, the SED reports the number of doctorates by gender, citizenship, and race/ethnicity.[9] I treat U.S. citizens and permanent residents as one category termed native doctorates, and temporary residents as another category termed foreign doctorates. I then create a panel of 49 fields for 37 years, with field-year as the unit of analysis. After aggregating small categories appropriately, I obtain the number of doctorates in various groups, such as total female, total male, native male, and minority doctorates. Further, I calculate the share of a particular subcategory within a larger category, such as the share of female doctorates, the share of native female doctorates, and the share of foreign female doctorates.

The National Center for Education Statistics has data on the number of baccalaureate recipients from American universities each year. The Webcaspar also reports these numbers in same fields as in the SED. I use the number of college graduates to control for the year-to-year fluctuation in the number of doctorates due to the change in the flow of college graduates. Finally, the decision of foreign students to pursue doctoral degrees might be influenced by the prospect of remaining in U.S. after graduation. Since 1967 the National Research Council has published series of annual reports based on the SED, which asks doctorate recipients their post-graduation plans. Among those who have definite commitments after graduation, the proportion of foreign doctorates who will remain in U.S. is reported. Although this information is available only since 1988 in the published annual report, these data are probably sufficient because the tipping effect is most likely to happen in later years when the proportion of female doctorates has reached a certain level. (See Appendix Table 2 for the proportion of foreign doctorates remaining in the U.S. after graduation in different fields.)

To test the crowding-out effect of one group on another, the number of doctorates in the two groups in the same year is used. Take the crowding-out effect of foreign doctorates on native doctorates as an example. Let N_{it} denote the number of doctorates earned by native students in field *i* at time *t*, and let F_{it} denote the corresponding number of doctorates earned by foreign students. The following model is then estimated:

[9] In all three dimensions, there is an unknown category. For example, the SED reports doctorate recipients in three gender categories: female, male, and unknown. Similarly for citizenship, the SED reports U.S. citizen, permanent resident, temporary resident, and unknown. In calculating the aggregated number of certain categories, I retain all the possible categories while ignoring the unknown categories. For example, the total number of female doctorates may include those with unknown citizenship, and the total number of native doctorates may include those with unknown gender. Hence, the total number of native doctorates may not equal the sum of native male doctorates and native female doctorates, although the difference is small. The unknown category also creates some difficulties in calculating the share of a subcategory within a larger category. For example, because the total number of doctorates is slightly greater than the sum of male and female doctorates, the proportion of female doctorates is most likely under-estimated if we simply divide the number of female doctorates by the total number of doctorates. As a result, I calculate the proportion of female doctorates as the ratio between the number of female doctorates and the sum of male and female doctorates. This general rule is applied throughout this study if not specified otherwise.

$$N_{it} = \beta F_{it} + \alpha_i + \eta_t + \mu_{it} \quad (1)$$

where α_i is a vector of fixed effects for fields, and η_t is a vector of fixed effects for year. The field fixed effects control for any time-invariant field-specific factors that may influence the number of native doctorates. For example, some fields traditionally produced more native doctorates than others. The year fixed effects control for any time-specific factors such as immigration policies. For example, stringent visa policies may deny admitted applicants from entering the U.S., leaving more spaces for native students. The same model can be estimated for different dependent and independent variables to test whether a crowding-out effect exists between two groups of doctorate recipients.[10] Because the field classification is somewhat arbitrary and there are substantial variations in the size of fields, it is necessary to weigh the analysis by the total number of doctorates in each field.

In estimating the tipping effect, i.e., the impact of the proportion of female doctorates on the number of male doctorates, it is important to "match up" the share variables with the correct doctoral cohort. The rationale is that male students form their idea of the gender composition of a field from observing the gender of their junior professors, teaching assistants, and graduate students. These observations will likely affect their decision to pursue doctoral study.

The length of one doctoral cohort would probably be a good choice of the length of lags. The SED measures time to degree in two ways: (1) the total time elapsed from the completion of baccalaureate to the completion of doctorate, (2) the total time spent in graduate school to complete the doctoral degree. Typically, the former is about 2 to 3 years longer than the latter. Both measures of time to degree vary over time and by fields of study. The length of lags for the proportion of female doctorates is determined by the median time to degree when enrolled in graduate school, because that is the actual time of doctoral study. Hoffer et al. (2003) calculated that the median duration of graduate study has increased over the years, from 6.2 years in 1977 to about 7.5 years recently. Graduate school time to degree is shortest in the physical sciences (6.8 years) and engineering (6.7 years) and longest in the humanities (9.0 years), as reported for the 2002 cohort of doctorate recipients. To account for the fact that male students observe the gender composition of several doctoral cohorts (such as junior professors and graduate teaching assistants) and also to avoid large year-to-year fluctuations in small fields, I average the proportion of females in a field 5-8 years before the year when the cohort in question receives doctorates. Hoffer et al. (2003) also calculated that the median time to degree since completion of the baccalaureate has increased from 8.9 years in 1977 to 10.6 years in 1997. As a result, the number of students earning baccalaureate degrees in a particular field 9 years earlier is used to control for the available "pipeline" of

[10] This approach, however, raises several statistical problems including endogeneity of independent variables and causality between dependent and independent variables. In the next chapter, I employ a more structural model to address these issues.

students with an undergraduate major in the field. The last variable to be matched up is the proportion of foreign doctorates remaining in the U.S. after graduation. Because on average foreign students spend about half a year less in graduate school than native students, this variable is lagged for 6 years

IV. Results

The crowding-out effect

Table 2 presents the baseline specification of the crowding-out effect. The upper panel estimates the crowding-out effect of foreign doctorates on native doctorates, and the lower panel estimates the effect of foreign male and foreign female doctorates separately. Because the crowding-out effect could be quite different in different types of fields, the same model is estimated for SE fields (column 1), non-SE fields (column 2), non-SE fields except for non-science education (column 3), and non-science education (column 4). Non-science education deserves special attention because the number of doctorates awarded in this field account for one-sixth of doctorates in all fields and about one-third of doctorates in non-SE fields. Because of its magnitude compared with other non-SE fields, it is possible that the regression results for non-SE fields are driven mainly by non-science education. Consequently, a separate set of regressions is estimated for non-SE fields without non-science education. All models (except column 4) include institution and year dummies.

The first column of the upper panel indicates that an additional foreign doctorate recipient, at the margin, is associated with about one (1.03) additional native doctorate recipient. Obviously, there is no crowding out of foreign doctorates on native doctorates in SE fields. Estimating the effect of foreign male and foreign female doctorates separately gives the same result. The first column of the lower panel suggests that an additional foreign male doctorate is associated with 0.65 additional native doctorates. The estimated effect of foreign female doctorates is much larger at 1.54. However, these estimated effects (here and elsewhere in this chapter) should be viewed in light of the magnitude of the change of the variable. For example, during the period from 1966 to 2002, the number of foreign female doctorates in all fields increased from 166 to 2965, representing an increase of 2799, while the increase in the number of foreign male doctorates was 4994 (from 1742 to 6736). Thus the total change in the number of native doctorates associated with the increase of foreign male and foreign female doctorates is about the same during the period.

While the crowding-out effect of foreign doctorates on native doctorates seems non-existent in SE fields, the picture is quite different in non-SE fields. The second column in Table 2 reports the same specification in non-SE fields. In the aggregate, an additional foreign doctorate recipient, at the margin, is associated with about 1.17 fewer native doctorate recipients. Estimating the effect of foreign male and foreign female doctorates separately indicates that they might have quite a different impact on the

production of native doctorates. For example, an additional foreign male doctorate recipient is associated with about 1.11 more native doctorate recipients, while an additional foreign female doctorate is associated with 4.78 fewer native doctorates. These results suggest that, taken as a group, foreign doctorates might actually have crowded out native doctorates in non-SE fields.

Estimating the model separately for non-science education and other non-SE fields shows that the field of non-science education drives much of the negative correlation between the number of native and foreign doctorates. For example, in the field of non-science education, the estimated coefficient of foreign doctorates is –3.9 and that of foreign female doctorates is –5.5 (column 4). Consequently, leaving out non-science education greatly reduces the magnitude of the negative association between the number of native and foreign doctorates in non-SE fields. For example, in non-SE fields without non-science education, the estimated coefficient of foreign doctorates is much smaller in magnitude (-0.24) and not significant.

The aggregate results in Table 2, however, may disguise a great deal of dispersion within the native population. Indeed, much concern focuses on certain categories of the native population, such as male (especially white male) and minority groups. Because in both SE and non-SE fields the number of native female doctorates has increased over the years, excluding female doctorates from the native population would significantly decrease the estimated coefficient of foreign doctorates on native doctorates. Table 3 presents the crowding-out effect of foreign doctorates on native male doctorates. In SE fields, an additional foreign doctorate recipient, at the margin, is associated with about 0.1 additional native male doctorate recipients (column 1). And in non-SE fields, an additional foreign doctorate is associated with almost 2 fewer native male doctorates (column 2).

One particular field—non-science education—is the main driver of this large negative correlation between foreign and native doctorates in non-SE fields. In the field of non-science education, each additional foreign doctorate is associated with 9 fewer native male doctorates (column 4). This seemingly large "crowding-out" effect certainly needs further explanation and interpretation. The number of doctorates awarded in non-science education makes up about one-third of the total doctorates in non-SE fields. Since the early 1970s, the number of female doctorates (both foreign and native) has increased while the number of native male doctorates has decreased. Despite its 10-fold increase in number (from 26 in 1966 to 273 in 2002), foreign female doctorates still represent a very small proportion (less than 5 percent) of the total number of doctorates awarded in non-science education in recent years (see Appendix Table 3). Incidentally, the number of native male doctorates in this field decreased from over 4,000 in early 1970s to about 1,700 in recent years. As a result, a large negative correlation between foreign doctorates and native doctorates is observed. Not surprisingly, excluding non-science education from non-SE fields greatly reduces the negative association between foreign doctorates and native male

doctorates. In non-SE fields without non-science education, each additional foreign doctorate is associated with 0.47 fewer native male doctorates.

The upper panel of Table 3 ignores two factors. First, there could be a crowding-out effect between native male and native female groups. Historically, native females were under-represented in most fields of doctoral study; hence institutions might have preferred to produce more native female doctorates, thereby perhaps causing a crowding-out of native male doctorates. Consequently, in the lower panel of Table 3, I estimate the number of native males as a function of the number of doctorates in the other three categories. In both SE and non-SE fields, the number of foreign male doctorates has positive association with the number of native male doctorates, although the association is not significant in non-SE fields when non-science education is excluded. The number of foreign female doctorates, however, has a negative association with the number of native male doctorates in both SE and non-SE fields, and in non-SE fields it is largely driven by the field of non-science education. The number of native female doctorates has opposite associations with the number of native male doctorates in SE and non-SE fields. In SE fields, each additional native female doctorate is associated with 0.48 additional native male doctorates, while in non-SE fields, this figure is – 0.48.

These results are consistent with the model describing institutions' goal of a well-balanced diversity among different categories in doctorate production. In particular, the different effect of foreign male and foreign female doctorates on native male doctorates suggests that institutional decisions are multi-dimensional; focusing on one dimension may mask much of the dynamics. For example, consider the association between foreign male and native male doctorates: the foreign-native balance alone may lead to a negative association between these two categories; however, both of them belong to the male group, suggesting a possible positive association between the two. In contrast, both native-foreign and male-female balances suggest a negative association between the number of foreign female and native male doctorates.

Concerns about the crowding-out effect are often targeted to specific native groups, such as white males and minorities. Because white male doctorates make up the majority of the native male population, the estimation of the crowding-out effect on white males is similar to that on all native males (see Table 4 for detailed results). One particular concern about the growing number of foreign doctorates is that they might cause the continued under-representation of minorities among the doctoral population. To test whether foreign students replace minority students in doctorate production, I examine the association between the numbers of foreign and minority doctorates in Table 5. In the aggregate, there is a positive association between the number of foreign doctorates and the number of minority doctorates in both fields. In SE fields, each additional foreign doctorate is associated with 0.22 additional minority doctorates, and in non-SE fields this figure is 1.57 (this number is driven mainly by non-science

education). Estimating the effect of foreign male and foreign female doctorates separately indicates that the number of foreign female doctorates has a negative although very small association with the number of minority doctorates in SE fields, suggesting a gender preference in these fields.

One important variable omitted from the regressions is the number of minority baccalaureate recipients in each field over time, because the number of college graduates broken down by race/ethnicity is reported quite differently from the way the number of doctorates is reported. One difference is field classification. For example, the Webcaspar reports the number of minority college graduates in only one general engineering field instead of the eight different engineering fields in which the number of doctorates is reported. I aggregate the number of doctorates in all engineering fields into one field, making it conform to the way the number of college graduates is reported. After appropriate aggregations, the number of fields is reduced to 23. Another difference is that the number of college graduates broken down by race/ethnicity is available for only a limited number of years.[11] As a result, the final sample with the number of minority college graduates included in the model consists of 23 fields for an 11-year period. Results from regressions with the number of minority college graduates included are quite similar to the results in Table 5, except that the negative association between the number of minority doctorates and the number of foreign female doctorates disappears. In both SE and non-SE fields, there is a positive association between the number of foreign doctorates and the number of minority doctorates. When the effect of foreign male and foreign female doctorates is estimated separately, both have a positive association with the number of minority doctorates in both types of fields.

Several extensions of the above model are considered. First, it is possible that the year-to-year fluctuation in doctorate production might disguise the crowding-out effect of foreign doctorates on native doctorates. A small crowding-out effect each year could accumulate into a large effect over time. To check the robustness of the above analysis, the model is re-estimated using the moving averages of the number of doctorates awarded in each field over a certain number of years. The results turn out to be quite similar. For example, Appendix Table 4 presents the estimates of the crowding-out effects of foreign doctorates on different groups of native doctorates based on four-year moving averages, and these estimates are similar to those based on yearly numbers. Different lengths of moving averages are also tested, and the results are quite consistent.

Second, in all models estimated in this analysis, year dummies are included to account for time-specific factors that affect doctorate production. However, it is possible that these time-specific effects contain some crowding-out effects. To check for this possibility, year dummies are dropped from equation (1), and the model is re-estimated for different groups of native doctorates. Results in Appendix

[11] The number of college graduates broken down by race/ethnicity is available in 1977, 1979, 1983, 1985, 1987, and all years after 1989.

Table 5 suggest that excluding time-specific effects does not change the results much, although most estimates decrease slightly. For example, Table 2 estimates that with year dummies included in the model, each additional foreign doctorate in the SE fields is associated with about one (1.03) additional native doctorate. When year dummies are not in the model, each additional foreign doctorate in the SE fields is associated with about 0.80 additional native doctorates.

The final extension of the model excludes observations from recent years. Because the number of doctorates in some categories (such as native male and foreign male categories) has stabilized since the early 1990s, it is probable that the crowding out occurred before then. Thus the model is estimated using observations before 1990, and the results are reported in Appendix Table 6. In SE fields, it seems that foreign doctorates crowded out both native males and white native male doctorates with coefficients of – 0.54 and – 0.50; however, when the number of native female doctorates is included in the model, these negative coefficients reduce to – 0.02 and – 0.05 respectively (not reported in the table) and both are insignificant. In non-SE fields without non-science education, there is no evidence of a crowding-out effect either.

The tipping effect

In estimating the crowding-out effect of foreign doctorates on native doctorates and examining differences by gender, I assumed that universities are decision-making entities. This model, however, seems incapable of explaining the significant differences in gender composition between SE and non-SE fields and especially the increasing proportion of female doctorates in certain non-SE fields. It is not reasonable from the universities' perspective not to achieve gender balance in fields such as education, English, and psychology. Then other forces, such as "women-avoiding" behaviors, must be at work, making it difficult for universities to keep a gender balance in those fields. This section presents the estimation of the tipping effect toward women for different groups of doctorates.

Table 6 presents the baseline specification of the tipping effect. Because the tipping effect could be quite different in different types of fields, the same model is estimated for all fields (column 1), SE fields (column 2), non-SE fields (column 3), and non-SE fields excluding non-science education (column 4). All models include institution and year dummies. Because the main independent variable is the proportion of female doctorates, it is helpful to know the magnitude of one unit (one percentage point) of change. The average field size is about 700 for all fields with at least one doctorate recipient in a particular year; however, this average does not reflect the actual average size experienced by individual students, because students are more likely to be in large fields than in small ones. As a result, the field-size weighted field size seems appropriate for interpreting the estimated coefficients of regressions that

are also weighted by field size. The weighted field size is approximately 2500, so one percentage point stands for roughly 25 individuals.

Do men avoid fields when those fields get "too female"? The first column of the upper panel of Table 6 suggests a negative effect of a field's proportion of female doctorates on the number of male doctorates in that field 5 to 8 years later. On average, a one percentage point increase in the proportion of female doctorates (i.e., an increase of about 25 female doctorates) in a field leads to 17.76 fewer male doctorates awarded in that field 5 to 8 years later. Pooling all fields together disguises a great deal of difference between SE and non-SE fields, especially when the proportion of female doctorates in these two fields generally falls into two different ranges. As expected, in SE fields, an increase in the proportion of female doctorates does not appear to deter men's entry into these fields. In contrast, the third column shows a large and significant negative effect of a field's proportion of female doctorates on the number of male doctorates awarded in that field 5 to 8 years later. Excluding the field of non-science education does not seem to change the result much. During the period the model estimated (1988-2002), the proportion of female doctorates in both SE and non-SE fields has increased about 10 percentage points (see Table 1). Thus the difference in the estimated effect does not reflect a difference in the variation of the independent variable; instead, it may suggest some real differences in men's behavior in these two broad fields.

Meanwhile, if a higher proportion of female doctorates in a field lowers the salary in that field, women may also exhibit "women-avoiding" behavior. Indeed, similar results are shown in the lower panel of Table 6 that estimates the number of female doctorates in a field as a function of the proportion of female doctorates in that field 5 to 8 years earlier. That is, an increase in the proportion of female doctorates in SE fields does not appear to deter women's entry into those fields, while an increase in non-SE fields does appear to lead to avoidance. Excluding the field of non-science education yields similar results.

If both male and female doctorates exhibit "women-avoiding" behaviors, then how does one explain the growing proportion of female doctorates in most of the non-SE fields? One possibility is that male and female doctorates might have different thresholds for engendering the avoidance response. For example, the proportion of female doctorates in a field that induces avoidance behavior in male students could be smaller than the proportion that causes female students to shy away. Nonlinear functional forms seem appropriate for estimating the threshold of female doctorates that brings on the tipping effect. When the quadratic terms of the proportion of female doctorates are added to the base model, a concave functional form (with a positive linear term and a negative quadratic term) is revealed; however, the reflection points of the male and female equations are both around 50% (50.4% for the male equation and 52.6% for the female equation). That is, both men and women start to avoid fields when female doctorates constitute the majority.

Another possible explanation for the increasing share of female doctorates in non-SE fields could be the growing number of women earning baccalaureates in non-SE fields coupled with an increasing propensity of these women to pursue doctoral degrees in these fields. For example, in non-SE fields, the share of female college graduates was slightly less than 50% in the late 1960s and early 1970s. In recent years, the share of female college graduates has increased to more than 58%.[12] In some fields, such as non-science education, females account for about three-quarters of the college graduates. Consequently, the growing proportion of female college graduates in non-SE fields could lead to a high proportion of female doctorates. However, female students' "women-avoiding" behavior may keep these fields from tipping toward all female. Indeed, when the number of college graduates is dropped from the female equation, the negative effect of the proportion of female doctorates on the number of female doctorates 5 to 8 years later is eliminated. In contrast, when the number of college graduates is dropped from the male equation, the tipping effect is reduced to half in magnitude but is still marginally significant at the 0.1 level. These results suggest that although both male and female students exhibit "women avoiding" behaviors in pursuing doctoral studies, the faster growth in numbers of female college graduates in non-SE fields drives up the proportion of female doctorates in these fields.

Finally, because knowledge about gender composition could be very different for native and foreign students, it is probable that the growing share of native female and foreign female doctorates might generate different avoidance responses for native male and foreign male students. To test this hypothesis, I estimate the model for each category of doctorates. The upper panel of Table 7 shows that in the aggregate native male doctorates avoid fields with a high proportion of both native female and foreign female doctorates. In SE fields, a higher proportion of native female doctorates, but not foreign female doctorates, engenders an avoidance response from native male doctorates, while in non-SE fields both female groups engender an avoidance response. In contrast, the growing share of foreign male doctorates does not seem to deter native males' entry into doctoral studies.

The lower panel of Table 7 estimates the number of native female doctorates in a particular field and year as a function of the proportion of native female, foreign female, and foreign male doctorates 5 to 8 years earlier in that field. Results indicate that native female doctorates avoid non-SE fields what have a higher proportion of all three categories. Excluding non-science education does not seem to eliminate the negative effect. It appears that native female doctorates are sensitive not only to gender composition but also to citizenship composition in their fields of study.

[12] Data source: National Center for Education Statistics. The numbers of college graduates in non-SE fields was around 200,000 for both males and females in the late 1960s and early 1970s, and in recent years the numbers rose to 360,000 and 530,000 respectively. These non-SE fields include the social sciences.

Because foreign students have less opportunity to observe gender composition in American universities and/or because foreign students are less sensitive to gender composition, their response could be weaker than that of native students. Results in Table 8 confirm this hypothesis. Both foreign male and foreign female groups are sensitive only to the proportion of foreign female doctorates in non-SE fields.

V. Discussion and Conclusion

Do foreign doctorates crowd out native doctorates? It is unlikely. In SE fields, there is no evidence of a negative association between the number of foreign doctorates and the number of native ones. In fact, each additional foreign doctorate recipient, on average, is associated with about one more native doctorate. Admittedly, much of the growth in the native population has been fueled by females. However, even after excluding female doctorates from the native population, no evidence of a negative association between the number of foreign doctorates and the number of native male doctorates is observed. Although results show that there might be some crowding out between foreign female and native male groups, possibly due to a consideration for gender balance in SE fields, that negative association is effectively eliminated and reversed by the positive association between foreign male and native male groups. Moreover, there is no evidence of foreign doctorates crowding out specific groups of the native population, such as white males and minorities, who are often regarded as primary victims of the growing number of foreign doctorates.

In non-SE fields, the picture is different, however. In the aggregate, an additional foreign doctorate recipient, at the margin, is associated with about 1.17 fewer native doctorate recipients. This negative association is largely driven by the negative association between foreign female doctorates and native doctorates. However, one particular field—non-science education—is solely responsible for these negative correlations. Over the years, in the field of non-science education, the number of native male doctorates has dropped sharply, and the number of doctorates in other categories (native female, foreign male, and foreign female) has risen modestly. As a result, a large negative correlation between foreign doctorates and native doctorates is observed.

Unfortunately, when all fields are aggregated and the huge negative association between foreign doctorates and native doctorates in the field of non-science education is cushioned by other fields, it is tempting to interpret the mitigated negative association as a crowding-out effect. Nonetheless, this analysis shows no evidence of a crowding-out effect on native doctorates as a whole in non-SE fields after excluding non-science education. Although there is some evidence of a small negative association between foreign doctorates and native male doctorates in non-SE fields even after excluding non-science education, the effect is rather small considering the relatively small increase in the number of foreign doctorates in these fields. The real tension is between native female and native male groups.

Is there any tipping toward all female in some fields? Again, it seems unlikely. In most SE fields, the proportion of female doctorates is relatively low; specifically, it has not reached the 50% tipping point that engenders the "women-avoiding" behaviors apparent in non-SE fields. As a result, the tipping effect is not observed in SE fields for either male or female groups. In non-SE fields, both male and female groups exhibit "women-avoiding" behaviors. In particular, when the proportion of female doctorates reaches 50% in a given field, both men and women avoid it. Because of these two countervailing forces, the feminization of some non-SE fields has largely been driven by the growing number of female college graduates in these fields. In recent years, especially since the early 1990s, however, the share of female college graduates in "feminine fields" has started to stabilize.[13] When these cohorts earn doctoral degrees, it is unlikely that these fields will be tipping toward all female. Further research should probably focus on the determinants of undergraduate major choice decisions because in the final analysis it is the "pipeline" of students that matters.

The "women-avoiding" behavior of male students, especially native male students, is very suggestive for the interpretation of the large negative association between native male doctorates and foreign female doctorates in the field of non-science education. If native males indeed have avoided "feminine" fields, then it is difficult to make the case that it is foreign female students who have crowded out native males. The "women-avoiding" behavior suggests that native male students have opted out instead of having been crowded out of fields with a high proportion of female doctorates.

One finding that has important policy implications is the impact of the proportion of foreign doctorates staying in the U.S. after graduation on the number of native doctorates. Results suggest that in SE fields, the higher proportion of foreign doctorates remaining in the U.S. after graduation does not seem to negatively affect the number of native students pursuing doctoral studies in those fields, probably because most of the foreign doctorates continue to conduct their research as post-doctorates and do not compete in the same labor market with native doctorates. In contrast, because post-doctoral work is less common in non-SE fields, foreign doctorates' staying in the U.S. after graduation does seem to affect native students' decisions to pursue doctoral studies, although the effect is small and not significant in most cases.

The prospect of remaining in the U.S. after graduation clearly affects the number of foreign student pursing doctoral degrees in American universities. The effect is largest in SE fields where the majority of foreign doctorates continue to work as post-doctorates with relatively low wages. Although

[13] Data source: National Center for Education Statistics. The share of female college graduates in non-SE fields overall has increased slowly during the 1990s. And in fields with a high proportion of female college graduates, their share has started to stabilize. In fact, in fields such as education and sociology, there has been a slight decrease in the share of female college graduates in recent years.

there is some evidence that an increasing supply of foreign doctorates lowers the wages of competing workers, it is the foreign doctorates themselves who bear the brunt of the wage reduction (Borjas, 2004b).

If the United States wants to attract more foreign talent, immigration policies should encourage foreign doctorates to stay in the U.S. after completing their doctoral studies. Recent stringent visa and immigration policies have significantly reduced applications from foreign students. A recent survey by the Council of Graduate Schools indicated that more than 90 percent of U.S. institutions saw a drop in foreign applications for Fall 2004. The drop in applications crossed all fields of study, with an 80 percent plunge in engineering and a 65 percent decrease in the physical sciences. Even worse, there was a significant drop in foreign applications to take the GRE. For example, applications from China and India were reduced by 50 and 37 percent respectively. If this trend continues, the number of foreign doctorates is bound to decrease in the years ahead. While this reduction will presumably have certain benefits for American students in the short run, such as more educational resources and probably higher wages, it will inevitably harm this nation's leadership in science in the long run.

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Figure 1

Number of Doctorates Granted in the U.S., 1966-2002

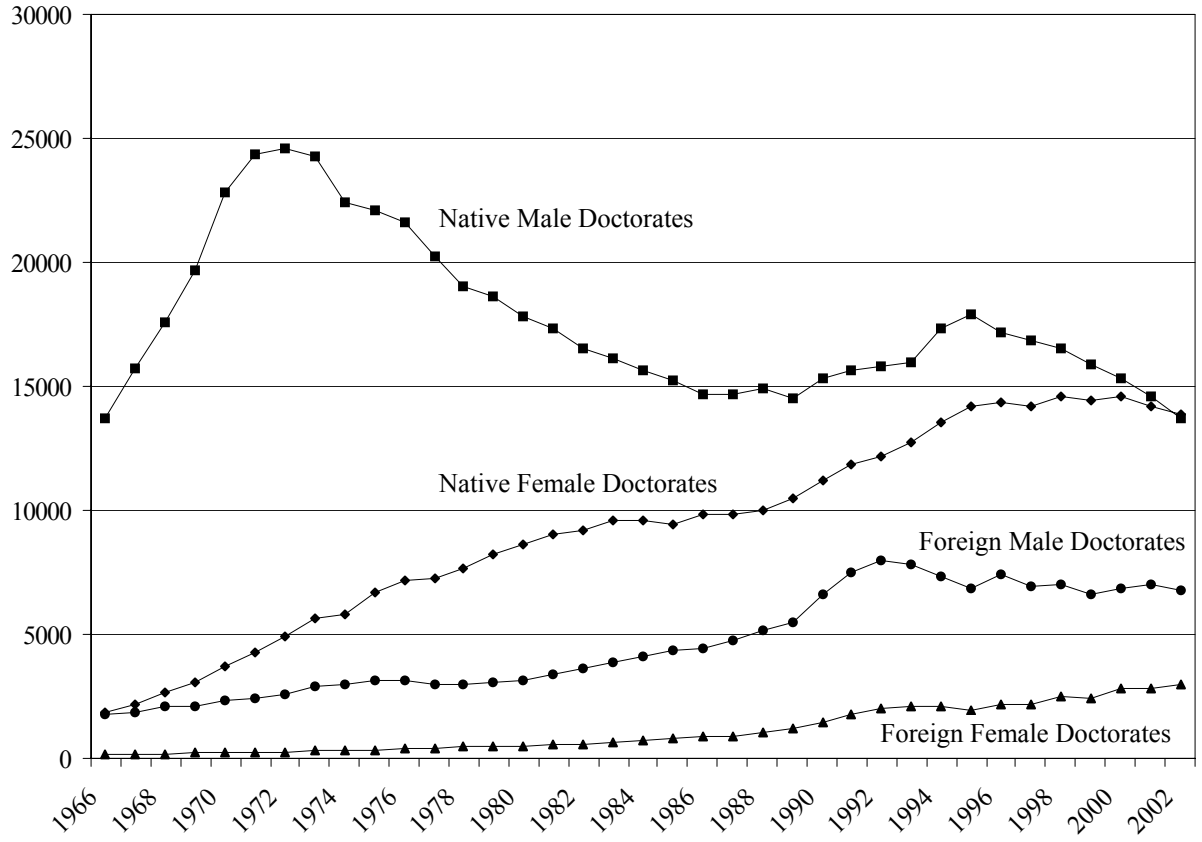

Table 1: Proportion of Female and Foreign Doctorates, by Fields

	Proportion of Female Doctorates			Proportion of Foreign Doctorates		
Year	All Fields	Sciences	Non-Sciences	All Fields	Sciences	Non-Sciences
1966	11.62	5.89	17.40	10.89	15.47	6.29
1967	11.97	6.31	17.49	10.26	14.42	6.17
1968	12.78	6.73	18.57	10.06	13.87	6.41
1969	13.16	6.90	18.97	9.29	12.99	5.83
1970	13.46	6.92	19.09	8.85	12.26	5.89
1971	14.42	7.81	19.83	8.58	11.83	5.91
1972	16.00	8.30	21.64	8.74	12.50	5.97
1973	18.03	9.84	23.60	9.58	14.10	6.48
1974	19.53	10.21	25.49	10.64	17.10	6.51
1975	21.85	11.37	28.44	10.93	17.60	6.74
1976	23.32	12.15	29.90	10.92	17.86	6.85
1977	24.78	12.93	31.79	11.14	17.91	7.12
1978	26.95	14.32	34.45	11.38	18.01	7.43
1979	28.61	15.33	36.73	11.81	18.09	7.93
1980	30.33	16.77	38.76	12.08	18.93	7.79
1981	31.55	17.50	40.42	13.01	20.07	8.52
1982	32.44	18.58	41.72	14.07	21.14	9.30
1983	33.67	19.40	43.30	14.91	23.03	9.39
1984	34.14	19.84	44.23	16.05	24.02	10.37
1985	34.33	20.71	44.43	17.47	26.25	10.89
1986	35.44	21.31	46.16	17.71	26.71	10.85
1987	35.32	21.44	46.38	18.60	28.07	10.98
1988	35.28	21.96	46.75	19.92	29.16	11.86
1989	36.45	23.51	47.98	20.99	30.46	12.45
1990	36.34	22.88	48.62	23.32	34.30	13.32
1991	36.96	23.50	49.71	25.34	36.73	14.49
1992	37.12	24.13	49.42	26.23	38.22	14.87
1993	37.99	25.29	50.14	25.70	37.36	14.57
1994	38.56	25.82	50.93	23.33	32.60	14.29
1995	39.32	26.67	51.60	21.56	29.86	13.49
1996	39.96	27.14	52.59	23.37	33.38	13.46
1997	40.53	28.18	52.54	22.82	33.06	12.67
1998	41.85	29.52	53.86	23.36	34.03	12.87
1999	42.54	29.76	54.21	23.02	33.83	13.10
2000	43.82	31.67	54.96	24.39	35.56	14.19
2001	43.97	32.07	55.00	25.40	37.30	14.26
2002	45.36	33.48	56.15	26.03	37.88	15.02

Table 2: Estimates of Crowding-out Effects on Native Doctorates

	(1)	(2)	(3)	(4)
Total Foreign Doctorates	1.0326	-1.1727	-0.2355	-3.9007
	(30.08)	(-4.48)	(-1.54)	(-2.85)
Total College Graduates at t-9	0.0083	0.0082	0.0020	0.0098
	(8.08)	(17.46)	(6.86)	(4.04)
# obs.	588	703	675	28
R-Squared	0.9926	0.9916	0.9882	0.4563
Foreign Male Doctorates	0.6523	1.1098	-1.0841	0.0114
	(6.76)	(3.63)	(-4.88)	(0.00)
Foreign Female Doctorates	1.5362	-4.7840	1.7809	-5.5290
	(12.42)	(-12.36)	(4.29)	(-3.59)
Total College Graduates at t-9	0.0084	0.0034	0.0025	0.0018
	(8.32)	(5.71)	(8.40)	(0.39)
# obs.	588	703	675	28
R-Squared	0.9929	0.9931	0.9887	0.5313

(1) Science and engineering fields
(2) Non-science and engineering fields
(3) Non-science and engineering fields excluding non-science education
(4) Non-science education

Table 3: Estimates of Crowding-out Effects on Native Male Doctorates

	(1)	(2)	(3)	(4)
Total Foreign Doctorates	0.0961	-1.978	-0.4698	-9.028
	(3.41)	(-5.63)	(-2.93)	(-4.93)
Male College Graduates at t-9	0.0094	0.0336	0.0066	0.0648
	(7.62)	(15.07)	(7.80)	(5.05)
# obs.	588	703	675	28
R-Squared	0.9879	0.9279	0.9363	0.6336
Native Female Doctorates	0.4756	-0.6066	-0.4780	-1.433
	(8.34)	(-11.81)	(-20.25)	(-3.24)
Foreign Male Doctorates	0.9160	1.9131	0.2265	2.7433
	(13.43)	(7.53)	(1.24)	(1.02)
Foreign Female Doctorates	-2.210	-7.4190	-1.5643	-3.2230
	(-12.06)	(-15.81)	(-4.40)	(-0.93)
Male College Graduates at t-9	0.0016	0.0049	0.0045	-0.0120
	(1.34)	(2.93)	(6.66)	(-0.56)
# obs.	588	703	675	28
R-Squared	0.9911	0.972	0.968	0.833

Table 4: Estimates of Crowding-out Effects on White Male Doctorates

	(1)	(2)	(3)	(4)
Total Foreign Doctorates	-0.1839	-1.6629	-0.5064	-7.7164
	(-7.99)	(-5.43)	(-3.31)	(-4.83)
Male College Graduates at t-9	0.0106	0.0292	0.0058	0.0581
	(10.57)	(15.02)	(7.19)	(5.19)
# obs.	588	703	675	28
R-Squared	0.9889	0.9235	0.9288	0.6359
Native Female Doctorates	0.0437	-0.5487	-0.4692	-1.2437
	(0.93)	(-12.73)	(-21.31)	(-3.52)
Foreign Male Doctorates	0.5168	1.7955	0.1354	3.3745
	(9.23)	(8.42)	(0.79)	(1.57)
Foreign Female Doctorates	-1.2889	-6.4372	-1.4862	-3.0665
	(-8.57)	(-16.34)	(-4.47)	(-1.11)
Total College Graduates at t-9	0.0061	0.0037	0.0038	-0.0156
	(6.16)	(2.62)	(6.07)	(-0.94)
# obs.	588	703	675	28
R-Squared	0.9917	0.9725	0.9658	0.8605

Table 5: Estimated of Crowding-out Effects on Native Minority Doctorates

	(1)	(2)	(3)	(4)
Total Foreign Doctorates	0.2205	1.5747	-0.025	2.2842
	(37.71)	(24.40)	(-0.61)	(10.25)
# obs.	814	999	962	37
R-Squared	0.9014	0.8747	0.7477	0.7501
Foreign Female Doctorates	-0.028	0.6654	-0.563	1.6429
	(-2.71)	(9.49)	(-12.14)	(4.55)
Foreign Male Doctorates	0.5352	3.4569	2.0336	2.8873
	(42.77)	(32.25)	(16.69)	(8.34)
# obs.	814	999	962	37
R-Squared	0.949	0.9128	0.812	0.7809

Table 6: Estimates of Tipping Effects (t statistics included)

	(1)	(2)	(3)	(4)
Dependent: Male Doctorates				
Prop. Female Doctorates	-17.7612 (-8.68)	-1.1746 (-0.17)	-10.5710 (-4.73)	-7.2261 (-6.39)
Male College Graduates at t-9	0.0276 (9.32)	0.0195 (3.97)	0.0491 (13.97)	0.0249 (13.65)
Prop. Foreign Staying in the U.S.	1.6433 (1.51)	5.0420 (3.67)	-2.1719 (-1.49)	1.8152 (2.17)
# obs.	425	189	236	227
R-Squared	0.9912	0.9963	0.9895	0.9800
Dependent: Female Doctorates				
Prop. Female Doctorates	-16.8907 -(7.30)	-1.0663 -(0.17)	-12.9780 -(3.86)	-9.3062 -(4.89)
Female College Graduates at t-9	0.0102 (7.16)	0.0284 (6.62)	0.0263 (13.59)	0.0138 (7.71)
Prop. Foreign Staying in the U.S.	2.8234 (2.25)	6.7160 (5.48)	-6.7810 -(3.07)	-0.3957 -(0.27)
# obs.	425	189	236	227
R-Squared	0.9951	0.9963	0.9940	0.9892

(1) All fields
(2) Science and engineering fields
(3) Non-science and engineering fields
(4) Non-science and engineering fields excluding non-science education

Table 7: Estimates of Tipping Effects on Native Doctorates (t statistics included)

	(1)	(2)	(3)	(4)
Dependent: Native Male				
Prop. Native Female Doctorates	-14.6381 (-5.54)	-15.3175 (-2.88)	-11.8494 (-3.04)	-11.1490 (-6.18)
Prop. Foreign Female Doctorates	-17.2590 (-2.77)	11.2994 (1.03)	-20.0428 (-2.54)	-11.1581 (-2.91)
Prop. Foreign Male Doctorates	-0.2104 (-0.07)	4.5079 (1.39)	-7.0054 (-1.39)	-10.9309 (-4.54)
Male College Graduates at t-9	0.0224 (8.37)	0.0129 (3.21)	0.0349 (8.15)	0.0144 (7.29)
Prop. Foreign Staying in the U.S.	-0.4524 (-0.49)	-1.6421 (-1.37)	-3.2443 (-2.29)	1.4438 (2.00)
# obs.	425	189	236	227
R-Squared	0.9907	0.9964	0.9881	0.9828
Dependent: Native Female				
Prop. Native Female Doctorates	-10.0572 (-3.28)	-4.8518 (-1.32)	-14.5302 (-2.74)	-12.2014 (-4.35)
Prop. Foreign Female Doctorates	-47.5846 (-6.68)	4.0551 (0.55)	-70.4907 (-6.32)	-36.4658 (-6.32)
Prop. Foreign Male Doctorates	-1.4523 (-0.45)	2.0161 (0.89)	-23.6993 (-3.68)	-19.5342 (-5.76)
Female College Graduates at t-9	0.0028 (2.14)	0.0132 (4.74)	0.0102 (4.72)	0.0031 (1.96)
Prop. Foreign Staying in the U.S.	2.3933 (2.29)	2.1937 (2.70)	-4.0258 (-2.12)	1.5572 (1.43)
# obs.	425	189	236	227
R-Squared	0.9959	0.9980	0.9950	0.9932

Table 8: Estimates of Tipping Effects on Foreign Doctorates (t statistics included)

	(1)	(2)	(3)	(4)
Dependent: Foreign Male				
Prop. Native Female Doctorates	-0.6913 (-0.61)	-4.8180 (-1.25)	-0.6894 (-0.92)	0.7391 (1.12)
Prop. Foreign Female Doctorates	-9.0816 (-3.44)	-4.5216 (-0.58)	-7.3109 (-5.30)	1.9571 (1.17)
Prop. Foreign Male Doctorates	2.3294 (1.84)	4.1011 (1.93)	-1.8940 (-1.96)	-1.9872 (-3.14)
Prop. Foreign Staying in the U.S.	1.4306 (3.42)	4.2272 (4.64)	0.2834 (1.02)	0.9741 (4.97)
# obs.	441	198	243	234
R-Squared	0.9776	0.9709	0.9749	0.9864
Dependent: Foreign Female				
Prop. Native Female Doctorates	0.4665 (0.54)	0.3265 (0.13)	1.0141 (1.42)	1.3803 (2.62)
Prop. Foreign Female Doctorates	-2.2216 (-1.10)	6.6594 (1.27)	-7.2575 (-5.51)	3.4869 (2.62)
Prop. Foreign Male Doctorates	3.6656 (3.79)	2.7864 (1.94)	0.0468 (0.05)	-0.7497 (-1.49)
Prop. Foreign Staying in the U.S.	0.6589 (2.06)	2.7317 (4.45)	-0.5016 (-1.88)	-0.1094 (-0.70)
# obs.	441	198	243	234
R-Squared	0.9643	0.9771	0.9725	0.9074

Appendix Table 1: Science and Non-Science Fields

Sciences

Engineering
- Aerospace Engineering
- Chemical Engineering
- Civil Engineering
- Electrical Engineering
- Mechanical Engineering
- Materials Engineering
- Industrial Engineering
- Other Engineering

Physical Sciences
- Astronomy
- Chemistry
- Physics
- Other Physical Sciences

Geosciences
- Atmospheric Sciences
- Earth Sciences
- Oceanography
- Other Geosciences

Math and Computer Sciences
- Mathematics and Statistics
- Computer Science

Life Sciences
- Agricultural Sciences
- Biological Sciences
- Medical Sciences
- Other Life Sciences

Non-Sciences

Social Sciences
- Psychology
- Economics
- Political Science and Public Administration
- Sociology
- Anthropology
- Linguistics
- History of Science
- Area and Ethnic Studies
- Other Social Sciences

Humanities
- History
- English and Literature
- Foreign Languages
- Other Humanities

Education
- Science Education
- Mathematics Education
- Social Science Education
- Other Science/Technical Education
- Non-Science Education

Other
- Religion and Theology
- Arts and Music
- Architecture and Environmental Design
- Business and Management
- Communication and Librarianship
- Law
- Social Service Professions
- Vocational Studies and Home Economics
- Other non-sciences or unknown disciplines

Appendix Table 2: Proportion of Foreign Doctorates Remaining in the U.S. after Graduation

	All Fields	Physical Sciences	Engineer-ing	Life Sciences	Social Sciences	Humani-ties	Education	Professional & Other
1988	55.5	70.1	66.6	48	45.6	46.6	10.7	49.8
1989	57.7	76.5	64.8	52.2	43.1	35.9	16.4	52.9
1990	54.1	66.8	59.4	50.8	42.7	44.7	16.9	53.3
1991	58.3	71.5	62.1	58.9	46.2	42.9	19.3	56.6
1992	58.9	72.0	59.4	60.8	43.7	52.3	24.9	56.3
1993	55.2	66.5	57.4	63.3	37.7	46.0	18.4	45.8
1994	52.1	63.5	55.1	57.1	39.2	46.9	19.5	39.1
1995	53.7	64.5	61.2	55.5	41.4	44.7	18.2	44.7
1996	61.8	74.2	71.4	65.1	40.6	44.8	22.3	43.7
1997	67.9	77.9	75.1	73.7	42.3	58.1	23.9	48.6
1998	70.0	81.0	75.7	71.8	53.5	51.5	34.1	58.9
1999	69.4	80.1	78.1	72.7	54.5	49.0	34.4	53.2
2000	69.9	81.7	78.2	73.1	56.2	48.7	27.9	57.6
2001	72.0	82.1	82.1	72.1	55.3	54.2	28.4	60.6
2002	70.7	80.6	78.0	72.0	55.8	57.0	33.5	61.6

Appendix Table 3: Number of Doctorates Granted in Non-Science Education, 1966-2002

		Native		Foreign	
Year	Total	Female	Male	Female	Male
1966	2771	499	2150	26	70
1967	3152	605	2391	26	78
1968	3681	700	2765	39	125
1969	4261	798	3171	38	131
1970	5357	1084	4048	42	143
1971	5924	1227	4457	38	167
1972	6513	1496	4708	60	186
1973	6760	1646	4751	46	224
1974	6864	1726	4599	69	215
1975	7020	2134	4479	71	250
1976	7393	2335	4602	82	233
1977	7116	2363	4236	84	275
1978	6912	2630	3756	110	268
1979	7089	2798	3633	137	307
1980	7257	3040	3534	128	338
1981	7186	3191	3262	124	362
1982	6987	3181	3043	154	373
1983	6813	3207	2890	133	372
1984	6457	3067	2702	147	331
1985	6393	3046	2582	157	363
1986	6310	3138	2387	136	279
1987	6110	3049	2315	143	243
1988	6040	2992	2217	158	282
1989	5942	3017	2099	172	245
1990	6173	3272	2227	185	274
1991	6107	3269	2229	194	255
1992	6307	3486	2212	239	265
1993	6345	3434	2253	225	262
1994	6319	3585	2148	252	227
1995	6284	3564	2104	242	227
1996	6397	3633	2113	218	214
1997	6216	3498	1938	197	170
1998	6177	3476	1930	217	217
1999	6213	3648	1877	257	225
2000	6099	3587	1804	273	222
2001	6054	3420	1790	268	200
2002	6226	3441	1727	273	169

Appendix Table 4: Estimates of Crowding-out Effects Using 4-Year Moving Averages

Native Groups	(1)	(2)	(3)	(4)
Total Native Doctorates	1.1185	-2.0431	-0.7558	-3.9768
	(38.34)	(-9.37)	(-4.14)	(-4.70)
Native Male Doctorates	0.1467	-4.2009	-0.6324	-11.0254
	(5.69)	(-11.97)	(-3.92)	(-10.35)
White Male Doctorates	-0.0864	-2.5770	-0.7081	-7.2804
	(-4.18)	(-9.02)	(-4.73)	(-7.04)
Minority Doctorates	0.2180	1.5186	-0.0466	2.3581
	(40.80)	(22.74)	(-1.09)	(10.53)

(1) Science and engineering fields
(2) Non-science and engineering fields
(3) Non-science and engineering fields excluding non-science education
(4) Non-science education

Appendix Table 5: Estimates of Crowding-out Effects without Year Dummies

Native Groups	(1)	(2)	(3)	(4)
Total Native Doctorates	0.7956	-1.4609	0.5814	-3.9007
	(29.97)	(-6.79)	(4.90)	(-2.85)
Native Male Doctorates	0.0008	-4.3594	-1.2652	-9.0280
	(0.04)	(-14.33)	(-10.71)	(-4.93)
White Male Doctorates	-0.2135	-3.8790	-1.3049	-7.7164
	(-13.89)	(-14.57)	(-11.80)	(-4.83)
Minority Doctorates	0.1863	1.7123	0.4953	2.2842
	(48.15)	(36.07)	(15.40)	(10.25)

Appendix Table 6: Estimates of Crowding-out Effects before Year 1990

Native Groups	(1)	(2)	(3)	(4)
Total Native Doctorates	0.1265	-3.3995	-0.3674	-8.0983
	(1.37)	(-7.66)	(-1.01)	(-4.19)
Native Male Doctorates	-0.5416	-3.4430	0.9929	-13.2284
	(-5.64)	(-6.77)	(3.47)	(-4.21)
White Male Doctorates	-0.4949	-2.9016	0.8346	-10.8824
	(-5.89)	(-6.90)	(3.24)	(-4.13)
Minority Doctorates	0.0805	1.9148	-0.0438	2.1223
	(4.19)	(30.99)	(-0.84)	(8.48)