Understanding STEM PhD Production: The Interplay Among Institutional Selectivity, Race/Ethnicity, and Field of Study

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Abstract: Focusing on census data of U.S. doctoral recipients during the last 10 years, we examined PhD production and undergraduate origins with a particular emphasis on institutional selectivity. Specifically, this study had three overarching goals: (1) examining STEM PhD production with an emphasis on the selectivity of doctoral programs; (2) examining the selectivity of undergraduate origins among STEM PhDs from highly selective doctoral programs; and (3) examining whether the patterns of STEM PhD production and undergraduate origins differ by race/ethnicity. This study found significantly different patterns in PhD production overall versus PhDs from top 10 doctoral programs and in the selectivity of undergraduate institutions that produce the number of PhDs overall versus PhDs from the top 10 doctoral programs. We further found that PhD production across varied selectivity of doctoral program and its association with the undergraduate origins differ significantly across different racial/ethnic groups. Implications for policy, programs, and future research are discussed.

Résumé : En nous concentrant sur les données du recensement des titulaires d'un doctorat aux États-Unis au cours des 10 dernières années, nous avons examiné la production doctorale et leur origine des programmes de premier cycle en mettant particulièrement l'accent sur la sélectivité institutionnelle. Plus précisément, cette étude avait trois objectifs primordiaux : (1) examiner la production doctorale en STEM en mettant l'accent sur la sélectivité des programmes de doctorat; (2) examiner la sélectivité à partir des programmes de premier cycle parmi les titulaires d'un doctorat en

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STEM issus de programmes de doctorat très sélectifs; et (3) examiner si les tendances de la production doctorale en STEM et leur origine des programmes de premier cycle diffèrent selon la race ou l'origine ethnique. Cette étude a révélé des tendances significativement différentes dans la production doctorale dans l'ensemble par rapport aux programmes des 10 principaux programmes de doctorat et dans la sélectivité des établissements de premier cycle qui produisent le nombre de doctorants dans l'ensemble par rapport aux doctorats des 10 principaux programmes de doctorat. Nous avons également constaté que la production de doctorants dans le cas d'une sélectivité variée du programme de doctorat et son association avec leur provenance des programmes du premier cycle diffèrent considérablement d'un groupe racial ou ethnique à l'autre. Les implications pour les politiques, les programmes, et la recherche future sont abordés.

In the 21st century knowledge economy, the U.S. strives to maintain its long-standing leadership and competitiveness in the advancement of knowledge and technology by placing heavy emphasis on STEM doctoral education. Reflecting such interests and efforts, 65% of recent doctoral graduates in the U.S. are from STEM-related fields (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). There are also significant increases in the number of doctoral degrees awarded across different racial/ethnic groups. Between 2000 and 2015, the number of doctoral degrees awarded for Hispanic or Latino/a students increased from 775 to 1,244—a 160% increase—and for Black and African-American students, from 821 to 1,855—a 126% increase (NASEM, 2018). The large increase rates in PhD production among Hispanic/Latino and Black/African-American students are artifacts, primarily due to the minimal number of doctoral degrees awarded in 2000. In 2018, merely 6% and 5% of all STEM doctoral degrees among U.S. citizens and permanent residents were awarded to Hispanic/Latino and Black/African Americans, respectively (National Science Foundation [NSF], 2020b).

In an effort to understand STEM PhD production, it is important to consider different characteristics (e.g., prestige or selectivity) of doctoral programs. This consideration is important because not all PhDs enjoy the same exchange value regarding career outcomes. The majority of tenure track faculty members were

trained in a limited set of prestigious departments in their respective fields (Katz et al., 2011). Furthermore, faculty members from prestigious doctoral programs tend to publish at higher rates, particularly in well-respected journals (Saunders et al., 2016), suggesting that the characteristics of doctoral programs, particularly prestige, continue to play a role, not only in terms of securing faculty positions but also in professional productivity measures. The effect of institutional characteristics on career outcomes is not limited to academic careers but extends to non-academic career outcomes as well (Jackson & Michelson, 2015). The distinct career outcomes among PhDs based on their institutional characteristics, are believed to be associated with available resources and social status which vary substantially by college and university (Weisbrod, 2009).

Nevertheless, little work has examined STEM PhD production by the characteristics of doctoral programs. Freeman et al.,(2007) showed that while more individuals are graduating with a PhD in engineering than in previous decades, most of this growth is being driven by less prestigious universities; research extensive institutions have produced a relatively steady number of PhDs, while added doctoral recipients tend to come from smaller, less research-focused universities. Although there were significant increases in racial/ethnic diversity of STEM PhD recipients during the recent decades, a large proportion of minority students received their doctorates from a relatively small number of universities (Freeman et al., 2007; Hoffer et al., 2007; NSF, 2020a). Therefore, it is crucial to understand the patterns of PhD production, not only in term of quantity of the doctoral degrees but also in terms of quality indicators (e.g., selectivity of doctoral program) and the extent to which the increases in PhD production, especially among those from underrepresented racial/ethnic backgrounds in STEM, are translated into the PhD production from more desired, highly selective doctoral programs.

Demonstrating the link between the selectivity of undergraduate and doctoral institutions, Zhang (2005) found that those who earned their bachelor's degrees from high-quality institutions, according to Barron's undergraduate ratings, were more likely to earn their doctoral degrees from research universities than their counterparts from middle- and low-quality institutions. With this, Zhang argued that the quality of the undergraduate institution is likely to determine the quality of the following

educational institution, suggesting "the academically 'rich' become richer while the academically 'poor' become poorer despite the massive expansion of higher education in the United States" (p. 336). Given that White students are more likely to attend selective undergraduate institutions than Black and Hispanic counterparts (e.g., Karen, 2002), and that the White-Black gaps in the selectivity of undergraduate institutions students attended have actually increased over time (Baker et al., 2018), we speculate that Black and Hispanic students might be still falling behind their White counterparts in terms of receiving their doctoral degrees from highly selective doctoral programs.

In this study, we have three overarching goals: (1) examining STEM PhD production with an emphasis on the selectivity of doctoral programs; (2) examining the selectivity of undergraduate origins among STEM PhDs from highly selective doctoral programs; and (3) examining whether the patterns of STEM PhD production and undergraduate origins differ by race/ethnicity. Guided by these goals, we examine (in)equality of PhD production across varied selectivity of doctoral program, its association with the undergraduate origins across different selectivity of undergraduate institutions, and the racial/ethnic differences within the same fields of study in STEM. Our specific research questions are as follows:

(1) What are the patterns of PhD production—in terms of the number of PhDs produced overall versus the number of PhDs produced from highly selective doctoral programs? Do the patterns differ across different fields of study in STEM?
(2) What are the relationships between the selectivity of undergraduate origins among PhDs overall versus PhDs from highly selective doctoral programs?
(3) What are the equality indicators (i.e., Gini coefficients and Lorenz curves) in PhD production—overall PhD production versus PhD production from highly selective doctoral programs—across different selectivity levels of undergraduate institutions?
(4) Are the PhD production and its association with undergraduate origins among STEM PhDs different by their race/ethnicity?

Conceptual Framework

With our basic assumption that not all doctoral degrees are valued equally in PhD career outcomes, we draw on the theory of effectively maintained inequality (EMI) which attends to the quality of educational opportunities as well as the quantity of these opportunities, or the rate of transition (e.g., from college to graduate school). Developed from a study of college access in the United States (Lucas, 2001, 2009), EMI holds that even when a particular level of education is more or less universal (primary and secondary education, for instance), socially advantaged families will secure educational opportunities and credentials that have better social returns. EMI theory suggests that, even if the odds of earning a PhD were equal for all students, socially advantaged students (e.g., graduates from highly selective undergraduate institutions) would seek to secure their positions in highly selective doctoral programs that would likely give their graduates better career outcomes after doctoral degree. Thus, the social inequality continues. In this study, we pay particular attention to examining whether the seemingly significant growth rates of doctoral degrees granted for African-American and Hispanic students are translated into increased doctoral attainment from preferred—highly ranked—doctoral programs.

From a different angle, the field of doctoral study also plays an important role in career outcome, including in annual income and career prestige (Burris, 2004; Hevenstone, 2008). For example, a recent study found that upon graduation, engineering PhD recipients earn on average approximately 58% more than education PhD recipients (Zolas et al., 2015). Using EMI as a theoretical lens, this study is able to uncover the extent to which equality indicators (e.g., the ratio of PhDs from highly selective doctoral programs to all PhDs produced) vary by the selectivity of undergraduate institutions across different fields of study.

Literature Review

In prior studies examining undergraduate origins of doctorate recipients, researchers have found a strong connection between undergraduate institutional prestige/selectivity and the likelihood of continuing on to graduate study (Wolf-Wendel, 1998; Xu, 2014; Zhang, 2005). Several of these studies showed that attending a more selective undergraduate institution increased the likelihood of being

admitted to a more prestigious doctoral program (Eide et al., 1998; Zhang, 2005). Posselt (2018) argued that doctoral admissions committees often used undergraduate prestige as a way to evaluate applicants due to a lack of other measures that predict the success of doctoral students. The committees see that achieving a high GPA from an elite school was a better indicator of future success in doctoral programs than the same GPA from a less well-known school.

This connection between prestige and future graduate study is particularly alarming given that significant disparities exist in the likelihood of attending highly selective, prestigious undergraduate universities by race/ethnicity. Minority students are far less likely to attend prestigious universities than their White counterparts and these trends have worsened over time (Posselt et al., 2012; Reardon et al., 2012). Furthermore, even when minority students attend prestigious undergraduate programs, they are less likely to complete their degrees (Griffith, 2010). These findings suggest that if undergraduate prestige is a strong predictor of doctoral study and attainment, then students from racial and ethnic minority backgrounds are at a disadvantage as they move from undergraduate to doctoral programs, particularly for the most coveted, selective doctoral programs.

Solorzano (1995) conducted an early study on the doctoral pathways of African American STEM graduates. He found that these students frequently received both their Bachelor's and PhDs from HBCUs, underscoring the importance of such institutions in addressing STEM inequalities (Upton & Tanenbaum, 2014). Over the last several decades, multiple studies have reinforced his findings, noting that the relationship is particularly strong for African American women who received PhDs (Joseph, 2013; Leggon & Pearson, 1997; Sharpe & Swinton, 2012). While no similar studies exist examining Latina/o pathways to STEM PhDs, Fernandez et al. (2020) find that overall STEM PhD achievement has decreased for Latinas as a whole since the 1970s. These gaps in the literature make our research particularly important to understanding how STEM students, particularly of different racial/ethnic groups, move through undergraduate and doctoral programs.

Research Methods

Data

To examine PhD production patterns and undergraduate origins among PhDs with a particular emphasis on the selectivity of doctoral programs and that of undergraduate institutions, we analyzed the Survey of Earned Doctorates (SED) data, sponsored by the National Science Foundation (NSF). The SED provides census data on all doctoral graduates in the United States. For this study, we focused on PhDs who received their doctoral degrees during the most recent decade for which the restricted data are available—PhD fiscal years from 2004 to 2013. Given that the selectivity of the undergraduate institutions is crucial information in our study, the data are limited to those who are either U.S. citizens or permanent residents and who earned their bachelor's degrees from U.S. higher education institutions.

As an indicator of institutional selectivity/prestige of doctoral programs, we used the U.S. News & World Report Best Graduate Schools (USN&W) rankings on broadly defined majors for which the U.S. News & World Report regularly publishes its rankings: Biological Sciences, Engineering, Computer Science, and Mathematics. Based on rankings during the most recent 10-year time frame between 2008 and 2017, we identified ten doctoral programs that were ranked in the top 10 most frequently during that time period. This measure has been used often in prior research as an indicator of quality doctoral programs and an elite group in the field (Morphew & Swanson, 2011).

For undergraduate institutions, we used Barron's Admissions Competitiveness Index, collected by the National Center for Education Statistics (NCES), grouping undergraduate institutions into four categories—very selective, selective, somewhat selective, and non-selective—as used in prior literature (e.g., Roderick et al., 2011; Vogel et al., 1998). Barron's index is calculated based on the SAT scores of admitted students, the GPA and class rank required for admission, and percentage of applicants accepted and has been widely used in prior studies examining institutional selectivity.

Data Analysis

The primary focus of this study is to understand patterns of PhD production and undergraduate origins among PhDs, not necessarily establishing causal relationships between the characteristics of

undergraduate and that of doctoral programs. Therefore, we conducted a series of descriptive analyses. Descriptive data analysis is recommended for projects which explore understudied topics, particularly with large datasets that are being used in novel ways (Loeb et al., 2017). The SED data in the study are technically census data, thus conducting inferential statistical analysis is not necessary. We also examined whether the production of PhDs from highly ranked programs is proportional to the total number of PhDs produced across undergraduate institutions of different selectivity levels. The Gini coefficient, a standard and commonly used measure of inequality is calculated. Lorenz curves showing the fraction of all PhDs produced as a function of producing institutions are presented in the finding section.

Limitations of the Study

It is worth noting that this study focuses on institutional level discussion—PhD production and undergraduate origins among STEM PhDs—rather than individual PhDs' specific education, education paths, or personal experiences that lead to doctorate receipt. Therefore, while this study is able to provide overarching macro ideas of PhD production and undergraduate origins with a particular emphasis on the differences by race/ethnicity, it provides little information on the specific education paths that individuals experience from undergraduate to doctoral education. It is, therefore, important to recognize what or how individual students—particularly those who are from underrepresented racial/ethnic groups in STEM fields—experience their undergraduate and doctoral education, which has significant implication for PhD production and its association with undergraduate origins. Prior literature that discusses structural racism, White supremacy, and racial microaggression that Black and Latino students experience in STEM fields (e.g., Alexander & Hermann, 2015; Burt et al., 2018; McGee, 2020) should offer a complementary understanding of the PhD production in STEM fields.

Another limitation is related to the measurement of institutional selectivity or ranking. While it is practically impossible to consider specific programs and their rankings in the study (i.e., no comprehensive information on specific, narrowly defined program rankings at the doctoral level is available), it is worth noting that the broadly defined rankings of graduate fields of study may not reflect

significant differences in the selectivity of program/specific majors within the broad fields of study.

Findings

PhDs Production Overall Versus That from the Top 10 Doctoral Programs

Figure 1 presents the patterns of PhD production overall versus PhD production from top 10 doctoral programs across different fields of study. Significantly different patterns of the total numbers of PhD production were found across different fields of study, ranging from fewer than 10,000 doctoral degrees in computer sciences and mathematics (5,373 and 6,024, respectively), to more than 45,000 doctoral degrees produced in biological sciences over the 10-year period. More interestingly, clearly distinct patterns in the proportion of PhDs from top 10 doctoral programs were found by field of study (see Table 1). In engineering and computer sciences, about a quarter (27% and 25%, respectively) of doctoral degrees were awarded from the top 10 doctoral programs as compared to mathematics and biological sciences where less than 15% of doctoral degrees were from the most selective doctoral programs. This finding suggests that even among the STEM fields, engineering and computer sciences present different patterns in doctoral degree production from biological sciences and mathematics.

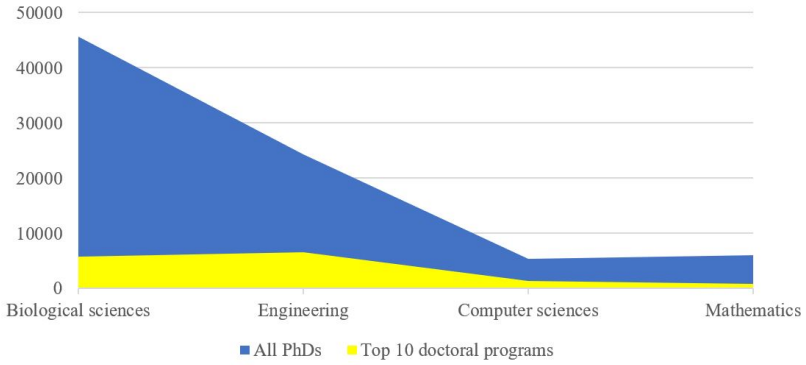

Figure 1. PhD production: Overall versus top 10 doctoral programs (2004-2013)

Table 1. PhD Production Overall Versus Top 10 Doctoral Programs (2004-2013)

	Biological sciences	Engineering	Computer sciences	Mathematics
# of PhDs	45,635	24,336	5,374	6,024
# of PhDs from top 10 programs	5,698	6,591	1,318	867
PhDs from top 10 / all PhDs	12.5%	27%	25%	14.4%

Table 2 presents % distribution of the selectivity of undergraduate origins among PhDs in general versus PhDs from the top 10 doctoral programs. Among all PhDs, roughly one-third were graduates of very selective undergraduate institutions, ranging from 35% in biological sciences to 43% in computer science. Graduates of selective or somewhat selective undergraduate institutions constituted another 50% of PhDs, suggesting about 90% of PhDs across all STEM fields were graduates from very selective, selective, and somewhat selective undergraduate institutions, leaving only about 10% of PhDs who were graduates of nonselective undergraduate institutions.

Rather a different picture emerged in PhD production from top 10 doctoral programs (Table 2). The share of PhDs from top 10 doctoral programs who were graduates of very selective undergraduate institutions ranged from 58% in engineering to 74% in mathematics, indicating heavily skewed distribution of PhDs from

highly ranked programs coming from very selective undergraduate institutions. Instead, the important roles that somewhat selective and nonselective undergraduate institutions play in producing PhDs overall diminish significantly when it comes to producing PhDs from highly selective doctoral programs. For instance, while graduates from somewhat selective undergraduate institutions constituted about 25% in computer sciences to 28% in biological science PhDs in general, they represent only 9% in mathematics and 16% in engineering PhDs from top 10 doctoral programs. Even worse, nonselective undergraduate institutions played a minimal role in producing PhDs from highly ranked programs, representing merely 2 to 4% of PhDs from top 10 programs in STEM. This finding indicates strong ties between undergraduate and doctoral programs, leaving little chance for those from less selective or nonselective undergraduate institutions to receive doctoral degrees from highly selective doctoral programs.

Table 2

% Distribution of Undergraduate Origins Among PhDs and PhDs from Top 10 Doctoral Programs: By the Selectivity of Undergraduate Institutions

	Selectivity of BA inst.	Biological sciences	Engineering	Computer sciences	Mathematics
All PhDs	Very selective	35.2%	38.3%	42.5%	39.2%
	Selective	27.4%	28.9%	24.7%	23.4%
	Somewhat selective	28.1%	25.5%	24.3%	27.5%
	Nonselective	9.3%	7.3%	8.6%	9.8%
	χ^2 (*df* =9)		315.82***		
PhDs from top 10	Very selective	64.3%	57.7%	69.8%	74.2%
	Selective	20.3%	22.5%	17.1%	15.1%
	Somewhat selective	12.3%	16.1%	11.0%	8.8%
	Nonselective	3.1%	3.7%	2.1%	1.9%
	χ^2 (*df* =9)		162.34***		

*** = p < .001

Figure 2 presents Gini coefficients based on Lorenz Curves for the distribution of PhD production versus PhD production from the top 10 doctoral programs across levels of selectivity of undergraduate institution. The Gini coefficient ranged from .37 in mathematics to

.46 in biological sciences for overall PhD production (Gini coefficient ranges from 0, perfect equality to 1, perfect inequality). First, there are nearly no differences in Gini coefficients for PhD production versus PhD production from highly ranked doctoral programs in computer sciences (.41 versus .40) and mathematics (.37 versus .38), indicating PhD production patterns across different levels of selectivity of undergraduate institution are similar for PhD production in general versus PhD production from top 10 programs.

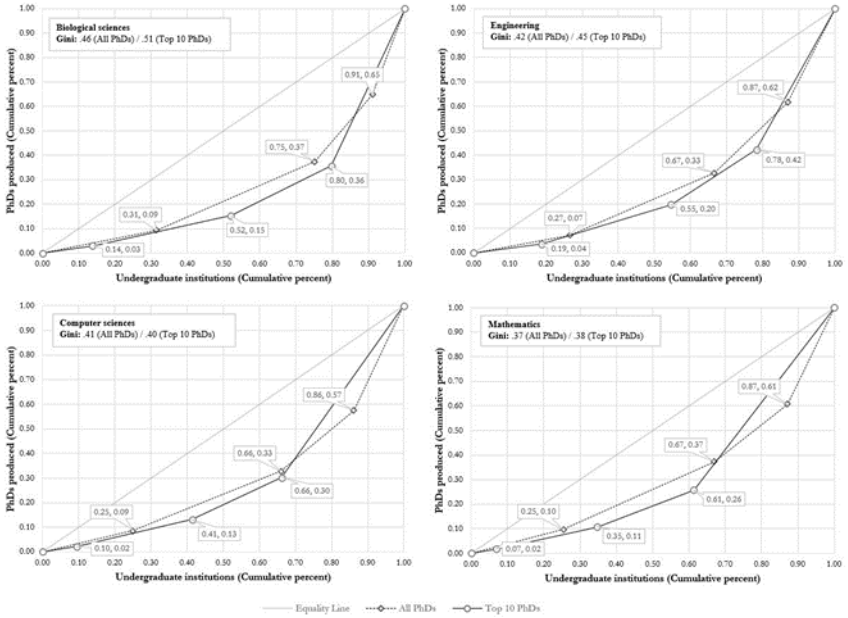

Figure 2. Gini coefficients and Lorenz Curves for the distribution of PhD production

On the other hand, slight increases in Gini coefficients from PhD production in general to PhD production from top ranked programs were found in biological sciences (.46 versus .51) and engineering (.42 versus .45). This suggests that there are increased inequalities in PhD production across different levels of selectivity of undergraduate institutions when it comes to PhDs from top 10 programs.

Examining the Lorenz Curves suggests more detailed stories of inequality in PhD production: In biological sciences, for instance, among the undergraduate institutions that produced at least one PhD,

about 10% were very selective institutions. However, these institutions produced 35% of PhDs in biological sciences (.91, .65). On the other hand, 64% and 58% of PhDs from the top 10 doctoral programs in biological sciences and engineering, respectively, were produced from the very selective undergraduate institutions that represent about 20% of undergraduate institutions (.80, .36 for biological sciences and .78, .42 for engineering) that produced at least one PhD from selective doctoral programs.

In sum, while inequitable distributions were found in all STEM PhD production across different levels of selectivity of undergraduate institution, the selectivity of undergraduate institutions became more important in PhD production by the top 10 doctoral programs than PhD production in general.

PhD Production and Undergraduate Origins by Race/Ethnicity

Table 3 presents the proportional representations of PhDs from top 10 doctoral programs by race/ethnicity. Among Asian PhDs in all STEM fields, ranging from 23% in biological science to 40% in computer science were from the top 10 doctoral programs. This representation was the greatest among all racial/ethnic groups. On the other hand, among African American PhDs, less than 10% in either biological science or mathematics received their doctorates from the top 10 doctoral programs. In general, Hispanic PhDs reported a greater representation among the PhDs from top 10 doctoral programs than African American PhDs in the same fields of study. This finding clearly suggests significant disparities in proportional representation of PhDs from highly selective doctoral programs (versus PhDs in general) by racial/ethnic groups, which may have significant implications for future career outcomes by racial/ethnic groups.

Table 3. Total Number of PhDs and % of PhDs from Top 10 PhD Programs: By Race/ethnicity

PhD Field	Asian/Pacific Islander	African American	Hispanic	White	Multiple & others	χ^2 (df=4)
Biological sciences	4,219 (23.30%)	1,813 (8.83%)	2,548 (13.38%)	35,579 (11.23%)	1,476 (14.77%)	533.88***
Engineering	2,732 (39.60%)	1,017 (25.37%)	1,177 (25.83%)	18,595 (25.17%)	815 (32.64%)	266.43***
Computer sciences	543 (39.96%)	217 (12.44%)	144 (20.83%)	4,261 (23.28%)	209 (24.88%)	91.67***
Mathematics	421 (27.08%)	163 (8.59%)	248 (11.69%)	5,013 (13.46%)	179 (19.55%)	68.28***

*** = $p < .001$

Note. % in parenthesis represents those who received their doctoral degrees from the top 10 doctoral programs out of all PhDs in the same field of study

Table 4 presents percentage distribution of PhDs who received their doctoral degrees from top 10 doctoral programs across different levels of selectivity of undergraduate institution and whether there are distinctively different patterns by race/ethnicity. For instance, of the biological science Asian PhDs from the top 10 doctoral programs, nearly 83% are graduates from highly selectivity undergraduate institutions, indicating a tight connection between the selectivity of undergraduate institution and that of doctoral program. The tightly connected education pathways are consistent across all fields of study, ranging from 77% in engineering (i.e., 77% of Asian engineering PhDs from top 10 doctoral programs are graduates of highly selective undergraduate institutions) to 90% in mathematics. In other words, only 10% of Asian PhDs in mathematics from the top 10 programs are graduates from undergraduate institutions that are not highly selective. This finding suggests that unless Asian PhDs graduated from highly selective undergraduate institutions, particularly those in mathematics, their chance of getting a doctoral degree from highly selective doctoral programs is rather slim.

The tight connection between the selectivity of undergraduate institution and that of doctoral program is much less noticeable among non-Asian PhDs, especially among African American or Hispanic PhDs. Among African American PhDs from top 10 doctoral programs, the proportion who are graduates of highly selective undergraduate institutions ranges from 43% in mathematics or engineering to 52% in computer science. It is particularly worth noting that relatively large percentages of African American PhDs from top ranked doctoral programs are graduates of somewhat selective undergraduate institutions, significantly greater percentages than Asian PhDs in the same fields of study. For both Hispanic and African American PhD production, it is certainly worth emphasizing that selective and somewhat selective undergraduate institutions play an important role in producing PhDs from highly selective doctoral programs—indicating relatively less dominant roles played by the highly selective undergraduate institutions compared to Asian or White PhDs, among the PhDs from highly selective doctoral programs.

Table 4. Undergraduate Origins of PhDs who Received Their Doctoral Degrees from Top 10 PhD Programs

PhD Field	Barron's Index of BA inst.	Asian/ Pacific Islander	African American	Hispanic	White	Multiple & others
Biological sciences	Very selective	82.91%	44.38%	48.39%	61.76%	67.43%
	Selective	10.78%	19.38%	27.86%	22.12%	17.89%
	Somewhat selective	4.98%	21.88%	17.60%	13.49%	9.17%
	Nonselective	1.32%	14.38%	6.16%	2.63%	5.50%
	N (%)	983 (17.25%)	160 (2.81%)	341 (5.98%)	3,996 (70.13%)	218 (3.83%)
	χ^2 (*df* =12)			304.11***		
Engineering	Very selective	77.08%	42.64%	49.01%	54.65%	57.14%
	Selective	15.53%	18.22%	29.28%	23.69%	25.94%
	Somewhat selective	6.56%	24.42%	15.79%	18.14%	11.28%
	Nonselective	0.83%	14.73%	5.92%	3.52%	5.64%
	N (%)	1,082 (16.42%)	258 (3.91%)	304 (4.61%)	4,681 (71.02%)	266 (4.04%)
	χ^2 (*df* =12)			331.83***		
Computer sciences	Very selective	80.18%	51.85%	66.67%	68.15%	69.23%
	Selective	12.90%	22.22%	13.33%	18.15%	13.46%
	Somewhat selective	5.53%	18.52%	16.67%	11.69%	13.46%
	Nonselective	1.38%	7.41%	3.33%	2.02%	3.85%
	N (%)	217 (16.46%)	27 (2.05%)	30 (2.28%)	992 (75.27%)	52 (3.95%)
	χ^2 (*df* =12)			22.95*		
Mathematics	Very selective	90.35%	42.86%	48.28%	73.04%	77.14%
	Selective	5.26%	7.14%	34.48%	16.15%	14.29%
	Somewhat selective	3.51%	42.86%	17.24%	8.74%	8.57%
	Nonselective	0.88%	7.14%	0.00%	2.07%	0.00%
	N (%)	114 (13.15%)	14 (1.61%)	29 (3.34%)	675 (77.85%)	35 (4.04%)
	χ^2 (*df* =12)			52.54***		

* = $p \leq 0.05$, *** = $p < .001$

Discussion

Focusing on census data of U.S. doctoral recipients during the last 10 years, this study examined PhD production and undergraduate origins with a particular emphasis on institutional selectivity. As students move between undergraduate and doctoral programs, multiple and interrelated forces influence their institutional mobility. At the individual level, students must want to continue their education and ultimately receive doctoral degrees. Pursuing (and completing) doctoral degrees demands significant financial, emotional, and social commitments, in addition to the opportunity costs that individuals take into consideration given the future labor market for PhDs and other higher-level occupations (Freeman et al.,

2007). At the institutional level, the characteristics of both undergraduate and doctoral institutions are closely interrelated: As feeder institutions, the prestige or selectivity of undergraduate institutions is known to influence the prestige or selectivity of doctoral programs, with the two being tightly connected. As for doctoral institutions, the admissions committee holds particular power to conduct insider assessments of undergraduate program prestige, measuring the quality of undergraduate education in terms of teaching, the general quality of graduates of various undergraduate institutions, and providing different weights to GPAs from different undergraduate institutions or specific course work (Posselt, 2014). In this process, graduate admissions committees may, intentionally or not, reinforce the hierarchical structure of institutional selectivity and prestige by placing more weight on graduates from highly selective undergraduate institutions than from less selective institutions.

In this study, we found distinctively different patterns in PhD production overall versus PhDs from top 10 doctoral programs across different fields of study. Going one step further, we found significant inequality in the selectivity of undergraduate institutions that produce the number of PhDs overall versus PhDs from top 10 doctoral programs. These findings suggest that operating under the current understanding of PhD production without taking a close look at where students receive their doctoral degrees may produce misleading findings. Not all doctoral degrees are equally appreciated and valued in career outcomes, continuing productivity, and social prestige. Unless one starts at a selective undergraduate institution, the likelihood of attaining a doctoral degree from a highly selective doctoral program is rather slim.

The tight connection between the selectivity of undergraduate institutions and that of doctoral programs, however, differs by race/ethnicity and across different fields of study. For example, African Americans were less likely to complete their PhDs at highly ranked doctoral programs, although this trend varied depending on the field of study. Many future PhDs tended to complete their degrees at highly selective universities—although for African American or Hispanic groups, selective or somewhat selective undergraduate institutions produced large segments of

PhDs from top 10 doctoral programs. This might be associated with the primary role that Minority Serving Institutions (MSIs) play in providing quality undergraduate education, which in turn influence their graduates' relative success in terms of attending highly selective doctoral programs (Gasman & Conrad, 2013; Jackson & Rudin, 2019). The crucial role that MSIs have played in educating students, particularly from under-represented racial/ethnic backgrounds is well documented (Gasman et al., 2015; Li, 2007). With the findings that corroborate the importance of MSIs in American higher education, this study suggests that government policy makers should provide strong supports for these institutions and widely publicize the value of these institutions in providing equitable outcomes of both undergraduate and graduate education.

While it is true that Asian PhDs are much more likely to receive their doctoral degree from top 10 programs than other racial/ethnic groups, the tight connection between the selectivity of undergraduate programs and that of doctoral programs among Asian PhDs ironically suggests that unless Asian students graduate from highly selective undergraduate institutions, they have very little chance of attaining their doctoral degrees from highly selective doctoral programs. For Asian students, the connection between undergraduate and doctoral program acts more as an education pipeline—if one cannot enter the pipeline from the beginning, they are not likely to be able to enter it later, "a sole path" to a doctoral degree with one inlet, one outlet, and one direction of flow (Cannady, Greenwald, & Harris, 2014, p. 445). On the other hand, of the African American or Hispanic PhDs from top 10 doctoral programs, relatively large percentages graduated from selective or somewhat selective undergraduate institutions, presenting the possibility of attaining a doctoral degree from a highly selective program even if one attended a less selective undergraduate institution. For this group of students, there is more room to move around between levels of selectivity of undergraduate programs and that of doctoral programs, although considerable differences remain between African American and Hispanic students and White students. Nevertheless, the significance of undergraduate institutions' selectivity in PhD production cannot be overemphasized. Institutional stratification by the selectivity of undergraduate and doctoral institutions is real and

continues to influence the inequality of PhD production by race/ethnicity.

Given that future faculty members tend to be trained in highly selective, research oriented doctoral programs, our discussion is important for emphasizing a continuing waterfall effect of the selectivity of undergraduate institutions, suggesting possible ways to broadening faculty diversity—not just focusing on doctoral program diversity but more on the entry point of education pathways, undergraduate institutions and their pathways to the selectivity of doctoral programs. This consideration is particularly important for those who are from underrepresented racial/ethnic backgrounds and who are less like to attend selective undergraduate institutions. With the findings that show the crucial roles undergraduate institutions play in education mobility to doctoral education, this study supports EMI theory that suggests educationally advantaged students (e.g., students from highly selective undergraduate institutions) continue to secure advanced positions by attending highly selective doctoral programs. Therefore, this study suggests today's higher education policies—those mainly focused on access to undergraduate education—should reconsider how they approach "education opportunity to higher education," given the unequal distribution of undergraduate attendance across different types of institutions (largely due to the stratified system of higher education), particularly for students from under-represented racial/ethnic backgrounds in STEM fields. With this, it is possible to expand the definition of education opportunity that takes into account which undergraduate and doctoral institutions one attends, moving beyond whether one attends higher education.

Implications for Future Research

The fact that Hispanic and African American students display different patterns than White and Asian students in PhD production from highly selective doctoral programs implies that the gains these groups have made in Ph.D. attainment, in terms of the number of doctoral degrees attained, may not be as significant as we would hope (Anderson & Kim, 2006). Given that they were more likely to receive doctoral degrees from institutions that are not as

highly valued in the higher education landscape, it is reasonable to speculate that they may continue to struggle to gain employment (desired or preferred) and recognition.

Noting that the inequalities in PhD production by the selectivity of doctoral programs are closely associated with the undergraduate institutions that doctoral graduates attended, it is important to emphasize the college experiences that lead to continuing education opportunities. By so doing, future research will be able to identify specific programs, advising practices, or mentorship initiatives that lead to students' successful movement toward doctoral degrees, particularly toward highly selective programs. With this emphasis, future research will contribute to fruitful and practical suggestions for higher education policy-makers and administrators.

In this study, we focused on fields of study in which PhDs received their doctoral degrees, assuming that they stayed in the same major from undergraduate to doctoral education. However, there are sizable numbers of PhDs who have changed their major on their doctorate pursuit and these numbers vary significantly by field of study. Therefore, in future studies, it might be useful to examine PhD production among those who changed their majors in their pursuit of advanced degrees.

The same holds true for students who may receive other graduate degrees, such as a master's, before continuing on to doctoral study. As with doctoral degree attainment, more and more underrepresented students are receiving their master's degrees (Musu-Gillette et al., 2017). However, overall master's attainment is still significantly lower for students from underrepresented backgrounds: 7.1% for African American students and 3.9% for Hispanic students compared to 10.5% for White students (American Council on Education, 2017). Furthermore, there is some evidence that degree attainment varies significantly by field, particularly in STEM fields (Musu-Gillette et al., 2017). Given the significant number of students who received their master's degrees, and differences in master's attainment by race and ethnicity, future research needs to examine degree production at the master's level, which may reveal inequalities similar to those we have described in this study.

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