Methods for Measuring Vertical Gender Segregation at Colleges and Universities:

The Value of Treating Departments as Neighborhoods

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Abstract

Colleges and universities are workplaces where men occupy more prestigious and better paying positions than women. This vertical gender segregation reduces women's access to resources and connections which, in turn, impacts their ability to earn tenure and promotion. In working toward the creation of a more equitable work environment, administrators in higher education institutions must be able to evaluate vertical segregation simply and thoroughly. We propose that viewing departments as neighborhoods will allow administrators and researchers to apply techniques for measuring residential segregation to evaluate vertical gender segregation. In this paper, we demonstrate how four dimensions of residential segregation—evenness, exposure, concentration, and proportionality—can be calculated for evaluating vertical gender diversity in higher education and argue that administrators armed with these kinds of information can better evaluate how their institution and individual departments are fairing over time, in comparison to peer and aspirational peer institutions, and in relationship to the larger academic labor market.

Keywords: segregation, gender diversity, higher education, evenness, exposure, concentration

Vertical gender segregation—the tendency of men to occupy more prestigious and better paying positions than women (Charles and Grusky 2004; Jacobs 1989; Reskin and Roos 1990)—negatively impacts work experiences and renumeration for women. Vertical gender segregation at colleges and universities that sort men in the professorate into higher prestige departments than women reduces women's access to resources and connections which, in turn, impacts their ability to earn tenure and promotion (Misra, Kennelly, and Karides 1999; Probert 2005; Weisshaar 2017). The problem of vertical segregation is also cumulative as it begins lower in the pipeline: departments with healthier gender balances attract more diverse pools of graduate students, while those that continue to be male-dominated have gradute student cohorts that are mostly comprised of men (Hale and Regev 2014; Moss-Racusin et al. 2012). Most university administrators are aware of the problem (see Shaw and Stanton 2012), and many universities have implemented programs that attempt to attract more women to their science, technology, engineering, and mathematics (STEM) departments (Xu 2008) as well as to other fields where women are traditionally underrepresented, like accounting, philosophy, and economics (Bayer and Rouse 2016).

Of course, eliminating vertical segregation among the professorate may be impossible when problems begin at the level of training (Carrell, Page and West 2010). Although women's representation in fields like biology is increasing (Yost, Winstead, Cotton, and Handley 2013), their representation in computer science has been decreasing over time (Ramsey and McCorduck 2005; Michell et al. 2017). Additionally, as more women enter the STEM professions, many are opting for positions in industry rather than jobs in education, reducing the size of the pool of women that colleges and universities can hire (Stewart, Malley, and LaVaque-Manty 2007; Valian 1999; Zumeta and Raveling 2002; Piatek-Jimenez 2005). Thus, when departments are not diverse, they often argue that their pools of candidates applying for positions are not diverse (see Shultz 2018). This may be true, but it may also reflect a lack of commitment to diversity (Bystydzienski et al. 2017). Thus, college and university administrators need to develop a range of methods for tracking how their departments are doing over time and relative to the overall field-specific academic labor market in order to determine which departments need extra attention.

An examination of basic college and university diversity statistics—percentages of the faculty comprised of women versus men on campus—has some value, but this value is limited and often masks vertical gender segregation. A university whose faculty are comprised of 50 percent women may still see women segregated in women-dominated departments (like Library Sciences) while men dominate the Business School and Engineering departments where positions are better renumerated (Li and Koedel 2017). Even when these statistics are reported by field, the information is not much more illuminating. If 16 percent of the Biology faculty are women, is that because the Biology Department has done a poor job of recruiting and retaining women on faculty, or is it indicative of the larger labor market from which the department could select new faculty members? It is also difficult to determine from basic percentages if improvements over time reflect real institutional progress—real improvements to the work environment, better recruiting and retention techniques, and stronger leadership—or if they reflect larger, systemic changes such as changes in the stream of women into particular types of institutions and fields.

We assert in this paper that calculating relatively simple indices of segregation using data that colleges and universities already collect will provide administrators more in-depth information about progress across time, institutions, and fields, particularly with regard to issues such as vertical segregation. Using algorithms already developed and commonly employed to study neighborhood segregation at the metropolitan level and applying those alogrithms to college and university settings will allow for a greater understanding of gender diversity and change among the professorate. In this paper, we demonstrate methods for examining *evenness*, *exposure*, *concentraton,* and *field proportionality* using data from the University of Tennessee-Knoxville (UTK). These same techniques can be implemented at other institutions relatively easily and can be adapted for use in measuring other types of diversity, such as racial inclusion. Our methods in this paper are neither novel nor complex; we argue that the simplicity of our idea and the basic measures used make these especially valuable tools for developing and implementing better university diversity metrics.

Residential Segregation and Its Applications

Sociologists and geographers have long grappled with understanding the degree to which people of color live apart from whites in segregated neighborhoods and whether neighborhoods are becoming more integrated or separated over time (e.g., Massey 1985; Iceland, Weinberg, and Steinmetz 2002; Crowder and Krysan 2016). In their quest for understanding, social scientists developed (and continue to develop) myriad methods for measuring neighborhood diversity. In fact, there are so many methods that, thirty years ago, Massey and Denton (1988) examined commonly used measures of residential segregation to conclude that twenty-five indices represented five distinct dimensions of segregation: evenness, exposure, concentration, centralization, and clustering.

In the study of neighborhood racial segregation, *evenness* is the degree to which people of one race are clustered in same-race neighborhoods while people of another race are clustered in other neighborhoods. *Exposure* is the degree to which a person of one race is likely to encounter a resident of their race or another race in their neighborhood. *Concentration* is the degree to which neighborhoods largely occupied by people of color consume the same amount of physical space as white neighborhoods. *Centralization* is the degree to which people of color are concentrated in the inner city. *Clustering* is the degree to which neighborhoods of color are adjacent to each other.

We argue that it is instructive to think of college and university departments as neighborhoods and, when conceptualized this way, four of the five dimensions of segregation (evenness, exposure, concentration, and clustering) can be usefully applied in conceptualizing gender diversity in universities, especially in regard to vertical segregation. In this paper, we examine evenness, two ways to evaluate exposure, an adaptation of concentration, and a measure that lies outside of Massey and Denton's five dimensions: field proportationality.

Of the five dimensions of diversity, we will exclude clustering because the methods of examining it require more complex spatial techniques, and we wanted to limit our analysis to methods that could be easily implemented by anyone. However, we assert that it is worth studying if women are clustered on campus in systematic ways other than the departmental structure. For instance, we wonder if the tendency to cluster types of departments together in buildings (e.g., Humanitities Buildings) or in sections of the campus (e.g, Agriculture Campuses) limits meaningful interactions between students and faculty of different genders.

Beyond the five concepts operationalized by Denton and Massey, we also argue that another dimension—one we call *field proportionality*—is useful for comparing departments to their fields. What we are calling field proportionality is a measure of the degree to which a department's gender balance is reflective of the academic job market in that field. We derive this measure from the location quotient, which is another measure of residential diversity employed by geographers and urban economists (c.f. Guimarães, Figueiredo, and Woodward 2009) but one that was not part of Denton and Massey's study.

To better conceptually understand how residential segregation measures can be applied to studying gender diversity among the professorate at the institutional level, let us examine how one measure of evenness—the index of dissimiliarity—is used in urban studies. The index of dissimiliarity measures the extent to which the racial composition of neighborhoods reflects the racial composition of a city, as a whole. For example, if a city is 80 percent white and 20 percent people of color, then it is "even" if every neighborhood that makes up that city is also 80 percent white and 20 percent people of color. It is uneven if whites live in all-white neighborhoods, while people of color live only in neighborhoods of color.

One of the advantages of the index of dissimilarity is that it yields a number that is easy to interpret. An index score of .75 means that 75 percent of the population would have to be relocated (white residents to more black neighborhoods or black residents to more white neigborhoods) in order to achieve evenness. Overall, numbers closer to 1 indicate that neighborhoods tend to be segregated by race; numbers closer to 0 indicate that neighborhoods are more racially even.

Researchers have used the index of dissimiliarity to demonstrate that the implementation of Civil Rights legislation banning discrimination in housing has not improved metropolitan segregation (Massey 1990; Wilson 1996). People of color continue to be concentrated in neighborhoods of color, although the degree to which they are ghettoized is worse in some cities than others. In many places, this condition is getting worse, not better (Iceland and Scopilliti 2008). Likewise, we argue that using a dissimiliarity index to measure the degree to which women are concentrated in departments mostly comprised of women and tracking this number across time will allow university administrators to see when, where, and if they are making progress in gender diversity and how much.

The University of Tennessee reports that, of all tenure-line faculty employed in Fall 2016, 939 were men, and 576 were women (University of Tennessee Factbook 2016). Hiring more tenure-line women would make the overall gender proportions look better, but adding more women to Child and Family Studies, which is already 93 percent women (see Appendix A), will do little to improve diversity, while adding more women to Chemical and Biomolecular Engineering, which is 95 percent men (see Appendix A), would improve diversity greatly.

In this paper, we demonstrate how to calculate a dissimilarity index (a measure of evenness), an isolation index (a measure of exposure and isolation), an exposure index (another measure of exposure and isolation), absolute concentration (a measure of concentration) and a location quotient (a measure of field proportionality) using gender data by department from the University of Tennessee. We focus on gender diversity, but the techniques employed here could be applied to other forms of diversity, such as race and disability status, given sufficient data access.

Data

For the calculations employed here, it was necessary to have a count of the University of Tennessee's total number of men and women (separately) by Department. To obtain these data, we examined faculty listings on UTK's 63 department websites. Faculty gender was determined by the researchers from names and/or photos on department webpages. When no photo was provided and names did not have a clear binary gender signifier (e.g., Chris), we did a search via Google for articles about the faculty member, searching for pronouns. For example, if an entry on Wikipedia said, "He has made important contributions..." we counted that professor as a man. Of the more than 1400 tenure-line faculty, there was only one professor whose binary gender could not be determined[1]. That person was not included, and while the exclusion of him or her skews our statistics, the overall size of UTK's faculty suggests that the coverage error will have little impact on our overall findings.

Arguably, data collection could be simplified by access to administrative data. We could have gained such access for our own institution, but we were interested in seeing how difficult it would be to collect the data without it, since, in a comparative study, it might not be possible to have access to another college or university's data. We knew that if we could implement gender identification manually, then Big Data techniques like web scraping could be employed to collect data from the websites of multiple colleges and universities, and gender could be identified using machine learning. Our approach is a first step in exploring this possibility.

In our calculations, we included only people whose departmental web page listed their title as professor (including assistant professors, associate professors, clinical professors, research professors, teaching professors, and so forth) excluding adjunct professors, visiting professors, and professors emeriti. We included deans, provosts, and associate deans, since some of these administrators may have originally been hired as faculty in their department before being promoted to administration. Additionally, those administrators holding faculty positions could return to their home departments, and some may participate in their home departments by teaching, conducting research, and so forth. We excluded lecturers and people for whom their status was unclear (e.g., internship coordinators). For faculty members holding joint appointments, we counted them twice (once in each department), since we could not determine a better means for allocating them. UTK Librarians were excluded from the analysis, because the UT Libraries webpage did not provide the title of "professor" for any of their faculty. Thus, it was impossible to determine their positions within the schema used to allocate other faculty members. Since the library faculty appears to be overwhelmingly comprised of women, the omission likely makes our results more conservative. Overall, researchers should follow their own logic and purpose in determining inclusion and exclusion criteria. We report ours as a guide.

At the time of this writing, the most recently publicly available administrative data on gender was the *University of Tennessee, Knoxville Fact Book* for Fall 2016, published by UT's Office of Institutional Research and Assessment. This document reports the binary gender distribution of tenure-line faculty as 62 percent men and 38 percent women. The numbers we calculated for our analyses shows a distribution of 63 percent men and 37 percent women (or 167 men for every 100 women). Since we are using data from websites in Fall 2017 (i.e., one year later than the *Factbook*), the numbers are slightly different, but they are close enough to lead us to believe that we have correctly classified most of the current faculty simply by examining their names and photos. In

Appendix A, we show the binary gender composition by department for the University of Tennessees. This information is also available from the authors by request as an Excel spreadsheet with embedded formulas so that researchers can easily apply these calculations to their own institution.

Evenness: The Dissimilarity Index

An index of dissimilarity (D) is calculated as:

$$D = \frac{1}{2}\sum_{i=1}^{n} \left| \frac{m_i}{M_T} - \frac{w_i}{W_T} \right|$$

where:

n = number of departments at a college or university

m_i = number of men in a department

M_T = total number of men in the college or university

w_i = number of women in a department

W_T = total number of women in the college or university

In other words, for every department, researchers should take the number of men in a department and divide it by the number of men at the university. The same calculation should be done for women, and then the women's proportion is subtracted from the men's proportion in every department, ignoring whether the result is positive or negative. Once this is calculated for every department, the results are added together, and the sum is multiplied by .5. The resulting number is the index of dissimilarity.

As previously noted, indices of dissimilarity yield scores between 0 and 1, with higher scores indicating greater evenness. An index of dissimilarity of 1 would mean that all women faculty are in all-women departments, and all men faculty are in all-men departments. An index of 0 means that each department reflects the university's gender distribution as a whole. In other words, a score of 0 means that, since the university faculty is 36 percent women, each department is 36 percent women. Scores greater than 0 indicate a less equitable distribution of faculty across departments by gender. Our calculation of the index of dissimilarity for the University of Tennessee is .38.

A score of .38 means that UT's departments are moderately segregated, with women somewhat likely to be in women-dominated departments and men somewhat likely to be in men-dominated departments. Technically, a score of .38 means that 38 percent of women would have to move to departments dominated by men (and vice versa) to achieve gender evenness. Since faculty are not substitutable—in other words, it would not make sense to relocate 38 percent of the Social Work faculty to the Physics Department and vice versa—the usefulness of this index is arguably best found in making comparisons over time or across institutions. A single point estimate of the index of dissimilarity is less valuable than a comparison of that estimate against prior years, to a benchmark goal, or against other institutions. To illustrate this, we compared a dissimilarity index calculated for UTK—where 36 percent of the faculty are women—to Texas A&M University (TAMU)—where 31 percent of the faculty are women. We chose TAMU as a point of comparison because it is institutionally dissimilar to UTK, given TAMU's focus on agriculture and engineering and the fact that they do not offer some fields of study in which women tend to specialize, like education. Although the overall proportion of the faculty comprised of women is larger at UTK, we calculate a dissimilarity index of .34 for TAMU, meaning that Texas A&M's faculty are more less equitably distributed across departments than the faculty at Tennessee[2]. Simply put, a simple reporting of the global percent of women at the university masks some segregation within departments. TAMU has a smaller proportion of women in their tenure-line faculty than UTK, but TAMU does a better job of distributing women across departments than UTK does. Institutions making real progress on gender diversity would see their indices of dissimilarity grow smaller over time.

Although colleges and universities tend to envision equity and diversity holistically, the calculation of the index of dissimilarity shows how equity and diversity are quite different concepts. Evenness is an indicator of diversity, but it is not an indicator of equity. Since the University of Tennessee's tenure line faculty are split about 60-40, men to women, the index of dissimilarity measures the degree to which departments match this split. UTK's Department of Psychology—which is almost equally divided with 1.1 man for every woman (see gender ratio calculations in Appendix A)—is equitable but not "even," because its nearly 50-50 gender split does not reflect UTK's 60-40 gender split. "Evenness" refers to the distribution *across* departments rather than to the distribution *within* departments. The UTK Departments that are most "even" are Classics; Kinesiology, Recreation, and Sports Studies; Modern Foreign Languages and Literature; Music; and Sociology. Each has about 1.67 men for every woman, as does the university, overall. The least gender-diverse departments at UTK are Mechanical, Aerospace, and Biomedical Engineering (16.3 men for every woman) and Nursing (13.7 women for every man).

This begs the question of whether evenness is important. Would it not be better for more departments to be like Psychology, with about as many men as women? While not disputing this, we would maintain that certain types of institutions, such as TAMU, would tend to skew toward more men faculty since they tend to offer training in male-dominate fields like engineering and agriculture. In these cases, a measure of evenness has value. We also argue that—regardless of a college or university's orientation—an institution of higher education with an index of dissimilarity close to 1 (or hyper-segregated) should do more to achieve diversity across departments. Still, we would posit that—at this moment—it is more troubling for individual departments to lack diversity than equity, given gender differences in fields as a whole.

Exposure: Isolation and Interaction Indices

Although understanding evenness among the professorate is useful, it is certainly not the only diversity concern; additional measures of segregation are needed. *Exposure* can be conceptualized as the degree to which a woman is or is not likely to have colleagues in her department that are men. In other words, it is a measure of the degree to which women experience segregation, assuming that they interact with each faculty member in their department about the same amount. Exposure is important because organizational research suggests that mixed gender work teams are more innovative (Ely and Thomas 2001; Dezsö and Ross 2012; Rock, Grant, and Grey 2016). Since many universities are in the business of creating new knowledge, gender diversity at the department level can facilitate this. Although having a mixed gender department does not guarantee that men and women will collaborate, it is arguably harder to have mixed gender collaborations in departments that are dominated by a single gender.

There are several measures of exposure. Two of the most common are the *interaction index* (also called the exposure index) and the *isolation index*. Mathematically, these two indices capture conceptually obverse conditions. *Interaction* measures the degree to which women are likely to have colleagues who are men. *Isolation* measures the degree to which women are likely to have colleagues who are also women. In the case of binary gender (i.e., when only two groups are being compared), the isolation and interaction indices sum to 1, so, from a mathematical perspective, it does not matter which is calculated, but there may be institutional reasons to select one over the other. If applying these measures to race where there are several racial groups, a variant on this formula—called an entropy index—should be used.

An interaction index is measured as:

$$B_{wm} = \sum_{i=1}^{n} (\frac{w_i}{W_T})(\frac{m_i}{N_i})$$

where:

w_i = number of women in a department

m_i = number of men in a department

W_T = number of women at the university

N_i = number of faculty in the department

To calculate the interaction index (B), the proportion of the university's women represented by each department is calculated as the number of women in each department divided by the number of women at the university. Then the proportion of each department comprised of men is calculated by the number of men in each department divided by the total number on faculty. Those two proportions are then multiplied together for every department and those results are summed.

For women on faculty at UTK, their interaction index is .50. This means that a woman on tenure-line faculty at UTK would have only about a 50 percent chance of encountering a male colleague, assuming that she has the same chance of encountering all of her colleagues. Unlike the dissimilarity index, interaction depends on the size of the two groups being compared, so the top end of the interaction index is bound by the proportion of the second group. In other words, since men make up 64 percent of UTK's faculty, the highest possible interaction index for women would be .64. Obtaining a maximal value requires that the index of dissimilarity equal zero.

The isolation index is measured as:

$$P* = \sum_{i=1}^{n} (\frac{w_i}{W_T})(\frac{w_i}{N_i})$$

where:

w_i = number of women in a department

W_T = number of women at the university

N_i = number of faculty in the department

To calculate the isolation index (P*), for each department, the number of women in the department are divided by the number of women at the university. Then the number of women in the department are divided by the number of faculty in the department. These two proportions are multiplied by each other, and then the department-level results are summed. The resultant number measures the degree to which women only encounter other women, assuming that women on tenure-line faculty only encounter those in their own department. The values of the isolation index range from 0 to 100, with 100 representing maximal isolation (i.e., women will encounter only other women). Note that the interaction and isolation indices are not symmetrical; they are minority-weighted. In order to understand how likely men are to encounter women colleagues or not, the indices would have to be recalculated.

For women faculty at UTK, the isolation index is .50. This means that there is a 50 percent probability that a professor who is a woman will only encounter other women assuming that she has an equal chance of encountering every other professor in her department. Overall—as with the dissimilarity index—the measures of exposure calculated here show moderate segregation at UTK. There are universities that are likely to be worse, but given the research that demonstrates the value of mixed-gender governance and interactions (Campbell and Mínguez-Vera 2008), especially in complex environments that engage in risk (Francoeur, Labelle, and Sinclair-Desgagné 2008), such as research universities, regularly encountering colleagues of another gender matters. College and university officials should track interaction and isolation indices across time to ensure that they are making progress in ways that benefit their institutions.

Concentration: Absolute Concentration

In the study of residential segregation, concentration refers to the amount of physical space occupied by some groups versus others. Specifically, Massey and Denton (1988) define concentration as the amount of physical space (typically square footage of living space) occupied by a minority group. With institutional data, a researcher could examine physical space—a resource that is at a premium at most institutions—allocated to faculty by gender such as the average square footage of office and laboratory space for women on faculty versus men. However, using one particular measure of concentration—absolute concentration—we can substitute a number of other useful resources that might vary by gender for “space” to measure vertical segregation as long as the substituted variable can be ordered. For example, “space” could be replaced by average student contact hours, average research budgets, average grant portfolio sizes, or average start-up funds.

To demonstrate the use of the absolute concentration to examine gender differences in resource allocation, we will measure “space” in terms of the aggregate claims of women on university politics through representation by their department heads. In other words, we define the amount of "political space" occupied by women, under the notion that each department head has the right to make claims for their faculty, and an individual woman in a large department may have less political influence than an individual woman in a small department. This, or course, is not strictly true, and we encourage scholars to develop other notions of space.

The mathematical definition given by Massey and Denton is not well defined here, but working with their verbal description of concentration as "the total area inhabited by a group," compared with the "minimum and maximum possible areas that could be inhabited by that group," we define the measure as

$$ACO = 1 - \frac{\sum_{i=1}^{n} w_i \frac{a_i}{N_i} - \sum_{i=1}^{n1} a_i}{\sum_{i=n2}^{n} a_i - \sum_{i=n2}^{n} a_i}$$

where, first the data are sorted in ascending order based on a_i/N_i, with

a_i = the "area" or size of a department.

w_i = number of women in a department

N_i = number of faculty in the department

n1 = the index of the department where the cumulative faculty total equals the total number of women in the university, counting from the smallest to largest,

n2 = the index of the department where the cumulative faculty total equals the total number of women in the university, counting from the largest to smallest.

In our case, the area is the number 1 representing one department head, and the fraction a_i/N_i is the size of an individual faculty member's claim on representation by their department head. Of course, some departments and universities are more representative and egalitarian than others, and this particular measure of "space" may not be widely applicable.

At the University of Tennessee, women faculty could almost entirely fill the 12 largest department or the 36 smallest departments, representing bounds on the amount of space that could be occupied by women. If smaller departments give more voice to women and women tend to be in smaller departments, then a larger ACO would mean better outcomes. For UTK, the absolute concentration is .501, indicating that women are not systematically located in large or small departments. For example, among the 12 largest departments, there are some departments, like Mechanical Engineering and Mathematics with many more men, and other departments, like Small Animal Clinical Sciences and Nursing with many more women.

The concentration measure employed here is really a measure of the distribution of women across the distribution of departments according to some size or density measure. For the

University of Tennessee, this measure does not seem very helpful, but other colleges and universities may find this helpful. This measure is likely quite helpful when examining other resource allocations.

Field Proportionality: The Location Quotient

When examining faculty diversity, an important objective is to examine how departments do relative to their field. Given how few PhDs are given to women in computer science, for example, we cannot expect that many institution's Computer Science Departments would have large proportion of faculty members who are women. To look at how departments fare relative to their field, this might best be determined using a location quotient. Location quotients are sometimes used to study residential segregation, but they are more commonly used by economic geographers to examine the extent to which a city's industrial sector reflects the share of that industry in the state or country (Baer and Brown 2006). To apply this to the academy consider that, in 2013, about 13 percent of full professors in computer science were women (Corbett and Hill 2015); thus, a Computer Science Department that has no women at the ranks of full professor is not reflecting the field as a whole. Knowing the gender split in a field (information that is sometimes available from professional organizations and is available in broad categories from the National Science Foundation), those concerned with diversity in higher education can compare diversity in their own departments to national data to track progress and to see where Departments might be falling short.

Location quotients are calculated as:

$$LQ_i = (\frac{w_i}{N_i})/(\frac{E_i}{E})$$

where,

LQ_i = location quotient for every department

w_i = number of women in a department

N_i= number of faculty in the department

E_i = number of women employed in field i

E = number of people employed in field i.

In other words, the location quotient is calculated by merely dividing the proportion of a department that is women to the proportion of the field that is women. A location quotient of 1 means that a department's gender distribution matches the professorate nationally in the same field; a location quotient less than one indicates that the department's gender disparity is even more unequal than the larger discipline. To understand an exact interpretation, if women hold only 1.5 percent of all tenure-line positions in a field in the United States, and 16 percent of all tenure-line jobs in a department, then the location quotient is (.16/.015)=10.67. In other words, the department is hiring women at about eleven times the field rate nationally. If the location quotient was .5, then the department's share of women is half of the average for the field. The Bureau of Labor Statistics indicates that location quotients between .8 and 1.2 are within a normal range for industries (C_2ER 2012), but we cannot assert that this is a reasonable standard for colleges and universities to adopt.

We calculated the location quotient for the several engineering departments at UTK compared against 2014-2015 data from the American Society of Engineering Education (Yoder 2016)[3] limiting our comparisons to just those holding tenure-line positions. At UTK, the location quotient for Industrial and Systems Engineering is .53, Chemical and Biomolecular Engineering is .30, Civil and Environmental Engineering is .55, Electrical Engineering and Computer Science is 1.76, Materials Science and Engineering is 1.03, and Nuclear Engineering is .58. Our results indicate that the gender distribution in the Department of Materials Science and Engineering—where men outnumber women 5 to 1—is reflective of the gender distribution of the field as a whole. Electrical Engineering and Computer Science is better than many other universities in attracting women to tenure-line jobs. By contrast, we would argue that our administration should take a closer look at gender conditions in the Departments of Industrial and Systems Engineering, Chemical and Biomolecular Engineering, Civil and Environmental Engineering, and Nuclear Engineering. These departments are attracting and/or retaining women on the tenure-line at a rate far lower than what would be expected given the supply of women in these fields of engineering.

Although the calculation of a location quotient is simple, the ASEE data illustrate that not all calculations are straightforward. For example, at UTK, three of the tenure-line faculty in Mechanical, Aerospace, and Biomedical Engineering are women, and 49 are men. Thus, (e_i/e) is .06, indicating that women are 6 percent of the faculty in that department. However, ASEE reports mechanical, aerospace, and biomedical engineering separately (13.5, 9.1 and 22 percent women, respectively) whereas UTK combines faculty with these expertise into a single department. We added the three ASEE percentages as a total and divided by 300 to get .15. Thus, the location quotient for the department at UTK as a ratio to the nation is .4, indicating that the Department has far fewer women than are in these fields in tenure-line positions nationally. However, since the Department is comprised of three fields, a field proportionality quotient of .4 is more alarming if most of the Department is comprised of biomedical engineers and less alarming—but still not good—if most of the faculty members in the Department are aerospace engineers.

It is also worth noting that the location quotient may hide gender divides within departments, depending on how departments are structured. For example, the location quotient for Biosystems Engineering and Soil Science is 1.29, but what looks on the surface as a good situation for women (i.e., they are being hired at 1.29 times the national rate) may mask the fact that the biosystems engineers in the department could be all men, while the plant pathologists, horticulturalists, and botanists could be all women. To the extent that differential prestige and salaries are allocated across these specializations, vertical gender segregation may still be an issue.

At UTK, the picture with regard to field proportionality is mixed. Although women's representation among tenure-line engineering faculty is better than the nation in some engineering departments, it is far worse in mechanical, industrial, chemical, civil, and nuclear engineering. In other words, some UTK engineering departments are making nation-wide gender imbalances in engineering worse, not better.

Although the calculation of the location quotient is quite simple, we speculate that this is the most time-consuming calculation with respect to data acquisition and, perhaps, the least accurate. Finding national data is difficult. Because we are not engineers, we were initially unaware of the existence of ASEE, and searching the professional organizations for the various engineering fields (which was what we did first) yielded no data. Additionally, some associations make their data available only to members. Presumably there are other fields where no gender data are collected; we only looked at engineering. The National Science Foundation captures gender information from the STEM fields, but they report these data in broad categories which make them hard to apply at the department level.

Additionally, we do not know to what extent we are comparing apples to oranges. For example, ASEE reports gender data on Biological and Agricultural Engineering, which we compared to UTK's Department of Biosystems Engineering and Soil Science. We are unsure whether that is a straightforward comparison or not, and conversations with women who are faculty members in this Department suggest that it is not. Additionally, ASEE reports data on Electrical/Computer Engineering (of which women comprise 12.4 percent of the field) as well as Computer Science within engineering (of which women comprise 16.9 percent of the field). It was unclear to us which denominator to use in the UTK calculation. Still, these numbers give some indication of the

Departments which need the most improvement, and field proportionality numbers can be used to guide administrators in making decisions about which departments might best benefit from the opportunity to make strategic hires of women.

Conclusions

Gender equity in higher education means more than simply filling half of all tenure-line positions with women. Administrators must consider the extent to which their institution is vertically segregating men into more prestigous and better paying positions than women. When women are segregated into departments with fewer resources or are able to make fewer useful connections with male colleagues, they face real limitations in their ability to earn tenure, to be promoted, or to achieve equitable pay (Misra, Kennelly, and Karides 1999; Probert 2005; Weisshaar 2017). As universities attempt to overcome these problems by creating programs to attract more women to STEM and other traditionally male-dominated fields (Shaw and Stanton 2012; Xu 2008), a larger set of tools is needed to allow administrators to examine gender diversity in in more than a uni-dimensional way.

Academic careers are typically long, so progress toward diversity is slow (Shaw and Stanton 2012). Thus, it is important that college and university administrators have a set of tools for measuring diversity progress incrementally over time and across institutions. Simple percentages may mask larger structural changes. Any individual department's percent women faculty members may increase simply because some men quit or retire without replacement or because the field as a whole is attracting more women, while the department's share of women increases but still lags far behind the field.

We offer some relatively simply tools for measuring progress in vertical gender integration. In this paper, we draw from the literature on residential segregation to suggest adding four dimensions to the understanding of faculty gender segregation—evenness, isolation, concentration, and field proportionality. In the cases of evenness and isolation, we suggest that point estimates for a single year are less valuable than using those estimates to compare across time and to peer institutions. We also argue that measures of concentration allow considerable flexibility in defining "space" in order to examine many ways in which resources may be differentially allocated by gender. The location quotient helps to compare an individual department to its discipline. Location quotients can help administrators better allocate diversity resources, because they can be used to determine which departments need the most attention in developing new strategies for early recruitment, creating an inclusive workplace, retention, and mentoring.

In this paper, we demonstrated five techniques for measuring four dimensions of segregation using data from the University of Tennessee. We find that women at the university are moderately segregated in women-dominated departments and are more likely to encounter women colleagues than men. We also find that women are about as equally likely to be in large departments than in small. We also find that while UTK's electrical engineering department is hiring women at a disproportionately high rate, relative to the field as whole, and the mechanical engineering department is on par with its field, most departments within the College of Engineering have gender imbalances that cannot be explained by gender imbalances in the job market. Alarmingly, many of Tennessee's engineering departments are making gender disparities in the engineering professorate worse. These are areas for greater attention, especially since gender diversity is linked to innovation and performance (Herring 2009).

In this paper, we examined gender, but the techniques we used were initially developed to study racial segregation. Thus, all calculations presented here could be applied to other dimensions of diversity such as race, LGBT status, or disabilities, which likely require access to administrative data, some of which—like sexual orientation—may not be collected. Although each of the indices we calculated involved relatively simply mathematics, the collection of new data is time consuming and access to administrative data may be limited, especially when a researcher wants to compare across institutions. However, for those wanting to compare across colleges and universities and across time, big data techniques such as web scraping and machine learning could be employed to more easily collect data. Using internet archives such as the Wayback Machine (https://archive.org/web/) could also allow researchers to find data from previous years for institutions for which they do not have direct data access, although those data are limited. Researchers should also anticipate the need to create many decision rules about which cases are included in their study, since every university is different.

Vertical gender segregation in higher education has been studied extensively over many years (c.f. Berggren 2008; Charles and Bradley 2002; 2009). Although in-depth studies are instructive, administrators need information that is more immediate and accessible than what can be found in a lengthy and complex research endeavor. By implementing the techniques demonstrated here—and developing others—administrators will have a range of tools for self-assessment that are easy to calculate and understand, so that an entire range of diversity statistics can be generated annually, and resources to improve diversity can be allocated more efficiently.

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Appendix A: Gender Division of Faculty by Department, 2016

m_i/M_T	men	women	sex ratio
Department	**m_i**	**w_i**	**m/w**
Accounting and Information Management	8	5	1.60
Advertising and Public Relations	4	8	0.50
Agricultural & Resource Economics	15	4	3.75
Agricultural Leadership, Education & Communications	6	2	3.00
Animal Science	15	7	2.14
Anthropology	8	7	1.14
Architecture	15	6	2.50
Art	14	10	1.40
Biochemistry, Cellular and Molecular Biology	19	8	2.38
Biomedical and Diagnostic Sciences	15	13	1.15
Biosystems Engineering & Soil Science	27	7	3.86
Business Analytics and Statistics	13	4	3.25
Chemical & Biomolecular Engineering	18	1	18.00
Chemistry	25	4	6.25
Child and Family Studies	1	13	0.08
Civil and Environmental Engineering	30	3	10.00
Classics	6	3	2.00
Communications Studies	2	8	0.25
Earth and Planetary Sciences	15	5	3.00
Ecology and Evolutionary Biology	21	15	1.40
Economics	19	4	4.75
Educational Leadership and Policy Studies	6	5	1.20
Educational Psychology and Counseling	14	11	1.27
Electrical Engineering and Computer Science	35	9	3.89
English	19	25	0.76
Entomology & Plant Pathology	16	7	2.29
Finance	10	3	3.33
Food Science & Technology	9	3	3.00
Forestry, Wildlife, & Fisheries	25	6	4.17
Geography	12	4	3.00
History	15	12	1.25
Industrial and Systems Engineering	10	1	10.00
Information Sciences	4	10	0.40
Interior Architecture	2	4	0.50
Journalism and Electronic Media	11	5	2.20
Kinesiology, Recreation, and Sport Studies	15	10	1.50
Landscape Architecture	4	2	2.00
Large Animal Clinical Sciences	14	4	3.50
Law	22	20	1.10
Management	7	2	3.50
Marketing and Supply Chain Management	13	5	2.60

Materials Science and Engineering	26	5	5.20
Mathematics	38	7	5.43
Mechanical, Aerospace, and Biomedical Engineering	49	3	16.33
Microbiology	12	5	2.40
Modern Foreign Languages & Literature	18	17	1.06
Music	25	14	1.79
Nuclear Engineering	14	1	14.00
Nursing	3	40	0.08
Nutrition	5	7	0.71
Philosophy	7	2	3.50
Physics and Astronomy	31	6	5.17
Plant Sciences	32	9	3.56
Political Science	15	7	2.14
Psychology	20	18	1.11
Public Health	3	11	0.27
Religious Studies	1	7	0.14
Retail, Hospitality, and Tourism Management	2	9	0.22
Small Animal Clinical Sciences	15	33	0.45
Social Work	3	18	0.17
Sociology	10	6	1.67
Theatre	8	5	1.60
Theory and Practice in Teacher Education	32	11	2.91
Sum (n=63)	**928**	**526**	

Notes

[1] We acknowledge that gender is a social construct and that both sex and gender are continuums (see Ward and Edelstein 2013). However, in this paper we treat gender as a binary—as it is typically treated in institutional data collection—without asserting that what is typical is correct.

[2] Data and calculations for the index of dissimilarity for Texas A&M University is available from the researchers by request.

[3] We readily admit a mismatch between the year that our institutional data were collected and the year the ASEE data were collected. However, given that progress in diversity in education is incrementally slow (Shaw and Stanton 2012), we do not expect that the fields of engineering have changed much over two years. Until newer data are released, it will be impossible to determine how far off our calculations are, but it is likely that our results are conservative.