ICT Gender-Equality Paradox Re-Analysis

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2020-06-17

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Chapter 1

Introduction

In 2018, Stoet & Geary published a paper titled, “The Gender-Equality Paradox in Science, Technology, Engineering, and Mathematics Education.” This paper was the first to introduce this idea of a gender-equality paradox in Science, Technology, Engineering, and Mathematics (STEM) education, and therefore gained traction in the popular media (e.g., [Stoet and Geary, b]). The STEM gender-equality paradox (STEM-GEP) represents the counterintuitive, negative correlation between gender equality (as measured by the Global Gender Gap Index (GGGI)) and the percentage of STEM graduates who are women. That is, countries with higher gender equality tend to have a lower percentage of STEM graduates who are women.

These findings are controversial for multiple reasons. First, one can imagine how the results could used as evidence in support of politicized ideas about gender differences in the pursuit of STEM: in countries with higher gender equality, women presumably face fewer barriers to pursuing a STEM education, thus the low percentage of women STEM graduates could reflect women’s choice to pursue other fields due to intrinsic factors like interest. Similarly, one might argue that the high percentage of women STEM graduates in countries with low gender equality reflects a choice to pursue STEM due to extrinsic factors like financial incentives.

Secondly, Stoet & Geary’s findings are controversial due to several errors in the original paper that have since been corrected, though these changes did not impact the conclusions of the paper. Richardson et al.’s [] commentary article illuminates two major aspects of Stoet & Geary’s [b] STEM-GEP paper that merit consideration. Richardson et al. (2020) point out that the x-axis of the STEM-GEP was misidentified. The original paper included a graph with the x-axis labeled “Women Among STEM Graduates (%)”, which has been corrected to “Propensity of Women to Graduate With STEM Degrees” in the updated, 2020 paper. The new label still evokes confusion, as “propensity” could be interpretted in various ways. An even more representative x-axis label would read, “Women Among STEM Graduates (%) When Adjusted for Differences in Graduation Numbers of Men and Women.” The x-axis label was changed because the data used in that correlation were not, in fact, data concerning the percent of women among STEM graduates. Rather, the data used and what Stoet & Geary (2020) now call *propensity*, is an estimate of the percentage of women among STEM graduates after adjusting for equal graduation rates among men and women.

Richardson et al. (2020) also bring attention to the importance of which gender equality index measure is used. When re-analyzing the data with the Basic Index of Gender Equality (BIGI), the correlation between percent of women among STEM graduates and gender equality ceases to exist. However, in a reply to Richardson et al., Stoet & Geary [a] argue that the BIGI (which they developed themselves) is not an appropriate index to compare to the STEM gender data, as the BIGI measures merely well-being and not empowerment. Richardson, who directs the GenderSci Lab at Harvard University, continues to write about this controversy in a series of blog posts on the lab’s website, GenderSci Lab Blog Series.

1.1 The ICT Gender-Equality Paradox

Using Stoet & Geary’s (2018) paper as a launching pad, the UNESCO for the EQUALS Skills Coalition dedicated part of their 2019 report on digital skills and gender [West et al.] to a Thinkpiece introducing the Information and Comminication Technology (ICT) version of the STEM-GEP, henceforth the ICT-GEP. ICT refers to education programs that one might conceptualize as technology programs and broadly refers to computer science and related programs. More specifically, UNESCO provides a definition[1] outlining four categories that qualify as ICT. The ICT-GEP follows the same trend as the STEM-GEP, that is, the higher the gender equality (GGGI) of a given country, the lower the percentage of ICT graduates who are women. Though UNESCO’s analysis of the ICT-GEP mostly mirrors that of Stoet & Geary (2018), the ICT-GEP has not received criticism and undergone a re-analysis like the STEM-GEP has.

1.2 The Present Research

The ICT-GEP Thinkpiece lacks many details concerning the method of analysis; additionally, the ICT-GEP has only been measured using one correlation strategy. The present research aims to investigate the ICT-GEP data in order

[1] UNESCO defines ICT education and training as “(1) the study of techniques and acquisition of skills to produce newspapers, radio/television programmes, films/videos, recorded music and graphic reproduction with ICT; (2) the study of the design and development of computer systems and computing environments; (3) the study of using computers and computer software and applications for different purposes; and (4) the study of planning, designing, developing, maintaining and monitoring electronic equipment, machinery and systems”

to fill those methodological disclosure gaps, as well as re-analyze the ICT-GEP using two alternative methods of correlating ICT data with GGGI data.

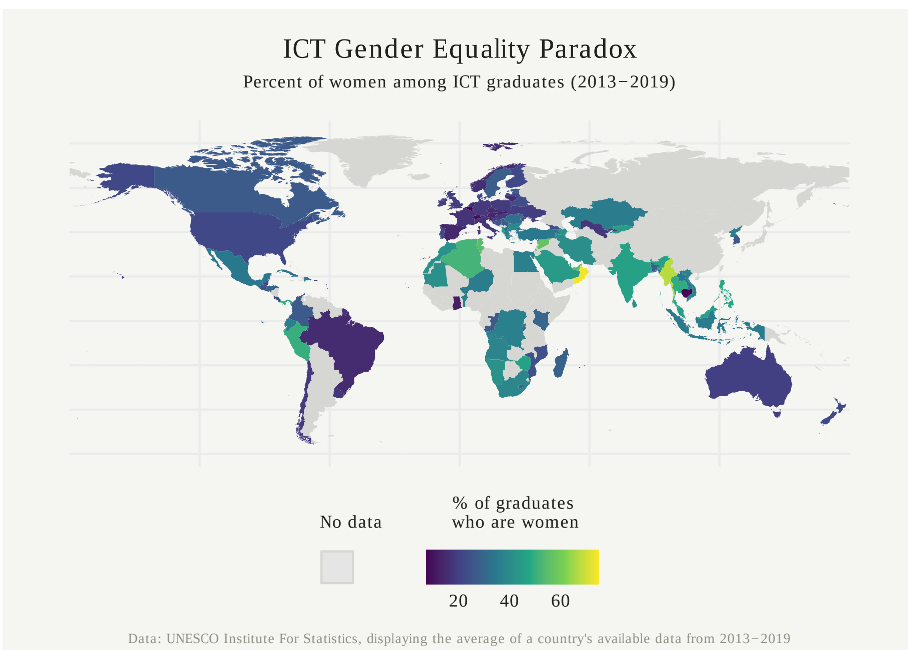
Following from the three related, but disparate approaches, the present research asks, for the ICT-GEP, do the three approaches result in parallel results?

Chapter 2

Visualizing the ICT-GEP

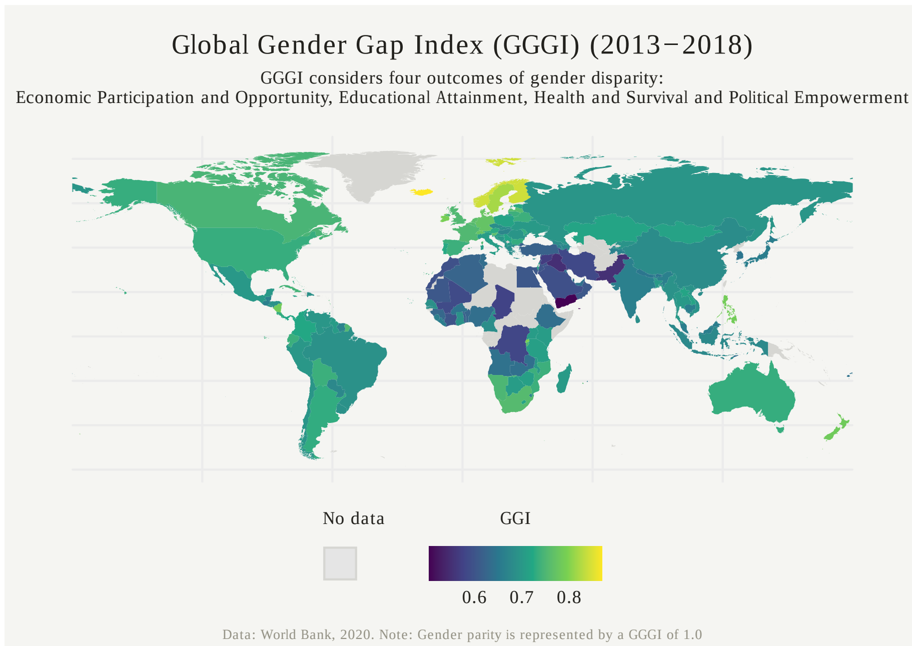
Before diving into the data, these maps offer a visual explanation of the ICT-GEP when using the analysis method from the UNESCO Thinkpiece.

2.1 Percent of women among ICT Graduates worldwide



Note the visual reversal of colors when comparing the ICT map to the GGGI map. This is exactly the idea behind the ICT-GEP: the higher the gender equality, the lower the percentage of women among ICT graduates.

2.2 Global Gender Gap Index worldwide



Chapter 3

Methods

3.1 Clarifying the UNESCO statistics and their usage in prior literature

Both Stoet & Geary (2018) and the Thinkpiece utilize The UNESCO Institute for Statistics (UIS) education database. Though the two analyses seemingly mirror each other, a closer look suggests that there are important nuances in the application of the UIS statistics in both. To offer clarity, definitions of two important statistics, henceforth **percent_of_women** and **percent_of_ict**, follows.

3.1.1 Percentage of female graduates from ICT programs in tertiary education: percent_of_women

This percentage is derived from dividing the number of women who graduate with an ICT tertiary degree by the number of women who graduate with any tertiary degree. For example, in Algeria, this number was 2.13% in 2016, whereas in the US, it was 1.53% in 2016.

3.1.2 Percentage of graduates from ICT programs in tertiary education who are female: percent_of_ict

This percentage is derived from dividing the number of women who graduate with an ICT tertiary degree by the total number of men and women who graduate with an ICT tertiary degree. Note that this statistic does not account for any gender differences in overall tertiary degrees earned. Presumably, the number of ICT tertiary degrees earned is correlated with the total number of degrees earned, so differences in these base rates should be considered in analyses, contrary to the arguments of Richardson et al. (2020). As an example of what these **percent_of_ict** statistics look like, 54.28% of Algerian ICT tertiary graduates in 2016 were women, wherease 23.61% of American ICT tertiary graduates in 2016 were women.

3.1.3 Which statistics do Stoet & Geary (2018) and the ICT-GEP Thinkpiece use?

Stoet & Geary (2018) plug the **percent_of_women** data into a formula they claim represents the percentage of women in STEM when equal numbers of men and women enroll at the university. This formula is $a/(a+b)$ where a is the "percentage of women who graduate with STEM degrees (relative to all women graduating)" and b is "the percentage of men who graduate with STEM degrees (relative to all men graduating)". Stoet & Geary's (2020, p. 1). The explanation of this formula states that "the resulting number can be interpreted as the percentage of women in STEM when equal numbers of men and women enroll at university" (Stoet & Geary 2020, p. 1). There are a few notable subtleties about this language: the UIS education data is collected on the country level (not the university level) and additionally, the data the authors utilized represent when equal numbers of men and women *graduate with tertiary degrees* within that country (there is a subtle difference between enrollment and completion/graduation). Lastly, Stoet & Geary (2018) take the average of each country's available data from 2012-2015.

Taking a different approach, ICT-GEP Thinkpiece utilizes the **percent_of_ict** data and does not transform this data in any way. It is unclear what criteria were used for determining which year's data was selected for the analysis, as there was not a consistent method for each country's data. The Thinkpiece was published on May 22, 2019 [Khazan], which was before the 2018 UNESCO Education data was released on September 12, 2019 [UIS]. However, this does not explain the inconsistency in year selection. For example, the Thinkpiece uses 2017 data for Singapore (latest data available), but 2016 data for Switzerland though there is 2017 data available. Though the Thinkpiece visually and verbally presents the negative correlation between GGGI and the percent of women among ICT graduates, the authors do not provide any further statistical detail (e.g., Pearson's r). The language presented on the Thinkpiece correlation plot suggests confusion (or else, lack of precision) between **percent_of_women** and **percent_of_ict**. As mentioned, the Thinkpiece plots the "Percentage of graduates from ICT programs in tertiary education who are female" (**percent_of_ict**); however, labels on opposite ends of the graph read, "HIGH percentage of women completing ICT programmes" and "LOW percentage of women completing ICT programmes." This language describes to the **percent_of_women** data, though that is not what was plotted in the Thinkpiece.

3.2 The present research

Stoet & Geary (2018) and the Thinkpiece represent two different methods for understanding the correlation between GGGI and the percentage of ICT tertiary graduates who are women, the **percent_of_women** and **percent_of_ict** approaches, respectively. In line with prior research that is interested in correlations with the GGGI [**?**], a third method is proposed here. This method, henceforth **ict_disparity**, examines the correlation between the GGGI and the ICT graduation sex-difference index. All three methods will be compared using the `corcor()` function to determine whether each of the three strategies produce the same correlation. As a summary, the following three correlations will be computed with the ICT data:

- Method #1: the **percent_of_ict** approach (Thinkpiece)
- Method #2: the **percent_of_women** propensity approach (Stoet & Geary)
- Method #3: the **ict_disparity** approach

All data is available for free download online (ICT data, GGGI data). For all ICT variables, each country's value was determined by averaging all available data from 2013-2019. Each country's GGGI value represents the average GGGI across the years 2013 to 2018 (2019 data not available). Though 2019 data is included in the ICT data, but not the GGGI data, only two countries, Georgia and Kazakhstan, have 2019 ICT data.

Chapter 4

Analysis

4.1 Variables

The normality of all six variables needed for the correlations is examined via Shapiro-Wilk tests for normality:

1. percentage of women graduates who graduate from ICT programs,
2. percentage of men graduates who graduate from ICT programs,
3. percentage of women among ICT graduates,
4. percentage of women among ICT graduates adjusted for the disparity in the ratio of women to men who graduate from all programs,
5. disparity between the percentage of all women versus all men graduates who graduate from an ICT program and
6. GGGI

4.2 Normality

Of these six variables, only three follow a normal distribution: variable (3) variable (5), and variable (6). The table below displays all results of the Shapiro-Wilk tests. Because Pearson's correlation coefficient (r) is the metric of interest, no transformations to the data are needed because Pearson's r requires continuous, but not normal data.

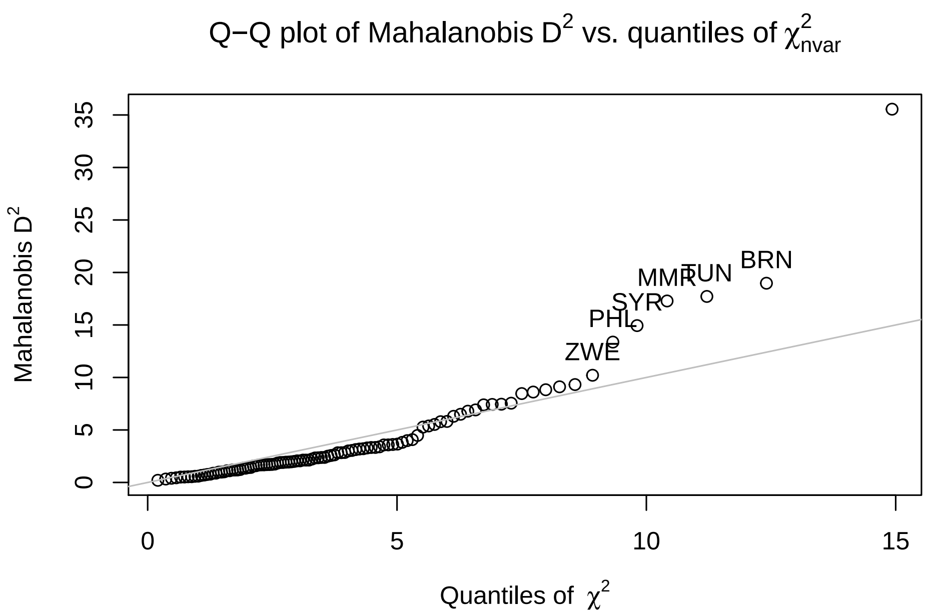
variable	W	p-value
1	0.7473	5.056e-12
2	0.9033	1.499e-06
3	0.9693	0.0170
4	0.9498	0.0007
5	0.9809	0.1433

variable	W	p-value
6	0.9890	0.5647

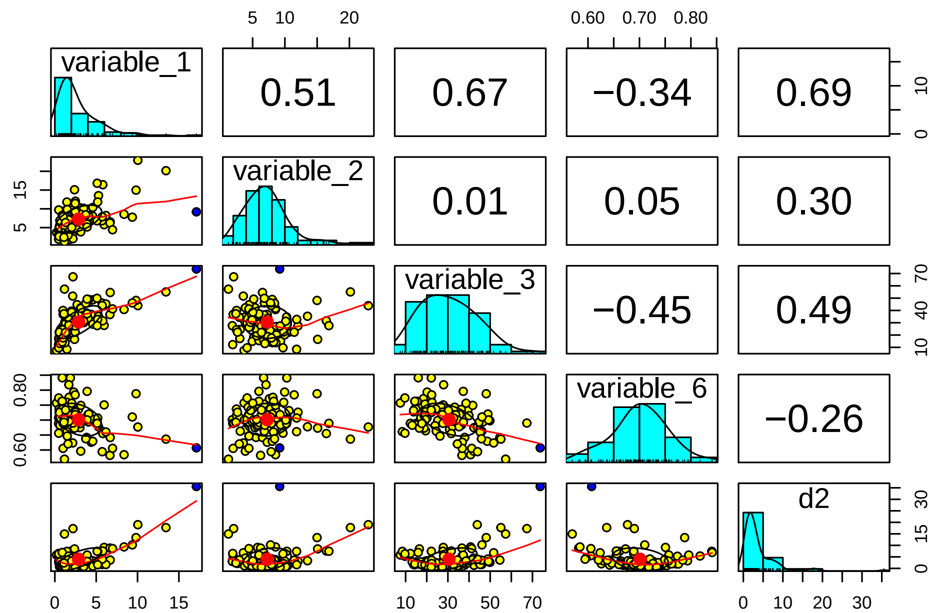
4.3 Outliers and data omission

Mahalonobis D^2 values were computed for four of the six variables. The other two variables, variables (4) and (5) were omitted, as they were computed directly using variables (1) and (2). Including these variables and thus, their dependencies, will not allow for Mahalonobis D^2 calculations to be possible.

The Q-Q plot below displays each of the countries' Mahalonobis D^2 values (the seven countries that deviate the most are labeled with their iso_a3 country code).



The figure below shows bivariate scatter plots, histograms, and the Pearson correlations for and between each of the four variables, with any outliers marked with a blue dot. Only one country, Oman (iso_a3 'OMN'), has a Mahalonobis D^2 value of greater than 25. Therefore, Oman is the sole country to be removed from the analysis for being an outlier.

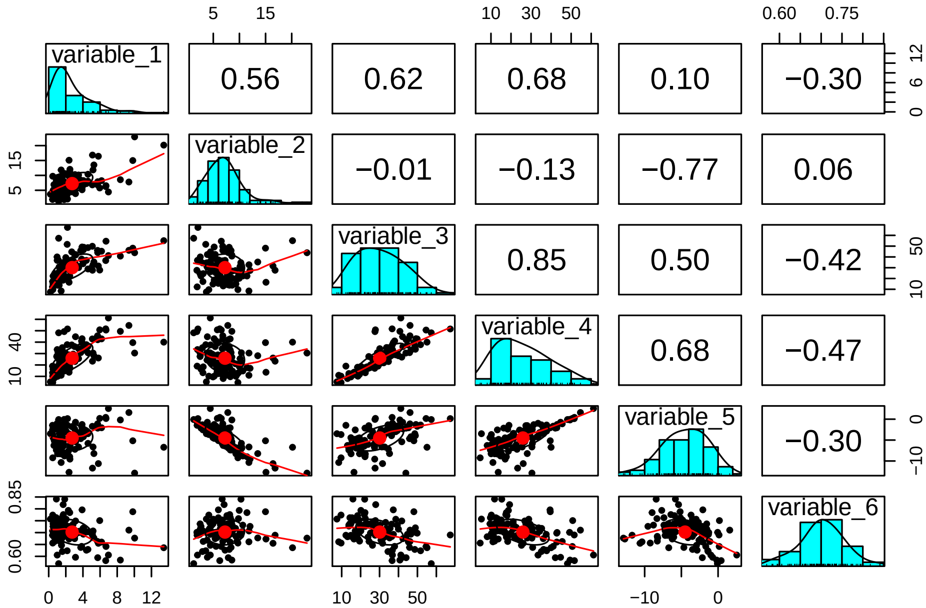


However, in order to correctly compare the three correlations, an identical set of countries must be the subject of each. The second and third correlations depend on the existence of data for variables (1) and (2), whereas the third correlation depends on the existence of data for variable (3). One country, Sri Lanka, has data for variable (3), but not variables (1) and (2). Thus, Sri Lanka was the second and final country to be removed from the analysis. This leaves 102 remaining countries for which sufficient data is available.

4.4 Data description

Descriptive statistics for the 102 countries and the bivariate scatter plots, histograms, and the Pearson correlations for the data after removing the outlier:

```
##             vars   n  mean    sd median trimmed   mad    min   max range  skew kurtosis   se
## variable_1     1 102  2.74  2.41   1.74    2.32  1.20   0.20 13.44 13.24  1.84     3.83 0.24
## variable_2     2 102  7.24  3.74   6.82    6.83  2.72   1.25 22.93 21.68  1.42     3.26 0.37
## variable_3     3 102 30.09 12.60  28.40   29.53 13.52   7.49 67.35 59.86  0.39    -0.48 1.25
## variable_4     4 102 25.94 13.04  23.80   24.93 14.58   4.62 61.17 56.55  0.55    -0.60 1.29
## variable_5     5 102 -4.50  3.10  -4.31   -4.39  3.25 -12.89  2.55 15.44 -0.36    -0.14 0.31
## variable_6     6 102  0.70  0.05   0.70    0.70  0.05   0.57  0.84  0.27 -0.06     0.15 0.01
```



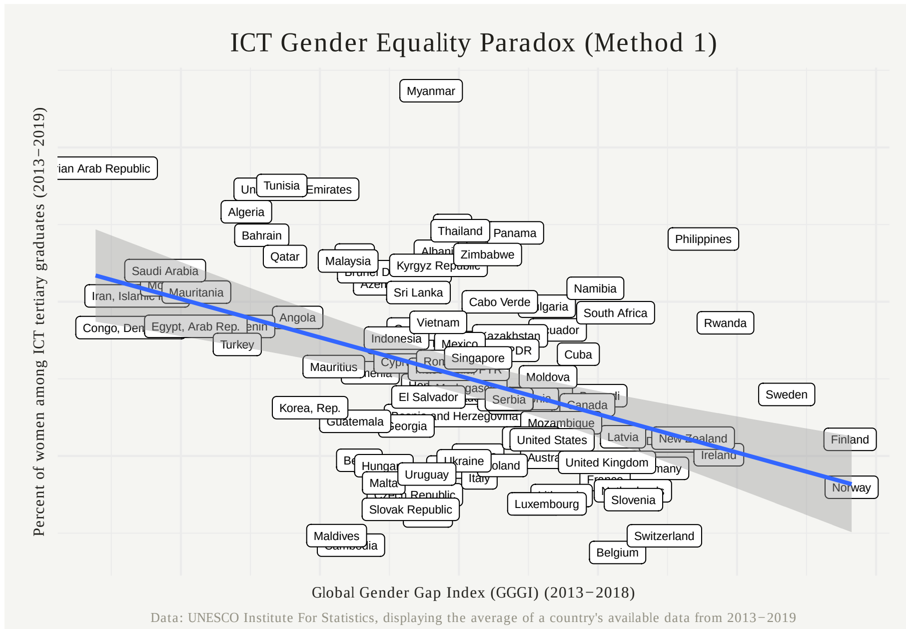
The ICT-GEP Thinkpiece does not offer an explanation regarding the consideration or removal of outliers. However, through a simple count of the countries listed in the Thinkpiece's reference data, it appears that only 79 countries were included in the analysis.

Chapter 5

Results

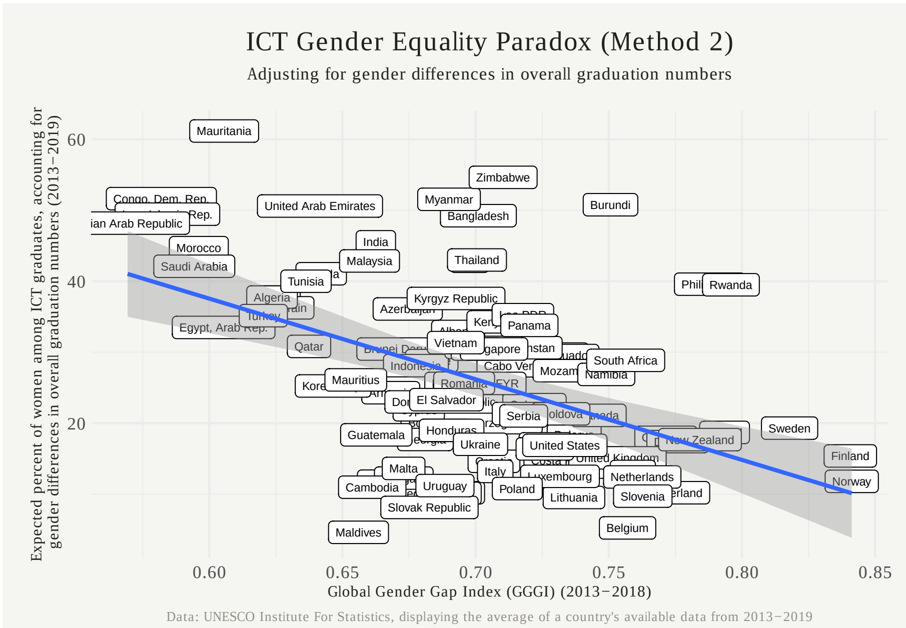
5.1 The ICT-GEP using percent_of_ict data (correlation method #1)

After an investigation of the data used in the UNESCO Thinkpiece, this method exactly replicates the method employed there given the available information. For example, this analysis examines 102 countries, whereas the Thinkpiece appears to examine 79. Becuase the method for selecting those 79 countries is unknown, that aspect is not replicated. The Thinkpiece also provides no inferential statistics regarding the correlation depicted in the ICT-GEP plot. Using the same correlation method, but 102 country's data, the GGGI and the percent of women among ICT graduates are moderately, negatively correlated (r = -0.43, $p < 0.001$).



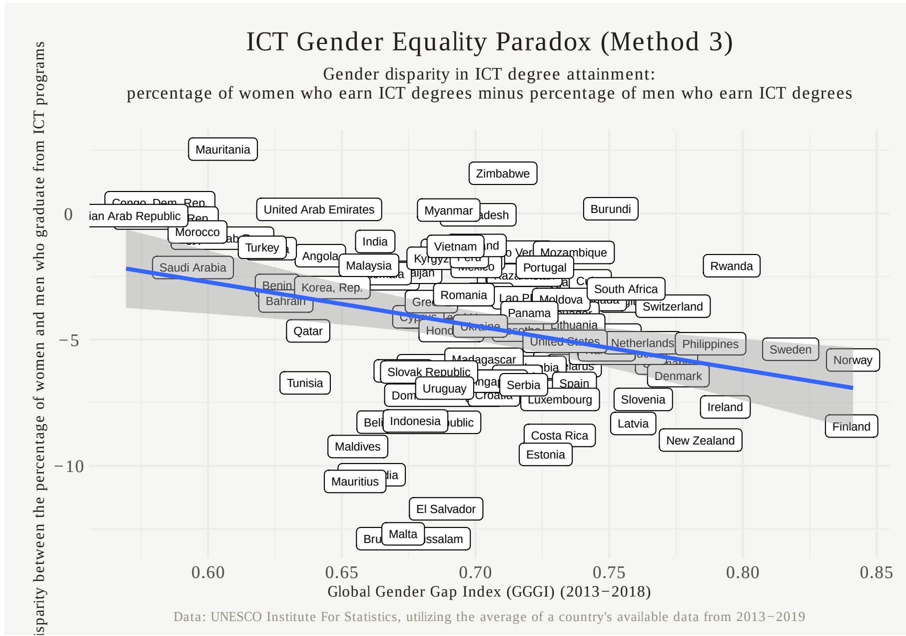
5.2 The ICT-GEP after adjusting the percentages to reflect when equal numbers of men and women graduate with tertiary degrees within each country

This method replicates Stoet & Geary's (2018) *propensity* method, where they estimate the percentage of women among STEM graduates when there are an equal number of men and women graduates overall. In this case, in the formula $a/(a+b)$, a represents the percentage of women graduates who graduate from an ICT program, and b represents the percentage of men graduates who graduate from an ICT program. Stoet & Geary (2018) explain that they use Spearman's correlation coefficient because some of the variables are not normally distributed. However, the variables are continious, and it is a misconception that variables must be normally distributed in order to use the more robust Pearson's correlation coefficient [Nefzger and Drasgow]. Following the *propensity* method, but using the Pearson test, GGGI is moderately, negatively correlated with the estimated percentage of women among ICT assuming equal graduation numbers of men and women (r = -0.47, $p < 0.001$). For the sake of comparison (though not endorsed), the *propensity* method paired with Spearman's test also results in a moderate, negative correlation (ρ = -0.40, $p < 0.001$) to a lesser extent.



5.3 The ICT-GEP as a function of the disparity between ICT graduation rates for men and women

The final method is unique from the methods utilized or posed by Stoet & Geary, Richardson et al., and UNESCO. This *disparity* method considers the correlation between the GGGI and the disparity between the percent of women graduates and percent of men graduates who graduate from an ICT program. There is a weak correlation between GGGI and this disparity index (r = -0.30, $p < 0.01$).



5.4 Correlation comparison

Are the three correlation methods equivalent to each other? One method may have more theoretical support for its usage, but this step of the analysis concerns whether that methodological decision bears any impact of the conclusions of the analysis. The three correlations compose a set of dependent, overlapping correlations. That is, the correlations are dependent on each other because all three share a common variable, the GGGI. The `cocor()` function from the `cocor` package [Diedenhofen and Musch] was used with the formula for dependent, overlapping correlations to test for a significant difference between each pair of the correlations. Ten different tests[1] were run for each comparison; the results of the three comparisons reflects unanimous results from the ten tests. Results of Steiger's (1980) test are reported.

The correlation results from Method #1 and Method #2 are equivelant ($z = 0.9674$, $p = 0.33$), thus, using either the raw percentage of women among ICT graduates or the expected percentage adjusted for the gender disparity in overall graduation results in statistically equivalent correlations with the GGGI.

The correlation results from Method #1 and Method #3 are also equivalent

[1]The ten tests for correlation comparison are Pearson and Filon's z (1898), Hotelling's t (1940), Williams' t (1959), Olkin's z (1967), Dunn and Clark's z (1969), Hendrickson, Stanley, and Hills' (1970) modification of Williams' t (1959), Steiger's (1980) modification of Dunn and Clark's z (1969) using average correlations, Meng, Rosenthal, and Rubin's z (1992), Hittner, May, and Silver's (2003) modification of Dunn and Clark's z (1969) using a backtransformed average Fisher's (1921) Z procedure, and Zou's (2007) confidence interval

(z = -1.32, p = 0.19), thus using either the raw percentage of women among ICT graduates or the disparity between the percentage of women versus men graduates who graduate from ICT programs results in statistically equivalent correlations with the GGGI.

Lastly, the correlation results from Method #2 and Method #3 are not equivalent (z = -2.30, $p < 0.05$). Though Methods #2 and #3 do not produce equivalent correlations, the two methods debated by Stoet & Geary (2020) and Richardson et al. (2020) do produce equivalent correlations. Similarly, Stoet & Geary (2020) re-analyzed the STEM-GEP using Method #1, which also resulted in a statistically significant, moderate, and negatative correlation. However, Stoet & Geary (2020) did not statistically test for the equivalence of the two correlations, which could have strengthened their argument.

Chapter 6

Discussion

The ICT-GEP as presented in the UNESCO report on digital skills and gender lacks many of the statistical details expected in research reports of this nature. Many unknowns about the exact methods employed remain, including, but not limited to: selection criteria, consideration of outliers, and tests used to measure correlation. This re-analysis confirmed that there is a moderate, negative correlation between GGGI and the percent of women among ICT graduates. Additionally, this correlation is equivalent to the correlation produced when adjusting for the disparity between the base number of women and men graduates. A third correlation concerning the disparity between the percentage of women and men graduates who graduate from an ICT program produced a weaker correlation that is not equivalent to the other two correlation methods.

These findings demonstrate the need for further scrutinization of the methods employed by Stoet & Geary (2018) and the UNESCO Thinkpiece. Further consensus and clarification is needed before countries accept these results as evidence for the necessity (or lack thereof) of particular policy interventions.

Future research should further investigate the validity of using the GGGI as the index of gender equality and consider alternatives other than the BIGI. Other variables besides gender equality should also be examined, such as the size of the ICT industry in each country. Future qualitative research should also be considered to avoid some of the pitfalls of this quantitative approach, like the possibility of spurious correlation. For example, interviews of women who pursued an undergraduate ICT education in an Arab State but a graduate ICT education in a European country would offer a wealth of information about the potential factors underlying the ICT-GEP hypothesis.

Bibliography

UIS Education Data Release: September 2019.

Birk Diedenhofen and Jochen Musch. Cocor: A Comprehensive Solution for the Statistical Comparison of Correlations. 10(4):e0121945. ISSN 1932-6203. doi: 10.1371/journal.pone.0121945. URL https://dx.plos.org/10.1371/journal.pone.0121945.

Olga Khazan. The More Gender Equality, the Fewer Women in STEM. URL https://www.theatlantic.com/science/archive/2018/02/the-more-gender-equality-the-fewer-women-in-stem/553592/.

M. D. Nefzger and James Drasgow. The needless assumption of normality in Pearson's r. 12(10):623–625. ISSN 1935-990X, 0003-066X. doi: 10.1037/h0048216. URL http://doi.apa.org/getdoi.cfm?doi=10.1037/h0048216.

Sarah S. Richardson, Meredith W. Reiches, Joe Bruch, Marion Boulicault, Nicole E. Noll, and Heather Shattuck-Heidorn. Is There a Gender-Equality Paradox in Science, Technology, Engineering, and Math (STEM)? Commentary on the Study by Stoet and Geary (2018). 31(3):338–341. ISSN 0956-7976, 1467-9280. doi: 10.1177/0956797619872762. URL http://journals.sagepub.com/doi/10.1177/0956797619872762.

Gijsbert Stoet and David C. Geary. The Gender-Equality Paradox Is Part of a Bigger Phenomenon: Reply to Richardson and Colleagues (2020). 31(3):342–344, a. ISSN 0956-7976, 1467-9280. doi: 10.1177/0956797620904134. URL http://journals.sagepub.com/doi/10.1177/0956797620904134.

Gijsbert Stoet and David C. Geary. The Gender-Equality Paradox in Science, Technology, Engineering, and Mathematics Education. 29(4):581–593, b. ISSN 0956-7976, 1467-9280. doi: 10.1177/0956797617741719. URL http://journals.sagepub.com/doi/10.1177/0956797617741719.

Mark West, Rebecca Kraut, and Han Ei Chew. I'd blush if I could: Closing gender divides in digital skills through education.