DISCUSSION PAPERS IN ECONOMICS

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September 2004

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ABSTRACT

The impact of international students and skilled immigration in the United States on innovative activity is estimated using a model of idea generation. In the main specification a system of three equations is estimated, where dependent variables are total patent applications, patents awarded to U.S. universities, and patents awarded to other U.S. entities, each scaled by the domestic labor force. Results indicate that both international graduate students and skilled immigrants have a significant and positive impact on future patent applications as well as future patents awarded to university and non-university institutions. Our central estimates suggest that a ten-percent increase in the number of foreign graduate students would raise patent applications by 3.3 percent,

The United States remains at the cutting edge of technology despite frequent complaints about quality deficiencies in its secondary education system.[5] Indeed, among the major developed countries and the newly industrialized countries, the United States ranks near the bottom in mathematics and science achievement among eighth graders.[6] What may reconcile these factors is that the United States attracts large numbers of skilled immigrants that enter directly into such technical fields as medicine, engineering, and software design. Moreover, the education gap is filled by well-trained international graduate students and skilled immigrants from such countries as India, China, Korea, and Singapore (the last two of which rank at the top in mathematics and science achievement). Certainly the United States sustains a significant net export position in the graduate training of scientists, engineers, and other technical personnel.

It is likely that international graduate students and skilled immigrants are important inputs into the U.S. capacity for continued innovation, but this basic hypothesis surprisingly has not been formally tested. In this paper we estimate an innovation production function in which graduate students and skilled immigrants are an input into the development of new ideas, bo

applications and grants awarded to both firms and universities. This finding extends to the relative presence of skilled immigrants in the labor force, with an increase in the skilled immigrant share significantly raising later patent awards in both types of institutions. Put simply, we find that both enrollment of foreign graduate students and immigration of skilled workers have a strong and positive impact on the development of ideas in the United States.

The paper proceeds as follows. In the next section we review literature that motivates this study. In Section Three we develop a simple model and set out the econometric specification. In Section Four we provide results and discuss their economic and policy significance. In Section Five we conclude.

2. Background and Literature Review

The question of whether skilled and other forms of immigration bring net benefits is much discussed in media and policy circles in rich countries.[7]

2a. Basic Economic Models

Labor economists have focused on the static implications of immigration into the

support rising aggregate real incomes in the long run.[9] Ultimately, the impacts of immigration on real incomes through innovation are an empirical issue.

Indeed, pessimistic claims about the impacts of foreign workers seem inconsistent with continued political support, arising from the high-technology sectors, in the United States for sustaining immigration of skilled workers and engineering and science students.[10] Thus, an essential motivation for our paper is to investigate whether this support is rooted in the dynamic innovation impacts of such foreign workers studying and residing in the United States.

2b. Foreign Graduate Students and Skilled Immigration

The issue of international students and their contribution to host-country economies has been addressed only recently although students have been leaving their home countries for study abroad for nearly four thousand years (Cohen, 2001). Until

which removed the National Origins quotas established by the Johnson-Reid Immigration Act of 1924, and resulted in greater flows of skilled immigration and foreign students. These trends were accelerated after passage of the Kennedy-Rodino Immigration Act of 1990. Studies by Cobb-Clark (1998), Clark, et al (2002) and Antecol et al. (2003) indicate that legislative reforms resulted in a sharp increase in the flow of highly talented international workers into the United States. Further, there is an important relationship between human capital investment and im

As a result it is not surprising that a recent study (Freeman et al., 2004) indicates that there has been a sharp drop in the proportion of PhDs in science and engineering awarded to U.S.-born males between the early 1970s and 2000. In 1966 these students accounted for 71 percent of science and engineering PhD graduates, while six percent were awarded to U.S.-born females and only 23 percent of doctoral recipients were foreign-born. The situation was reversed by 2000, when only 36 percent of doctoral recipients were U.S.-born males, 25 percent were U.S.-born females and 39 percent were foreign-born. Contradicting Borjas (2004), the authors found that foreign students were not substituted for domestic students. The number of PhDs granted to undergraduates from U.S. institutions, most of whom were U.S. citizens, did not change much during this period, while there was a huge growth in the number of foreign bachelor's graduates obtaining U.S. doctorates. Thus the change in proportion is mostly due to the expansion of PhD programs, with a majority of the new slots being taken by foreign students rather than through substitution.

These same trends explain the fact that the proportion of foreign born faculty with U.S. doctoral degrees at U.S. Universities has gone up sharply during the past three decades, from 11.7 percent in 1973 to 20.4 percent in 1999. For engineering it rose from 18.6 percent to 34.7 percent in the same period.[14]

In the last few years, however, there has been a steep decline in foreign student applications for admission into U.S. universities and a corresponding increase in applicants to universities in Asia, Australia and New Zealand. [15] This is due both to difficulties in obtaining U.S. visas since September 2001 and to the fact that some

[13] http://nces.ed.gov/pubs99/1999081.pdf
[14] http://www.nsf.gov/sbe/srs/seind02/append/c5/at05-24.xls

countries are catching up to the United States with regard to attracting foreign students and skilled labor from abroad (Hira, 2003). Recent evidence also suggests that collaboration between foreign and U.S. universities has shown marked increase during the past two decades and increasingly research activities are being "dispersed" abroad, particularly to Asian countries, partly to take advantage of complementary capabilities (Adams et al., 2004). While modern communication technologies and cuts in public funding presumably have contributed to this trend, it is likely that if qualified students become increasingly unavailable in the United States the tendency will accelerate.

2c. University Research and Patenting

In the United States, patenting of new inventions by universities began to accelerate during the 1960s, although such institutions as Stanford had been innovating and attempting to patent inventions from the early 1920s (Etzkowitz, 2003; Henderson and Jaffe, 1998). University innovation and patenting may have been significantly boosted by the Bayh-Dole Act of 1980, which allowed U.S. universities to commercialize research results (Sampat et al., 2003; Mowery et al., 2001). Currently the determinants of university patenting in the United States and its implications for the economy are a central subject for inquiry (Lee, 1996; Thursby and Kemp, 2002; Jensen and Thursby, 2001; Thursby and Thursby, 2000; Owen-Smith and Powell, 2003).

National governments typically play a significant role in financing research that supports patenting. Furthermore, there is also considerable university-industry collaboration, especially in the United States, with a significant proportion of research funding coming from industries (Cohen et al., 1994; Dasgupta and David, 2002; Agrawal

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[15] http://smh.com.au/articles/2004/07/14/1089694426317.html?from=moreStories&oneclick=true

and Cockburn, 2003; Link and Scott, 2003). Indeed, U.S. state and federal budget cuts have created a vacuum in research financing that is increasingly being filled by both domestic and international corporations (Beath et al., 2003). For example, recently BMW set up a fund to finance most of the research of the Automotive Engineering Department at Clemson University in South Carolina. [16]

As noted earlier, prior studies of university patenting have not analyzed the role of skilled immigrants or foreign graduate students as input into the innovation production function. That role could be important as most countries in the world are not in a position to produce domestically all the skilled labor necessary for rapid technological development and innovation. Hence, they must rely on skilled immigration and foreign talent to augment their skills. Recent experience indicates that countries such as the United States, Australia, Singapore, United Arab Emirates and more recently, People's Republic of China, which have been relatively open to foreign talent, have experienced faster rates of economic growth than such countries as Germany, Japan and Korea, where opposition to any form of foreign talent is significant. Thus, it seems plausible from this experience that a relatively open-door skilled immigration policy could play an important role in innovation and follow-on growth.

3. Modeling Framework

To estimate the contribution of skilled immigrants and foreign graduate students to U.S. innovation, we modify the "national ideas production function" that is widely used in innovation studies (Stern, et al, 2000; Porter and Stern, 2000). This may be written in general form as

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[16] http://www.clemson.edu/centers/brooks/news/BMW.pdf

$$\dot{A}_t = \delta H_{A,t}^{\lambda} A_t^{\phi} \tag{1}$$

Thus, the rate of new ideas produced depends on both the allocation of resources to the

R&D sector ($H_{A,t}$), the productivity of those resources (λ), the stock of ideas already in

existence (A_t) and the ability of that stock to support new invention (ϕ). Note that if $\phi >$

0, prior research increases current R&D productivity (the "standing on shoulders" effect),

but if $\phi < 0$, prior research has discovered the easier ideas and new invention becomes

inputs into idea generation. We permit the productivity of each resource to differ, as follows.

$$S \qquad R$$

In the first equation the dependent variable is total patent applications as a percentage of the U.S. labor force, five years after inputs are employed. These inputs include foreign graduate students as a percentage of total labor force (FOR), U.S. graduate students as a proportion of

$$IPA_{t+5} = \alpha_1 + \lambda_{F1}FOR_t + \lambda_{G1}GR_t + \lambda_{I1}IM$$

own-patent stock. However, because there is likely to be learning by each group from the ideas protected by patents owned by the other, we anticipate a spillover impact measured by the coefficients on UPATSTOCK (in the non-university equation) and OPATSTOCK (in the university equation).

In a supplementary set of estimated equations we include another policy variable, which is a dummy for those years in which the U.S. government might be expected to enforce its student-visa restrictions rigorously. U.S. immigration laws allow students to convert visas to one of the employment categories. However, a regulation known as Section 214(b) of the Immigration and Nationality Act of 1952 allows consular officers to reject visas to students who might attempt to convert their visas once in the United States. In turn, this regulation makes it difficult to obtain student visas, affecting the inflow of graduate students. The law places the burden of proof on the applicant to demonstrate the existence of links in his home country (e.g., family) that would make return more likely.

For our purposes the interesting feature of the law is that it provides flexibility to consular officials in the rigor with which student visa applications are scrutinized. We argue that this regulation is more likely to be strictly enforced during periods when there is restrictive immigration legislation pending in Congress, such as the Simpson-Mazzoli legislation of the early 1980s, or during periods of high unemployment. It is evidently less strictly enforced when there is a liberal immigration bill pending in Congress, as during the late 1980s with the Kennedy-Rodino Immigration Bill, or during periods of low unemployment. These various periods, and their classification into "rigorous" and "lenient" enforcement epochs, are presented in Table 1.

Because stricter enforcement of Section 214(b) can be seen as increasing the costs of obtaining admission to the United States, it can affect both the number and quality of students. The impact of a lower level of student arrivals presumably already is included in the earlier specifications. However, increases in mobility costs could also affect the composition of students coming to the United States. The impact on composition is not obvious and would depend on the distribution of (skilled) incomes in the home country relative to that in the United States (Roy, 1951; Borjas, 1987). If students came from

Doors, the publication of Institute for International Education. No data were available on

international graduate students in science and engineering for the period prior to 1983 and hence

total international graduate students had to be used as a proxy.   This is not overly restrictive for

approximately 80 percent of international graduate students enter science and engineering fields

and most of the rest go into business fields and economics.[18]

Data on patents awarded to different institutions, such as universities and

industry, were gathered from the National Science Foundation, *Science and Engineering*

Statistics. Figures on research and development expenditures (divided by the GDP

deflator), total number of scientists and engineers, total labor force, total number of

international students and total skilled immigrants entering the country are available from

the *Statistical Abstracts of the United States* published annually by the U.S. Census

Bureau. Skilled immigrants are defined to include both those coming under H1-B1 visas

(both capped and uncapped) and employment-based immigration. Simple correlations

among the variables in this study are listed in Table 2.

cumulative measure.[19] We argue that the second pair

It is interesting that the sensitivity of patent activity with respect to foreign graduate students is more than three times larger than that with respect to skilled immigration. However, lagged enrollments of U.S.-native graduate students did not have a significant impact on total patenting activity. This result strongly supports the view that the presence of foreign students and skills in the United States is pro-innovation in relation to the enrollment of domestic students. Finally, implementation of the Bayh-Dole Act had positive and marginally significant impacts on later patent applications and grants in the second pair of equations.

In Table 4 the regressions are broken down into total patent applications, university patent grants, and other patent grants, using the SUR technique. The coefficients for the patent applications equations are quite similar to those in Table 3, as expected, and require no further discussion. Of interest here is whether there are detectable differences in behavior between patent grants to universities and patent grants to non-university actors. Beginning with the university equations, it is interesting that both lagged university patent stocks and lagged other patent stocks were significant and positive. The own-elasticity estimate is large,

the importance of university-registered patents as sources of technical information for general innovation in the U.S. economy.

As anticipated, lagged R&D expenditures had strongly positive effects on patenting activity in all six equations. The implementation of the Bayh-Dole Act appears to have induced significantly more patent grants to university researchers but had an insignificant impact on total patent applications and other patents awarded.

Turning to human inputs, we find that the ratio of foreign graduate students to total labor force had a significant and positive effect in all six patenting equations. The elasticity of total patent applications to increases in foreign students is around 0.33 to 0.35, similar to that of the previous specification. As expected, foreign graduate-student enrollments had a larger positive impact (0.60 to 0.68) on future university patent awards than on other patenting (0.40 to 0.46), though both estimated elasticities are significant and large. Note that these impacts are also larger than those found for the overall patent-grants equations in Table 3. Further, the results indicate that the presence of US domestic graduate students had little impact on any patenting activity.

It is of interest to put these elasticities in perspective by computing the impacts on patent levels from a change in migration. Using the estimates in the last three columns of Table 4, a ten-percent rise in the number of foreign graduate students (from its mean level

Comparing Tables 5 and 3 we note first that the inclusion of the indicator variable

The estimates in the final three columns suggest that a ten-percent rise in foreign graduate students would increase later patent applications by 5,301, university patent grants by 73 and other patent grants by 6,829, again evaluated at sample means. The Bayh-Dole Act has significantly positive effect

contributing academic department. Furthermore, industries also tend to purchase the intellectual property rights of any discovery from the innovating university and hence tend to benefit indirectly from international student contributions.[22]

It is interesting that the results consistently show that foreign students, skilled immigrants, and doctorates in science and engineering play a major role in driving scientific innovation in the United States, while the proportion of U.S. graduate students plays no role. It should be noted that our variable includes all domestic graduate students and not just those in science and engineering. There are only a few observations available that distinguish between domestic and foreign graduate students in these technical fields. These data indicate that enrollments of domestic students as a proportion of total graduate students have remained fairly steady at around 65 percent recently. However, the former accounted for an average of only 45% of all graduating students during the 1990s, suggesting a significantly larger school-leaving rate. Furthermore, a significant proportion of U.S.-born students go into other fields, such as law and management, perhaps due in part to under-preparation in mathematics and science. U.S. census data indicates that only nine percent of U.S.-born graduates work in scientific fields whereas 17 percent of foreign-born graduates work in scientific fields.

While the Bayh-Dole Act increased patenting activity by universities and non-university institutions, strict implementation of Section 214(b) by consular officers contributed to declines in future patenting activity at all levels. As discussed earlier, this law authorizes consular officers to deny student visas to so-called "intending

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[22] Dasgupta and David (1992) and Cohen, Florida, and Goe (1994).

immigrants". The results indicate that stringent enforcement of this regulation has been a significant impediment to patenting activity in the United States.

The results also indicate indirectly that the United States gains from trade in graduate education services. Relatively open access to international students has allowed U.S. universities to accept the brightest graduate students in science and engineering from all over the world. In turn, international graduate students contribute to innovation and patenting in science and engineering while domestic graduate students evidently do not in the aggregate. Presumably, this is because international graduate students are more concentrated in such fields as science and engineering than are domestic students. Indeed, in a number of highly ranked engineering schools, international students account for nearly 80 percent of doctoral students, while in fields such as law they rank as low as one percent.[23] Further, because of work restrictions for international students, domestic students have greater opportunities to be employed in non-research activities in both university and non-university institutions. Hence, it is not surprising that the presence of international students along with skilled immigrants, including international faculty, exchange visitors, research fellows and post-doctoral research associates, is a significant factor behind sharp increases in innovation and patenting at universities.

5. Concluding Remarks

This study provides the first systematic econometric results about the contributions of foreign graduate students and skilled immigrants to U.S. innovation and technological change. While it may have become conventional wisdom in some circles that these personnel flows contributed extensively to learning in the United States, the

idea had not been tested. Our results strongly favor the view that foreign graduate students and immigrants under technical visas are significant inputs into developing new technologies in the American economy. The impacts are particularly pronounced within the universities but spill over as well to non-university patenting.

The significant contributions of international graduate students and skilled immigrants to patenting and innovations in the United States may have international and domestic policy implications. At the international level, it is evident that the United States has a significant direct comparative advantage in exporting the services of higher education, especially in training scientists, engineers, and related personnel. This situation is broadened by the contributions of foreign students to innovation in the United States, whereby the indirect impact of technical education is additional patent rents.

However, as other countries improve their offerings of scientific graduate education, visa restrictions in the United States could have adverse implications for competitiveness. Specifically, global liberalization of higher education services would permit U.S. universities to get around visa problems by locating research campuses in other countries, such as Singapore,[24] that welcome international talent (Amsden and Tschang, 2003), following the examples of INSEAD and the University of New South Wales. Indeed, studies indicate that Japanese corporations have moved research activities abroad partly in response to strict Japanese immigration policies (Iwasa and Odatiri, 2004). It is also noteworthy that U.S. corporations have significantly increased patenting activity and innovation abroad (Maskus 2000) and recent evidence indicates

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that U.S. universities are increasingly collaborating in research with universities abroad (Adams et al. 2004).

One of the striking findings in the current paper is that tight enforcement of restrictions on student visas bears the potential to reduce innovative activity by as much as it is stimulated by provisions of the Bayh-Dole Act. It is conceivable that prior to the 1980s, in the pre-globalization era, restrictive immigration policies through strict implementation of Section 214(b) worked to protect the jobs of American workers and ensure higher wages for domestic graduates. However, with the rapid economic development of countries in regions such as South East Asia and with global job mobility increasing, such restrictions are likely to be self-defeating, at least in economic terms.

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Table 1. Periods of Stringent and Lenient Implementation of Section 214(b)

Year	Status of the Economy or Legislation	Enforcement
1965-1973	Hart-Cellar Act passed in 1965	Lenient
1974-1978	High unemployment	Restrictive
1979-1986	Simpson-Mazzoli legislation pending in the conference committee	Restrictive
1987-1991	Kennedy-Rodino legislation passed in 1990	Lenient
1992-1993	High unemployment	Restrictive
1994-1995	Simpson-Smith legislation	Restrictive
1996-2001	Abraham-Brownback-Cannon-Drier-Lofgren legislation on H1-B passed in 2002	Lenient

Table 2. Correlations among Variables

	IPA	IPG	UIPG	OIPG	FOR	USGR	IM	IM2	SK	RD	URD	ORD	TPS	UPS	OPS	BD	SEC

Table 3. International Students, Skilled Immigration, and Patenting Activity in the United States, 1965-2000

	IPA	IPG	IPA	IPG
CONSTANT	-4.899	-8.320	-4.995	-7.852
	(-5.93)*	(-5.58)*	(-5.34)*	(-4.09)*
FOR	0.313	0.333	0.336	0.384
	(4.24)*	(3.27)*	(4.04)*	(3.19)*
USGR	-0.377	-0.422	-0.481	-0.526
	(-0.63)	(-0.51)	(-0.57)	(-0.34)
IM	0.074	0.111		
	(4.80)*	(4.56)*		
IM2			0.111	0.135
			(3.30)*	(2.14)**
SK	0.661	0.489	0.815	0.628
	(4.14)*	(2.32)**	(4.02)*	(2.05)**

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Table 4. International Students, Skilled Immigration, and Patenting Activity in the United States, 1965-2000

	IPA	UIPG	OIPG	IPA	UIPG	OIPG
CONSTANT	-4.800 (-5.82)*	4.240 (1.38)	-6.726 (-3.92)*	-4.848 (-5.19)*	4.687 (1.30)	-5.833 (-2.87)*
FOR	0.325 (4.40)*	0.596 (2.54)**	0.399 (3.85)*	0.352 (4.25)*	0.676 (2.69)**	0.463 (3.71)*
USGR	-0.385 (-0.65)	-0.487 (-1.23)	-0.526 (-0.51)	-0.500 (-0.59)	-0.544 (-1.33)	-0.548 (-1.36)
IM	0.074 (4.79)*	0.141 (2.56)**	0.063 (2.21)**			
IM2				0.113 (3.33)*	0.153 (1.55)***	0.047 (1.60)***
SK	0.674 (4.22)*	1.537 (3.02)*	0.661 (2.72)**	0.839 (4.10)*	1.580 (2.33)**	0.654 (1.98)**
RD	0.605 (10.84)*			0.575 (9.27)*		
URD		0.595 (3.14)*			0.542 (3.03)*	
ORD			0.399 (3.85)*			0.345 (3.42)*
TOTPATSTOCK	0.138 (2.00)**			0.148 (1.95)**		
UPATSTOCK		0.659 (4.22)*	0.280 (3.32)*		0.653 (4.10)*	0.285 (3.34)*
OPATSTOCK		0.192 (1.51)***	-0.500 (-1.48)		0.261 (1.55)***	0.352 (1.51)***
BD	0.053 (1.41)	0.129 (1.58)***	0.038 (0.63)	0.088 (1.95)**	0.172 (1.53)***	0.047 (0.71)
R-Squared	0.95	0.98	0.92	0.94	0.97	0.90
DW	1.95	1.68	1.59	1.63	1.63	1.49

Notes: IPA is patent applications, while UIPG and OIPG are university patents awarded and other patents awarded, all as a percentage of labor force. FOR and USGR are foreign and U.S. graduate students as a proportion of labor force. IM is skilled immigrants as a proportion of labor force and IM2 is the cumulative number of skilled immigrants as a percentage of the labor force. SK is total PhD scientists and engineers as a proportion of labor force. RD is total real R&D expenditures as a proportion of labor force. URD and ORD are, respectively, university and non-university real R&D expenditures as a proportion of labor force. TOTPATSTOCK is cumulative patents awarded as a proportion of labor force. UPATSTOCK is cumulative patents awarded to universities as a proportion of labor force. OPATSTOCK is cumulative patents awarded to non-university institutions as a proportion of labor force. BD is the dummy variable for the Bayh-Dole act. Independent variables in the IPA equations are lagged five years and those in the UIPG and OIPG equations are lagged seven years.

Figures in parentheses are t-ratios and marked as significantly different from zero at the one-percent (*), five-percent (**) and ten-percent (***) levels.

Table 5. International Students, Skilled Immigration, and Patent Applications and Awards in the United States with Section 214(b), 1965-2001

	IPA	IPG	IPA	IPG
CONSTANT	-5.088	-7.45	-5.53	-7.83
	(-6.75)*	(-5.19)*	(-6.77)*	(-4.37)*
FOR	0.351	0.393	0.372	0.435
	(5.11)*	(4.14)*	(5.16)*	(3.98)*
USGR	-0.540	-0.424	-0.585	-0.629
	(-1.11)	(-1.27)	(-1.35)	(-0.95)
IM	0.086	0.115		
	(5.84)*	(5.14)*		
IM2			0.180	0.201
			(5.18)*	(3.30)*
SK	0.387	0.267	0.748 -22.98 ref510.6 653.16 0.48 -22.98 refB5ia-.48 -22.9	
	(3.56)*	(1.62)**		

Table 6. International Students, Skilled Immigration, Patent Applications, and University and Non-University Patent Awards in the United States with Section 214(b), 1965-2001

	IPA	UIPG	OIPG	IPA	UIPG	OIPG
CONSTANT	-5.07	3.15	-6.47	-5.51	0.259	-7.26
	(-6.73)*	(1.28)	(-4.34)*	(-6.75)*	(0.09)	(-4.06)*
FOR	0.353	0.716	0.469	0.374	0.733	0.482
	(5.13)*	(3.80)*	(4.75)*	(5.20)*	(3.61)*	(4.48)*
USGR	-0.388	-0.199	0.217	-0.589	-0.663	-0.633
	(-1.34)	(-1.10)	(-0.94)	(-1.46)	(-1.38)	(-1.48)
IM	0.086	0.218	0.093			
	(5.83)*	(4.77)*	(3.72)*			
IM2				0437 98.74	TD833 0.4D0.0035	1.14

Figure 1. Trends in Skilled Immigration and International Graduate Students in the United States, 1965-2000