International Graduate Students and U.S. Innovation

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Abstract
This paper attempts to empirically evaluate the contribution of international graduate students to U.S. innovation. The main framework used is a simplified version of the "national ideas production function". Two econometric specification are estimated – one in which a time trend is incorporated to observe the short-term relationship between the variables and one in which no time trend is included with the goal of capturing the variables' long term equilibrium relationship. The results suggest that in the long-term the number of international graduate students significantly (at the 10% level) affects innovative activity. However, when the short-term relationship of the variables is analyzed it is found that the effect of the foreign students is negative and insignificant. This is attributed to the fixed size of graduate programs in the short run and their tendency to expand in the long-run.

Keywords
international students, graduate study, innovation
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ABSTRACT

This paper attempts to empirically evaluate the contribution of international graduate students to U.S. innovation. The main framework used is a simplified version of the “national ideas production function”. Two econometric specification are estimated – one in which a time trend is incorporated to observe the short-term relationship between the variables and one in which no time trend is included with the goal of capturing the variables’ long term equilibrium relationship. The results suggest that in the long-term the number of international graduate students significantly (at the 10% level) affects innovative activity. However, when the short-term relationship of the variables is analyzed it is found that the effect of the foreign students is negative and insignificant. This is attributed to the fixed size of graduate programs in the short run and their tendency to expand in the long-run.

4 I would like to thank Professor Hu for her help and guidance with this paper.
1. INTRODUCTION

Increases in unfavorable attitude toward immigrants are often observed in the face of rising unemployment and quite expectedly – in the face of threats to national security. International graduate students, the focus of this paper, are not left unaffected. For example, since the 9/11 attacks applicants for student visas have been required to have an interview at an American consulate. This has lead to delays of several months in order to sit for an interview that lasts a couple of minutes. Furthermore, new laws mandated the tracking of foreign students, regulated the type of research which they can perform and limited their access to certain biological materials (Warwick, 2006).

Such events are particularly alarming given the composition of US S&E doctoral graduates in recent years.

5 The most recent example is the Grassley-Sanders amendment, a part of the recent fiscal stimulus package that restricted the ability of recipients of federal money to hire high-skilled foreigners under the H-1B visa program.
6 Economist, 2004
In 2000, for example, the foreign-born represented 39 percent of that group. Furthermore, according to the 2000 Census foreigners comprised 47 percent of the US S&E workforce with a doctoral degree. Consequently, people from academia have repeatedly warned that restrictions to the number of foreign graduate student could lead to a crisis in research and scholarship.  

Economic theory suggests that there are a number of ways that international graduate students could contribute to US innovative activity and, in turn, to growth (Maskus et al., 2006). First, that is done through their direct impact as important inputs in university laboratories. International graduate students both perform valuable research and offer new ideas. Second, their publications and patents spill over to the broader economy by becoming knowledge for firms.

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7 In 2004, Lawrence Summers warned Colin Powell, then secretary of state, that the decline of foreign students threatens the quality of research coming from US universities (Financial Times, April 8, 2004).
and inventors. Last but not least, scientific discoveries with participation of international graduate students are frequently turned into licensing arrangements for applied product development.

This paper tries to analyze the role of international graduate students in expanding US innovation. It was primarily motivated by the existence of a number of studies arriving at contradicting results when analyzing the contribution of international graduate students to US innovation. For example, an empirical study by Challeraj et al found that a 10% increase in the number of foreign graduate students would raise patent applications by 4.5%.\(^8\) In contrast, Borjas concluded that international students displace native ones and, therefore, might not contribute to innovation (2004).

\(^8\) Note that patenting activity is the most commonly used proxy in innovation studies (Trajtenberg, 1990). The reasons for that are explained in the Data section below.
The current analysis tries to reconcile the previous contradicting results on the subject by attributing their inconsistency to the different effect of international graduate students on innovation in the long- and short-terms. Hunt made a similar observation concerning skilled immigrants’ influence on US innovation (2008). The author demonstrated that any potential crowd-out effects dissipate when the period of analysis extends over ten years. Undoubtedly, a potential finding indicating that foreign graduate students positively affect US innovation in the long term will have huge implications for immigration policy and it will allow for a more careful evaluation of shocks to the number of international graduate students as the one described above.

Five sections follow. The first reviews related literature on the contribution of international graduate students to innovation. The second describes the econometric model that will be used. The third displays the data sources used. The
fourth analyzes the statistical and economic results obtained for the effect of international graduate students on US innovation. The last section summarizes the findings and makes some public policy recommendations.

II. LITERATURE REVIEW

There are two related strands of literature that help build the foundation for this paper: one discusses the contribution of skilled-immigrants to innovation and the other does so for international graduate students. Most of the issues and methodology used in both research areas are quite similar. In both cases the main question of interest is whether skilled-immigration/international graduate students have a positive impact of innovation. In both cases a certain possibility for a crowd-out effect exists in which domestic workers/students are displaced. An overview of some of the results already obtained follows.
As usually done in the literature Kerr et al. use patenting as a proxy for innovation (2008). Since each patent provides the name of the inventors, the authors use a name-matching algorithm that detects the ethnicity of the inventor. The dependent variable is the log of overall patents by city. The key explanatory variables are the log of the total number of patents by Indian and Chinese inventors. The focus is on the patenting of these two ethnicities because they play a disproportionate role in the H1-B program. The results show that a 10% growth in the H1-B worker population is associated with a 2% increase in patenting. Furthermore, the authors estimate that a 10% increase in the H1-B population is associated with a 0.5%-1% increase in English invention, suggesting a crowding-in effect.

9 Note that patenting activity is the most commonly used proxy in innovation studies (Trajtenberg, 1990). The reasons for that are explained in the Data section below.
However, that estimate is not statistically significantly different from zero.

By exploring individual patenting behavior as well as state-level determinants of patenting, Hunt demonstrates the important boost to innovation by skilled immigrants (2008). Again U.S. patents are used as a proxy for innovation. For the individual-level analysis a probit for the probability of having a patent granted is estimated. The main variable of interest is a dummy variable for the foreign-born. The results indicate that immigrants that are working in S&E are 1.4 percentage points more likely to have a patent than domestic workers in S&E. The state-level analysis uses the share of the state’s workforce composed of skilled natives and immigrants as a dependent variable and the share of skilled immigrants as the main independent variable. A coefficient of zero on the independent variable would indicate that there is a crowd-out effect as an increase in the number of skilled
immigrant would be offset by a decrease in the number of skilled natives. The author finds that using ten-year differences leads to a small, but statistically insignificant crowd-out effect. Furthermore, Hunt observes that when the length of differences increases, the crowd-out disappears. The coefficient is 0.95 for 50-year differences. This suggests that any potential crowd-out effects disappear in the long-term.

A paper by Chellaraj tries to simultaneously estimate the effects of both groups (skilled immigrants and international graduate students) on innovation. Chellaraj et al. claim that the presence of foreign graduate students has a positive and significant impact on US patent applications and grants awarded to both firms and universities, meaning that international graduate students contribute to US innovation (2008). However, the authors also estimate that skilled immigration, while having a positive impact on innovation,
is not statistically significant from zero. The model used to account for the role of foreign students is a modified “national ideas production function”. Further details on the model are provided below.

A slightly different approach is used by Stuen et al. (2008). The authors explore the contribution of foreign science and engineering students to the creation of new knowledge in the U.S. economy. They estimate the impact of foreign and domestic graduate students on the publications of 2300 science and engineering departments at 100 large American universities from 1973 to 1998. They use fixed effects for each field for each university. The authors’ results suggest that the relative contribution of foreigners and Americans appear to depend on the type of foreign student. Overall, the marginal foreign student is neither clearly better nor clearly worse than the American one. Foreign students contribute more in terms of citations at the elite universities.
However, there are significant variations in the marginal productivity of students across source regions.

Levin and Stephan assert that foreign-born scientists play a disproportionate role in generating knowledge in the USA (1999). They look at six illustrative criteria to evaluate contributions to US science: individuals elected to the National Academy of Sciences and/or National Academy of Engineering, authors of citation classics, authors of hot papers, the 250 most-cited authors, authors of highly cited patents, and scientists who have played a key role in launching biotechnology firms. For each indicator of scientific achievement they determine whether the observed frequency by birth (or educational) origin was significantly different from the frequency one would expect given the composition of the scientific labor force in the United States. The authors used a “goodness of fit” test by computing the chi-square statistics. Only in the instance of hot papers in the
life sciences were they not able to reject the null hypothesis that the proportion was not the same as that in the underlying population. This means that according to the authors foreign graduate students contribute to US science and therefore to innovation.

Borjas implicitly disputes the findings of Chellaraj et al and Levin and Stephan (2005). He claims that foreign students crowd out native ones from graduate programs. He suggests that there might be two types of a crowd-out effect. The first one is within a particular university. The enrollment of an additional foreign student would imply that one fewer native student would be enrolled. The second type of crowd-out effect concerns the incentives natives have to pursue those educational programs where foreign students cluster. Such a cluster might indicate lower wages in that particular occupation, making natives avoid the program. Borjas focuses on the first type of crowd-out effect. He empirically
verifies that foreign students limit the opportunities available to white men in graduate education, especially at the most elite universities. However, the author admits that the implications of his finding vary on what happens to the displaced white men and to the foreign students after they graduate – questions without a definite answer.

Using a similar approach to Chellaraj’s this paper attempts to unify the contradicting claims about international graduate students made in the existing literature. In other words, it tries to explain why some studies imply a positive relationship between international graduate students and US innovation and why others imply a negative one. Just as Hunt’s analysis demonstrated the different impact of skilled immigrants on innovation in the different time periods, this paper tries to do so for international graduate students. An attempt is made to find an explanation that compromises the positive findings of Chellaraj et al and Levin and Stephan on
one hand and the negative ones by Borjasand Stuen et al on the other hand. In particular, the negative correlation between international graduate students and innovation is interpreted as the short-term effects of those students on innovation, while the positive relationship is seen as the true long-term connection between the two. The two time-horizons are empirically estimated.

III. MODELING

The contribution of international graduate students to US innovation can be only estimated on the background of some general framework aiming at explaining innovation. Usually the model used to estimate innovative activity is the widely recognized “national ideas production function” (Porter and Stern, 2001; Stern et al., 2002)\(^{10}\):

\[
A_t = \delta (H_t^{INF} H_t^{CLUS} H_t^{LINK}) H_{A,t}^{\lambda} A_t^{\phi}
\]

(a version of the model used by Porter and Stern).

\(^{10}\) Note that most of the models described in the Literature Review section use some simplified version of this model.
This framework suggest that the rate of new ideas production is a function of the total capital and labor resources devoted to the ideas sector of the economy - $H_{A,t}^\lambda$, the total stock of knowledge held by an economy at a given point in time – $A_t^\phi$, the level of resource commitment and policy choices that make up the innovation infrastructure – $(H_t^{INF})$, the environment for innovation in the country’s industrial clusters – $H_t^{CLUS}$ and the strength of linkages between the common infrastructure and the industrial clusters – $H_t^{LINK}$. According to Porter and Stern (2001) $A_t^\phi$, $H_{A,t}^\lambda$ and $H_t^{INF}$ are fairly easy to quantify. However, the environment for innovation and the linkages between the common innovation infrastructure and the industrial clusters are hard to measure directly.

Because of the limitations outlined above and because of the focus placed on one particular factor in determining innovative activity – the number of international
graduate students – a fairly simplified model is offered. It attempts to capture on one hand the effect of international graduate students and on the other all other relevant factors listed above. The model used is an autoregressive process:

$$A_t = A_{t-1}H_{A,t}^{\lambda F}.$$  

In other words, innovative activity in time period t is represented as a function of innovation in the previous time period and the flow of international graduate students, $H_{A,t}^{\lambda F}$. Note that $A_{t-1}$ is used to proxy all other factors from above - $H_t^{INF}, H_t^{CLUS}, H_t^{LINK}, A_t^\phi$ and $H_{A,t}^\lambda$. It should also be observed that under the model described above (the Porter and Stern version), the number of international graduate students is supposed to be implicitly incorporated into the labor and capital resources devoted to the ideas sector – $H_{A,t}^\lambda$. Here it is separated as the goal is to evaluate its individual impact.

Before the model outlined above could be estimated econometrically, it must be accounted for the time difference
between the variables in the model. New ideas production will be measured by total patent applications as a percentage of the labor force. Since there is a lag of five years between the usage of the inputs in the idea production function and the application for a patent, the number of international graduate students will have a five year lag with respect to patent applications (Popp et al. 2004). Furthermore, the number of international graduate students is taken as a proportion of the total number of graduate students in order to account for any changes in the overall size of the graduate programs. In its general form the econometric model used looks like:

\[ PALF_t = \alpha + \lambda F^*IGTG_t + \alpha_1^*PALF_{t-1} + \varepsilon_t \]

The dependent variable, patenting activity, is the most commonly used proxy in innovation studies (Trajtenberg, 1990). Patents are a reasonable proxy for innovation, because they reflect novelty and economic value
as exhibited by the fact that it is hard and expensive to obtain a patent. Using the lagged dependent variable as a regressor is not too unreasonable. As explained above there are many independent variables that are hard to capture directly and in this way it can be at least partially accounted for them. Furthermore, previous inventions help the creation of current inventions and therefore should be included in the model (Porter and Stern, 2000). Also, previous innovative activity is a manifestation of past inputs, which accumulate over time to determine current innovation.

Because this is a time–series estimation, the stationarity of the variables must be taken into account. Two econometric specifications are estimated – one in which a time trend is incorporated to observe the short-term relationship between the variables and one in which no time trend is included with the goal of capturing the variables’ long term equilibrium relationship. The last could be
performed because the two variables of interest – patent applications and international graduate students – are cointegrated. They share similar stochastic trends. The resulting econometric specifications are as follows:

$$\text{PALF}_t = \alpha + \lambda F * \text{IGTG}_t + \alpha_1 * \text{PALF}_{t-1} + \varepsilon_t$$

$$\text{PALF}_t = \beta + \lambda F_1 * \text{IGTG}_t + \beta_1 * \text{PALF}_{t-1} + \theta_1 * t + \varepsilon_t.$$

As already deliberated, the impact of international students on innovation has been differently evaluated using different methodologies. Levin and Stephan estimate that foreign-born scientists play a disproportionate role in generating knowledge in the USA (1999). This is confirmed by the assertion that a 10% increase in the number of foreign graduate students would raise patent applications by 5% (Chellaraj, 2008). However, as mentioned before, there are some studies saying that foreign students crowd out native white students from graduate programs, where the effect is biggest in the most elite institutions (Borjas, 2005).
Using the two economic specifications above the aim is to evaluate what the impact of international graduate students is. That depends on the signs of the coefficients $\lambda_F$ and $\lambda_{F1}$. While the coefficient in the long-term equilibrium relationship, $\lambda_F$, is expected to have a positive sign, the one in the de-trended version, $\lambda_{F1}$, could have either a positive or a negative value. This is because the short-term impact of international graduate students is not so clear – there might be a short term crowding-out effect that is later eliminated as graduate programs expand (Freeman, 2005). Such a crowd-out effect may mean that an increase in the number of foreign graduate students does not contribute to innovation at least in the short run.

IV. DATA

As already explained, patenting activity, is the most commonly used proxy in innovation studies (Trajtenberg, 1990). There are two important reasons suggesting that
patents are indeed a reasonable proxy for innovation. First, to be awarded a patent, a certain invention must be novel, meaning that patents indeed capture new ideas. Second, it is quite costly to apply for a patent – this suggests that the patenting entity must believe that there is some economic value associated to its patent. There are many pitfalls in using patenting activity as a proxy for innovation – not all inventions are patentable, not all inventions are patented and the inventions that are patented differ significantly in value (Griliches, 1984). Nevertheless, patenting activity is the best available measure (Trajtenberg, 1990). Data on patents awarded to different institutions was gathered from the website of the US Patent and Trademark Office.

Another measurement limitation is reflected in the variable IGTG. In the model employed here IGTG is the fraction of international graduate students to total graduate students. The innovation literature (Porter and Stern, 2001)
says that the resources devoted to R&D sector are an important input in the innovation function. That would mean that only the part of international graduate students that specializes in the sciences should be included. However, such data is unavailable. Consequently, the total number of international graduate students is used. This is not an over-restrictive assumption, as the number of international graduate students in the sciences and engineering is about eighty percent. Figures on international graduate students were obtained from *Open Doors*, the publication of Institute for International Education.

The two economic specifications outlined above are estimated over the period 1969 - 2003. Below is a table with the basic statistical properties of the variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGTG</td>
<td>37</td>
<td>8.411081</td>
<td>2.164665</td>
<td>4.61</td>
<td>11.97</td>
</tr>
<tr>
<td>L.PALF</td>
<td>35</td>
<td>1.565074</td>
<td>0.648049</td>
<td>0.936836</td>
<td>2.981165</td>
</tr>
<tr>
<td>PALF</td>
<td>35</td>
<td>1.565074</td>
<td>0.648049</td>
<td>0.936836</td>
<td>2.981165</td>
</tr>
</tbody>
</table>

V. EVIDENCE
A. The Long Term Equilibrium Specification

Estimating the first specification resulted in a model that had the following coefficients and significance of the variables:

<table>
<thead>
<tr>
<th>Long Term Equilibrium Specification</th>
<th>Coefficient</th>
<th>t-statitic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGTG</td>
<td>0.0223345</td>
<td>2</td>
<td>0.054</td>
</tr>
<tr>
<td>L.PALF</td>
<td>0.9962844</td>
<td>25.53</td>
<td>0.000</td>
</tr>
<tr>
<td>_cons</td>
<td>-0.123392</td>
<td>-2.26</td>
<td>0.031</td>
</tr>
</tbody>
</table>

Adj R-squared = 0.9876

The model did not pass the Breusch-Pagan test for heteroskedasticity. The null hypothesis that the variance of the error terms is constant was rejected, because the P-value of the chi-square statistic equaled 0.0446, which is rejected at the 5% level of significance. After correcting for the problem of heteroskedasticity, the following values were obtained from the regression with robust standard errors for the coefficients and the significance of the variables:
It was also found that the model is the appropriate functional form as it passes the Ramsey’s test. The null-hypothesis that there are no omitted variables is failed to be rejected, as the P-value of the F-statistic equals 0.4048. It is also ascertained that the model does not suffer from autocorrelation. The Durbin-Watson test has a statistic of 1.841373, which in a model with three estimated parameters and 33 observations is in the acceptable region. Multicollinearity was also not observed – the mean VIF was 3.44. Moreover, the model seems accurate as the coefficient of the L.PALF is positive and very significant – it has a P-value of 0.000, which means that the null-hypothesis that the coefficient is equal to zero is rejected. This is just as expected. Also, it should be noted that the adjusted R-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-statitic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGTG</td>
<td>0.0223345</td>
<td>1.94</td>
<td>0.062</td>
</tr>
<tr>
<td>L.PALF</td>
<td>0.9962844</td>
<td>21.68</td>
<td>0.000</td>
</tr>
<tr>
<td>_cons</td>
<td>-0.123392</td>
<td>-3.26</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Long Term Equilibrium Specification
Adj R-squared = 0.9884
squared is very high – 0.9884, suggesting that the model is a good fit. The test for overall significance of the model is confirming that the independent variables are jointly significant. The F-statistic is very high - 1283.64.

It can be seen that the coefficient of IGTG is positive. As expected, it is less significant than before the correction for heteroskedasticity, but the null hypothesis that it is equal to zero is still rejected at the 10% level of significance. The interpretation of this coefficient is that for every percentage point increase in the ratio of international graduate to total graduate students, the ratio of patent applications to the labor force increases by approximately 0.02 percentage points. This means that in the long-term the presence of international graduate students is exerting a positive impact on US innovation.
B. Specification with De-trended Variables

Estimating the second specification resulted in a model with the following coefficients and significance of variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGTG</td>
<td>-0.0210377</td>
<td>-0.95</td>
<td>0.35</td>
</tr>
<tr>
<td>L.PALF</td>
<td>0.9304208</td>
<td>19.72</td>
<td>0.000</td>
</tr>
<tr>
<td>_cons</td>
<td>0.0874489</td>
<td>0.81</td>
<td>0.425</td>
</tr>
</tbody>
</table>

Adj R-squared = 0.9890

The model did not pass the Breusch-Pagan test for heteroskedasticity. The null hypothesis that the variance of the error terms is constant was rejected, because the P-value of the chi-square statistic equaled 0.0084, which is rejected at the 5% level of significance. Therefore, it was corrected for the problem of heteroskedasticity and the following values were obtained from the regression with robust standard errors for the coefficients and the significance of the variables:
It was found that the model has the appropriate functional form as it passes the Ramsey’s test. The null-hypothesis that there are no omitted variables is not rejected, because the P-value of the F-statistic equals 0.4881. It was also ascertained that the model does not suffer from autocorrelation. The Durbin-Watson test has a statistic of 1.841373, which in a model with four estimated parameters and 33 observations is in the acceptable region. Moreover, the model seems accurate as the coefficient of the L.PALF is positive and very significant – it has a P-value of 0.000, which means that the null-hypothesis that the coefficient is equal to zero is rejected. This is just as expected. Also, it should be noted that the adjusted R-squared is very high –
0.9901, suggesting that the model is a good fit. The test for overall significance of the model is confirming that the independent variables are jointly significant. The F-statistic is very high - 850.23.

This time the coefficient of IGTG is negative. Furthermore, it is not significant as it has a P-value of 0.398. Therefore, the null hypothesis that the coefficient is different from zero is not rejected. This means that as we de-trend the variables, that is, as we capture their short-term relationship, the effect of international graduate students on innovation becomes negative and insignificant.

C. Summary of Results

In summary, as we compare the two econometric specifications we find out that in the long-term the number of international graduate students significantly (at the 10% level) affects innovative activity. However, when the short-
term relationship of the variables is analyzed it is found that the effect of the variable of interest is negative and insignificant. The last could be due to the fact that in the short-run the size of a particular university’s student body is fixed and accepting one additional foreign student would mean not accepting a domestic student. The former could be explained by the expansion of graduate programs in the long-run. Such an expansion allows for the accommodation of more international graduate students without the displacement of domestic ones.

In light of the results obtained, it is quite expected that a concentration on the short-term and university-level would lead to the observance of a negative relationship (Borjas, 2005). Furthermore, a concentration on the long-term and national-level would lead to the observance of a positive relationship (Chellaraj, 2008).
VI. CONCLUSIONS

This paper attempted to unify the contradicting studies existing so far in the literature about the contribution of international graduate students to US innovation. It tried to explain why some studies implied a positive relationship between international graduate students and US innovation, while others suggested a negative one.

Two econometric specifications were estimated – one in which a time trend was incorporated to observe the short-term relationship between the variables and one in which no time trend was included with the goal of capturing the variables’ long term equilibrium relationship. The results suggested that in the long-term the number of international graduate students significantly (at the 10% level) affects innovative activity. However, when the short-term relationship of the variables was analyzed it was found that the effect of the variable of interest is negative and
insignificant. This was attributed to the fixed size of graduate programs in the short run and their tendency to expand in the long-run.

Further research on the subject could improve the model by adding more variables. In its current version the analysis employs a simplistic auto-regressive form with two variables. Furthermore, more observations could be added as this was a time series model that had only a single observation per year. This could be achieved if a model that implements some form of the ideas production function at the state-level is used. 11

As already suggested, the findings of this paper have significant immigration policy implications (Maskus, 2007). First, graduate enrollments at domestic universities in technical fields should be increasingly made more open to foreign students. Second, investment into excellent research

11 Such a model was utilized by Hunt in estimating the impact of high-skilled immigrants on US innovation (2008).
facilities should be made a priority in order to attract the increasingly global pool of science and engineering students. Third, international graduate students in S&E should be placed on an accelerated track to citizenship.

---REFERENCES---


