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Global education trajectories and inequality: STEM workers from China to the US

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ABSTRACT

The United States has become reliant on workers from abroad to meet its demand for the knowledge-based economy. However, some migrants may face an earnings deficit relative to similar US-born workers. This paper examines the sources of the deficit and asks whether we should expect the initial deficit to disappear with education attainment and work experience in the US. They are challenging to answer as few data sources measure and track market experiences and educational trajectories of migrants over time. Migration and educational trajectories which reflect the country's source of formal educational credentials as well as other forms of capital may explain the deficit, this study applies sequence analysis to the National Science Foundation's 'National College Graduate Survey' to examine earnings differences between China- and US-born STEM workers. After identifying the dominant migration-education profiles for these STEM workers, I show that the wages of migrants with exclusively China-based education are 5–25% lower than those of workers with at least some US-based education, even among workers who are otherwise similar in terms of experience, legal status, employer type, occupation, degree level and time since migration. These findings point to significant and lasting penalties due to non-US education.

KEYWORDS

Migration; education; intellectual migration; trajectory; sequence analysis

Introduction

The rise of knowledge-based economy has fuelled a global race for talent, spurring increased migration rates among the highly skilled. Prior to the interruption of international migration flows by COVID-19, approximately 3 million migrants were moving globally across national borders, among which 35% are considered 'highly skilled' with tertiary education or above (International Organization for Migration 2022; Woetzel, Madgavkar, and Rifai 2016). Due to population aging and the post-COVID 'great resignation', the world's leading economies are now facing serious shortages in skilled labour and millions of future jobs needing to be filled (Bureau of Labor Statistics 2022; Smit et al. 2020; Oliinyk et al. 2021).

For decades, the US has been reliant on highly skilled foreign-born workers. Demand for these workers is particularly strong in the cutting-edge Science, Technology,

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Engineering and Mathematics (STEM) fields, which account for 40% of the nation's GDP (American Immigration Council 2017). Highly skilled foreign-born workers and international students, what Li et al. (2015) describe as 'Intellectual migrants' (IM), play important roles in facilitating the STEM sector (Li, Lo, and Lu 2023). In the US, migrants account for 17% of US labour force, but more than 20% of the STEM labour force (American Association for the Advancement of Science 2020). International students account for 25% of STEM degrees awarded, but only 5.5% of US higher education enrolment (Jeanne Batalova and Israel 2021; National Center for Science and Engineering Statistics 2019).

In spite of their overrepresentation in the STEM fields, scholars observe persistent earnings deficit among intellectual migrants when compared to US-born STEM workers of similar age, education level, occupation and location of employment (Xie and Connor 2022; Wright, Ellis, and Townley 2017). This article therefore asks what are the sources of these earnings deficit? Should we expect earnings differences to dissipate as migrants accumulate education and labour market experience in the US? These questions are challenging to answer as foreign-born workers acquire their multi-faceted 'intellectual capital (IC)' such as education credentials, work experience, and social connections in different education systems and labour markets around the world. Intellectual capital is essential for migrant career advancement, but it is also often tied to specific regional labour markets (Li et al. 2015; Li 2023). IC obtained elsewhere may not have perfect transferability to the US labour markets, partly because of differences in geopolitical and societal structures (Lancee and Bol 2017). While scholars in Europe, Australia and Canada have extensively studied the transfer of foreign education and experience (Boucher 2007; Gabrielli and Impicciatore 2022; Hawthorne 1997; Man 2004; Templeton 2011), there are few data sources in the US that measure and track these foreign experiences and credentials over time. We are not sure how intellectual capital gained overseas impacts economic outcomes in the US labour market and do not know whether the earnings prospects of intellectual migrants differ with education and labour market experience gained in the US.

This study delves into these issues by applying an innovative sequence-analytic approach to simultaneously document and analyse the education and migration trajectories of China-born intellectual migrants in the US, utilising the National Science Foundation's STEM-focused 'National College Graduate Survey' (NSCG) dataset (National Center for Science and Engineering Statistics 2019) for the 2015–2019 period. These education and migration trajectories document China-born intellectual migrants' credentials and migration history in different locations and time. They not only capture the effect of foreign credentials, but also that of the accumulation of other forms of intellectual capital across different time and regions of the world. Within this sequence analytical framework, I assess the extent to which the exposure to different education systems and regional contexts contributes to earnings differentials between US-born and China-born STEM workers in the US.

Using sequence analysis, this study identifies four dominant types of education trajectories among China-born intellectual migrants. These trajectories are associated with substantial earnings differences between the migrants and the native-born. Specifically, Chinese migrants with exclusively China-based education earn 5–25% less than individuals who have at least some US-based education, even when they are similar in terms of

age, gender, education level, employer type, occupation, legal status and duration in the US. On the other hand, China-born intellectual migrants with US-based education (especially undergraduate education) earn more, and eventually catch up with US-born workers after a period of time in the US. These findings suggest that non-US qualifications will continue to hamper the relative economic position of foreign-educated Chinese workers and migrants relative to those education in the US.

This study contributes to understanding the value of foreign-earned intellectual capital. Credential discounting subjects millions of college-educated migrants working in occupations that do not match their skills (Batalova, Fix, and Bachmeier 2016; Carneiro, Fortuna, and Varejão 2012; Friedberg 2000; McHugh and Morawski 2017; Richwine 2022; Wang and Lysenko 2014). It not only jeopardises migrants' income prospects and mental health but also results in substantial losses for the US economy (Batalova, Fix, and Bachmeier 2016; Mattoo, Neagu, and Özden 2008; Man 2004). This study complements previous studies with a more informed analytical approach. The findings imply that improvement of international mutual qualification and skill recognition could yield substantial benefits to foreign-educated immigrants.

Education trajectories, intellectual capital and economic outcome in STEM

Individual and labour market determinants of economic outcome

What factors account for earnings disparities among intellectual migrants? The first explanation lies in their human capital levels. Work in the knowledge economy tends to be highly rewarding for human capital. Even seemingly minor differences in education attainment and work experience (Alegria and Branch 2015; O'Keeffe 2013; Wang and Lysenko 2014) or in occupation and industry (Colakoglu, Yunlu, and Arman 2018; Hanson and Slaughter 2016; Wright and Ellis 2000) could result in notable earnings disparities. These discrepancies have been quantified in detail through microanalysis (Xie and Connor 2022).

A second explanation refers to the labour markets in which different workers occupy. In a recent work, Abramitzky, Boustan, and Eriksson (2020) document that immigrants and their children generally experience more upward mobility than natives because they are more likely to live in the most dynamic labour markets. For those working in the STEM fields that are highly specialised, relatively well remunerated, and at the technological frontier of the economy, different regional labour markets can be a key determinant of their earnings outcome (Executive Office of the President of the United States 2021; Xie and Connor 2022). A large body of literature in economic geography documents that STEM industries, 'Big Tech' firms and high earnings intellectual migrants all tend to cluster in regions with more vibrant knowledge-based economies, better economic prospects and stronger ethnic networks and welcoming environment (Grogger and Hanson 2015; Autor 2019; Feldman, Guy, and Iammarino 2021; Feldman et al. 2021; Kemeny and Osman 2018; Abramitzky, Boustan, and Eriksson 2020; Connor 2020; Florida and Mellander 2016; Storper and Scott 2008; Connor and Storper 2020). These cities are often characterised as 'superstar cities' or intellectual gateways (Kemeny and Storper 2020; Li et al. 2015).

Intellectual migrants tend to benefit from their concentration in these regions through knowledge spillovers and agglomeration effects while leaving workers in other peripheral cities behind. In addition to these well-recognised determinants, recent studies on inequality in STEM have revealed persistent earnings deficits for foreign-born workers especially women, regardless of their individual characteristics and location (Xie and Connor 2022; Wright, Ellis, and Townley 2017; Wright and Ellis 2019). This means that unobserved factors such as discrimination, immigration status or unobserved cognitive and non-cognitive differences may be at work (Alegria and Branch 2015; Grove, Hussey, and Jetter 2011; United Nations 2018).

Transferability of intellectual capital

In addition to the importance of employment location and education level in determining economic outcomes among intellectual migrants, the location where they obtained their education and labour market experience also plays an important role in shaping their economic fortune. The location of education often determines the development of labour market-specific skills and experience, social networking through mentorship, community engagement and so on, and access to different job and internship opportunities (Lysenko 2017). These different forms of capital, captured in terms such as 'intellectual capital' and 'career capital' (Li 2023; Tan et al. 2023; Zikic 2015), interact and reinforce each other in shaping the career outcome of highly skilled migrants.

Intellectual capital may not transfer well across borders due to the different societal structures, economic and geopolitical dynamics (Basilio, Bauer, and Kramer 2017; Batalova, Fix, and Bachmeier 2016; Lancee and Bol 2017; Li et al. 2015; Li 2023; Lysenko and Wang 2020; Paul 2011; Yeoh and Khoo 1998). Migrants are often pushed into earnings deficits or occupations below their skill level (Batalova, Fix, and Bachmeier 2016; Carneiro, Fortuna, and Varejão 2012; Friedberg 2000; McHugh and Morawski 2017; Wang and Lysenko 2014).

A range of factors hinders the trans-local/transnational transferability of intellectual capital. The low recognition of foreign credentials and experience accumulated prior to migration could heavily hinder the job access and earnings prospects of highly skilled migrants with foreign degrees (Ferrer and Riddell 2008). The quality of tertiary education in countries of origin, real or perceived, and as measured by the language of instruction, national expenditure on education and social instability could adversely weaken the credentials of college-educated migrants, thus lowering their earnings prospects (Mattoo, Neagu, and Özden 2008). The lack of transferrable labour market-specific information and skills, language proficiency and experience in host-country labour market could also exacerbate the earnings deficit and underemployment of intellectual migrants (Bazzi et al. 2016; National Academies of Sciences and Committee on Population 2016). Visa status, work authorisation and legal restrictions also limit the job mobility and job access of highly skilled migrants, especially those travelling as 'trailing spouses' (Bhatt 2018; Man 2004; Hunt and Xie 2019; Sumption and Flamm 2012). Last but not least, employer bias towards accented English and visible minority status can also damage migrants' earnings prospect and job access (McHugh and Morawski 2017).

Education and migration trajectories

It is rather challenging to study the effect of these factors due to migrants' complex migration histories. Foreign-born workers often acquire intellectual capital from different education systems and labour markets of the world. Few data sources can directly measure or document the complexity of education, employment and migration experiences overtime (Moretti 2012). Proxy measures such as years of schooling, job categories, immigration year and countries of origin are often employed (Batalova, Fix, and Bachmeier 2016; Wang and Lysenko 2014; Zhen and Xie 2004). But they tend to view immigration in a static and one-step process and often fail to address the transferability of skills and experiences gained overseas immediately upon arrival or over time in the STEM labour market of the US. For example, it is yet unclear whether a China-born worker with ample experience gained in the US through years of experience of US-based college education and employment would defer in career pathway in the US labour market, comparing to someone with relatively fewer US-based education but the long experience of education earned in China. More systematic analyses engaging the education and migration trajectories of highly skilled migrants can offer new insights. These education and migration trajectories document intellectual migrants' multiple exposures to different education and regional contexts, not only reflecting the skillsets and credentials acquired under different education systems, but also their social relations, experience and resources established in the different regional labour market (Li, Lo, and Lu 2023; Paul 2011; Paul 2015; Salamońska 2017; Schapendonk 2018; Wee and Yeoh 2021).

Traditionally, migration trajectory is viewed as a sequence of linked movements defined by periods of spatial settlement in socially constructed places (Schapendonk 2018). Immigrants encompass multiple geographies (intra- and international) and temporalities (Salamońska 2017), develop multiple belongings and are embedded in transnational networks of social relations (Wee and Yeoh 2021). This concept of migration trajectory is usually utilised to study how lower-skill migrants especially Asian domestic workers move in a hierarchy of destination regions, gradually establish and accumulate social, human and economic capital and legal status to move to their preferred destinations, often in the West (Liao and Gan 2020; Paul 2011; Kim 2019; Salamońska 2017; Paul 2017).

Nonetheless, this concept is certainly applicable to examine how highly skilled migrants accumulate monetary, social, ethnic, human and legal capital at different geographies and temporalities (Paul 2011; Paul 2015). The intellectual migration framework, with the notion of intellectual capital to capture the transnational and tans-local accumulation and transfer of different forms of human, social, cultural and symbolic capitals for career development, underscores the education and migration trajectories of highly skilled immigrants. Different trajectories reflect intellectual migrants' varying exposure to different spaces for economic and social activities and intellectual capital formation (Lysenko 2017; Li, Lo, and Lu 2023).

Data and method

Despite the importance of education and immigration trajectories in shaping the economic prospects of migrants, there is no documentation of foreign education experience

in US census data. Leveraging the retrospective education history from the NSF's STEM-focused 'National College Graduate Survey' (NSCG) dataset, this study aims to develop a new method to simultaneously document and analyse the migration and education trajectories of highly skilled migrants in the STEM fields of the US and examine the relative economic outcomes.

NSCG dataset

This study utilises the 2015–2019 NSCG public-use microdata. While Zhen and Xie (2004)'s study of 'place of education' demonstrated the potential utilisation of foreign education information in this study, few studies have fully utilised this data source to study the effect of overseas education on earnings prospect of STEM workers in the US. This dataset is sampled from the 'STEM-related persons[1]' from the American Community Survey (ACS), and contains roughly 100,000 stratified raw samples[2] (National Center for Science and Engineering Statistics 2019). It is useful to study the linkage between migration-education trajectories and economic outcomes as it directly documents the detailed education background and migration history of the STEM workforce in the US.

The NSCG data contain a detailed retrospective education history. As Figure 1 illustrates, it documents information such as the degree types, fields of study, locations and institution types of the fifth to the highest degrees of the respondents.[3] The information on migration history includes details regarding citizenship, visa type, years since moving to the US and so forth. In addition, it documents different economic and employment measures such as inflation-adjusted annualised wage, job-skill matching score,[4] employer sector and location,[5]

For this study, I focus on intellectual migrants moving between the two largest economies in the world, China-born STEM working age group in the US (25–65 years old).[6] China is the second largest sender of intellectual migrants to the US, and the largest sending source of advance degree holders. My sample contains an estimate of 834,000 China-born intellectual migrants in the STEM fields of the US, among which 60% hold advanced degrees in STEM; for comparison, the US-born sample contains an estimate population of 53,957,973, 35% of which hold advanced degrees (National Center for Science and Engineering Statistics 2019).

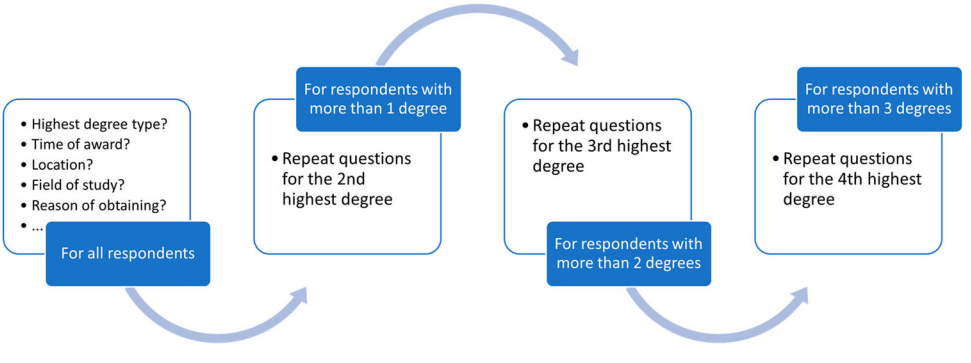

Figure 1. NSCG education history data collection process.

Multi-channel sequence

In this study, I apply an innovative multi-channel sequence analysis technique to simultaneously track and analyse the education and immigration trajectories of intellectual migrants. Sequence analysis is a method originated from biomedical and genome research to track multiple categorical changes over time. This method is adopted in social science to track multiple social trajectories, community changes or life stages such as employment, demography, housing and family (Connor et al. 2022; Gabadinho et al. 2011; Studer and Ritschard 2016). It is based on the optimal-matching algorithm and differentiates different trajectories by the number of stage changes needed from one sequence to the other. In my study, I use this method to simultaneously track the location, degree type, field of study and institution type to identify dominant education trajectories among China-born intellectual migrants in STEM. Countries are adopted as the indicators of exposure to different regional context and education systems, institution types are adopted as the proxy for school size and quality, degree type is adopted as the indicator of human capital level and field of study is adopted as the indicator of STEM-related knowledge and skills.[7] In addition to the trajectories among China-born intellectual migrants, I also reproduce similar analysis to US-born STEM workers for comparison. The analysis is conducted using the TraMine package in R (Gabadinho et al. 2011).

Earnings prospect models

I conclude the analysis by estimating the effect of migration-education trajectories on the earnings of China-born STEM workers in the US. I model the earnings within an ordinary least squares (OLS) framework with standard age and gender controls. I start with a baseline model estimating the earnings differential among different migration-education trajectories and sequentially add individual controls over key determinants of the realisation of foreign-earned intellectual capital. These models can be described as:

$$Y_i = \beta_1 AGE_i + \beta_2 GENDER_i + \beta_3 TRAJECTORY_i + \beta_k X_{i,k} + \mu_i \quad (1)$$

where Y_i is the natural logarithm of the annualised wage for individual i, and these wages are estimated as a function of a range of earnings determinants. $TRAJECTORY_i$ estimates for the effect of different migration-education trajectories. Earnings are also predicted by X, a list of k control variables including type of employer, occupation type, visa and legal status, a year spent in the US and years holding permanent residency.

Dominant education trajectories

I begin the results with an overview of the dominant trajectories extracted from the sequence analysis in Table 1. The sequence analysis fit statistics[8] all point to four dominant migration-education trajectories among China-born intellectual migrants. Each column in Table 1 describes the dominant location, degree, field of study and institution of the corresponding trajectory. As Table 1 shows, these trajectories are largely differentiated by location of education and degree types, while the field of study and institution types are relatively similar.

Table 1. Overview of the multi-channel education trajectories for China-born STEM workers.

China-born education trajectories					
Type	Population estimates	Location	Degree type	Field of study	Institution
Multiple US advance degrees	86,559	China to US, longer in US	2+ Advanced Degrees	STEM	Research 1 & 2
China-based education	254,606	Mostly China	Some Advance Degree	STEM & STEM-related	China-based
US-based college graduate	174,164	US	Bachelor's	STEM	Research 1 & 2
China–US hybrid education	318,900	China to US, shorter time	1 Advanced Degree	STEM	Research 1 & 2

Note: These sequences are generated using China-born samples from the NSCG, aged between 25 and 65. Column 2 documents the weighted count of population of each trajectory. Columns 3–6 describe the location, degree, field of study and institution of each trajectory. See Figure 2 for the detailed visualisation for the China-born trajectories.

Four faces of education trajectories

I begin introducing the details of the migration-education trajectories with Figure 2, visualising the representative sequences of the four dominant trajectories generated through the sequence analysis. Each row visualises the detail of the corresponding migration-education trajectory. Each column, from left to right visualises the corresponding location, degree type, field of study and institution classifications.

Each individual sequence plot, or each 'cell' in Figure 2 should be read from left to right, representing the corresponding stage changes for the person's fourth highest to the highest degrees earned. For example, the cell in the first row and second column of Figure 2 should be interpreted as people with an education trajectory of three or four degrees, or a bachelor's degree (fourth or third highest degree) followed by two or three master's degrees (third to highest degree). A blank stage indicates that either the person does not have the corresponding degree stage, or such information is absent in the NSCG dataset (such as institution classification of overseas schools). In addition, analysis of US-born education trajectories reveals five different trajectories and two of them are particularly similar to some of the China-born trajectories.[9]

I also present some descriptive demographic, education and economic profiles of each migration-education trajectory and visualise them in the radar charts in Figure 3. These radar charts display the standardised score of each trajectory's average age, years spent in the US, share of women, share of advanced degree holders, job-skill matching score, and annualised wage. I will explore the details of these trajectories in the following section.

China trajectory 1: multiple US advanced degrees

Row 1 in Figure 2 captures the trajectory associated with multiple US advanced degrees. This trajectory is characterised by China-based bachelor's degrees, followed by two or more US-based advance degrees. These degrees are mostly STEM major, from Research 1 or 2 institutions. The separate sequence analysis of US-born workers also identifies very similar trajectory with only differences in the locations of bachelor's degrees. China-born migrants with this trajectory have an older average age among all the STEM workers in

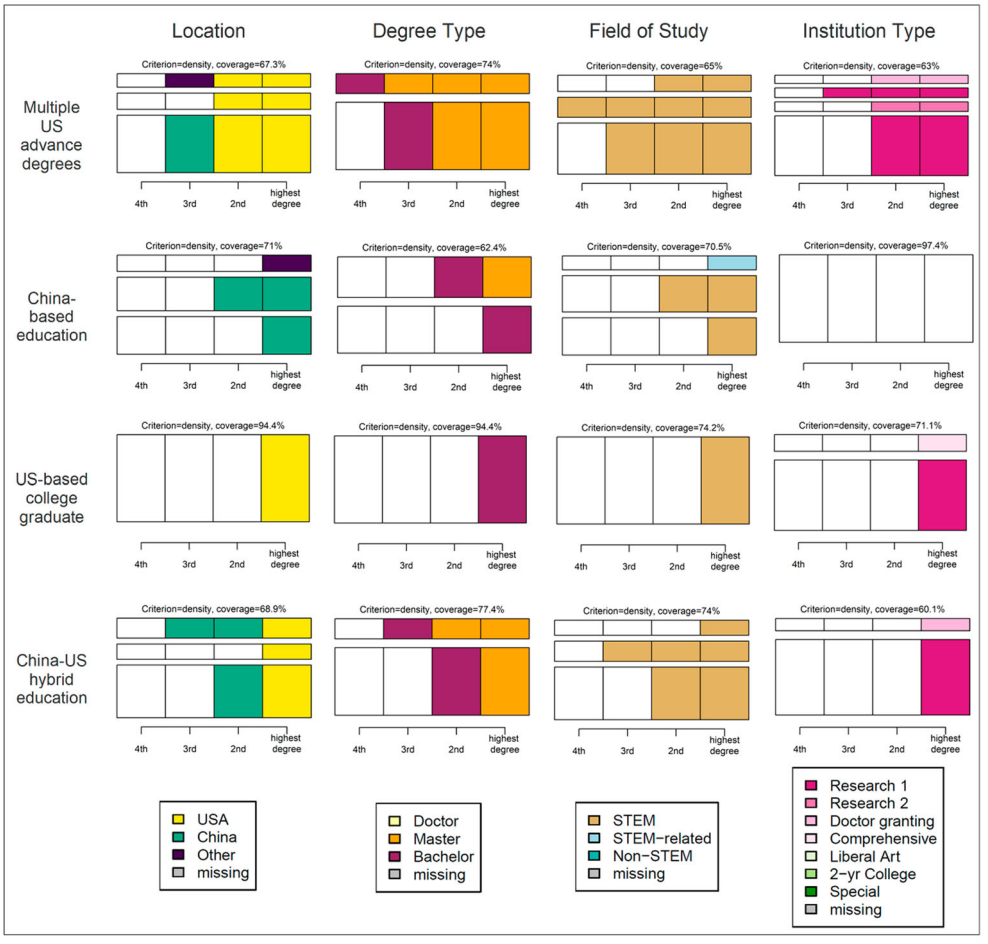

Figure 2. Representative trajectories of China-born college-educated intellectual migrants in STEM, aged between 25 and 65. These trajectory plots are generated with a minimum coverage of 60%. Each row visualises a multi-channel education trajectory, while each column plots the location, degree type, field of study and institution type changes from fourth highest to the highest degree earned.[11] These graphs only display representative trajectories in each typology, thus they only show certain portion of sequence member's education trajectories, as the coverage statistics at the top of each plot indicated.

the US, but they tend to be the oldest and spend the longest time in the US among China-born. They have the lowest share of women, highest wage and job-skill match score.

China trajectory 2: China-based education

Row 2 of Figure 2 captures the trajectory with only China-based education. China-born migrants in this trajectory tend to have their degrees in STEM major from China-based institutions, and 40% of them have advanced degrees. While they tend to have average ages, they spend the shortest time in the US, earn the lowest average wage and have the lowest job-skill matching score among China-born migrants. This trajectory also contains the highest share of women.

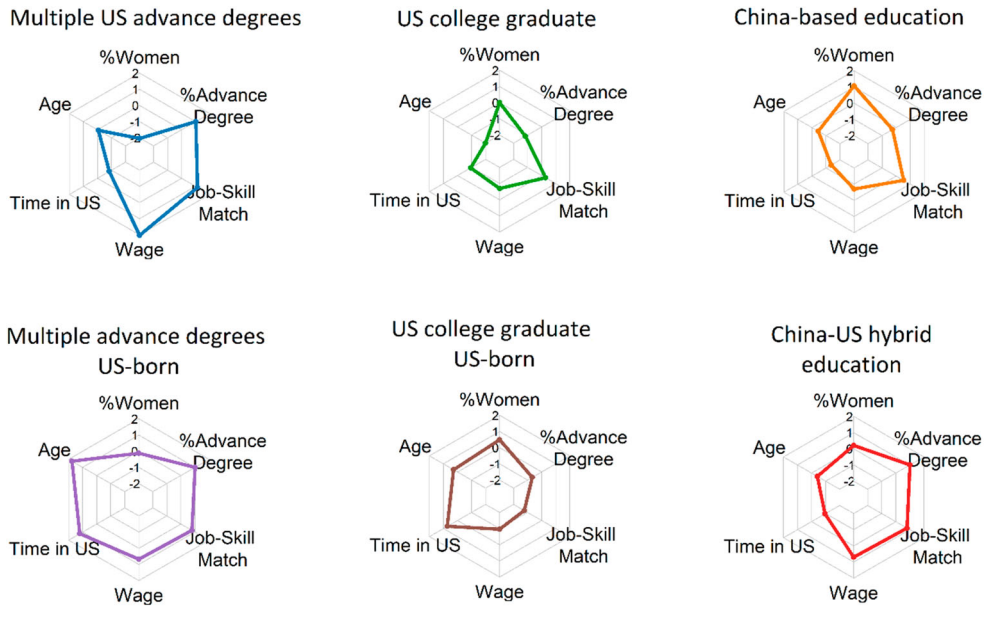

Figure 3. Demographic characteristics of China-born and US-born education sequences. These numbers are derived from the standardised scores of six different demographic and economic variables. They are calculated based on the profiles of all China- and US-born samples. % Women refers to the share of women in each sequence group, % Advance Degree is calculated through the share of sequence members holding at least one postgraduate degree. Job-Skill Match is derived from the 'OCEDRLP' variable in the NSCG dataset, measuring to what extent the respondent's work is related to their highest degree. In this analysis, I recoded the 'OCEDRLP' variable so higher score would indicate a higher relatedness between work and highest degree. Wage captures the annualised wage in US dollars, adjusted to 2019 value. Time in the US captures the time since the respondent first entered and lived in the US for over 6 months (or the respondent's age if US-born). See appendix 2 for details and raw numbers.

China trajectory 3: US college graduate

Row 3 of Figure 2 describes the trajectory associated with US college graduates. This trajectory is characterised by only US-based education and bachelor's degree. The separate sequence analysis of US-born workers also identified identical trajectory. China-born migrants with this trajectory tend to earn their bachelor's degree in STEM major from major research universities in the US. They tend to be the youngest group, but they spend slightly longer time in the US than those with China-based education given the length of both their education and employment in the US. They have an average share of women, and they achieve similar wage and job-skill matching score as China-based education, signs of depreciation of intellectual capital gained overseas.

China trajectory 4: China–US hybrid education

The last row of Figure 2 captures the trajectory associated with China–US hybrid education. This is the largest trajectory group among China-born migrants, and it is featured with China-based bachelor's followed by one US-based advanced degrees. China-born

migrants with this trajectory earn their degrees in STEM major, mostly from China-based institutions then Research 1 or 2 institutions in the US. They tend to have average age, average share of women and average time in the US among China-born. Notably, they have exceedingly high job-skill matching scores, and on average they even earn higher wage than most US-born STEM workers.

The visualisations and descriptive profiles of these trajectories present preliminary evidence of the discount of foreign-earned qualifications. Despite having a younger average age, China-born migrants with only one US-based bachelor's degree tend to earn a similar average wage as those holding advanced degrees from China. China-born with multiple US advanced degrees even out-earn US-born with similar education trajectory.

However, these descriptive results also show that demographic factors such as gender and age could affect earnings. Those with China-based education face a prominent earnings deficit, but they have the highest proportion of women. China-born multiple advance degree holders earn the highest wage, but women are most underrepresented in this sequence. We are unsure if the earning differential is a result of the prevailing gender pay-gap in STEM and age differences. Hence, I will explore these issues in greater detail in the next section.

Earnings prospect of China- and US-based education

I conclude my analysis by exploring the extent to which these migration-education trajectories can explain the earnings differential among China-born intellectual migrants in the US. I begin the analysis by examining how income varies by gender and age among the members of different trajectories. I explore these relationships using two sets of local regression models to fit a set of non-linear curves.[10] I visualise these relationships in Figure 4, in which each panel shows the earnings curve of men and women of the corresponding education trajectory at different ages.

The earnings curves reveal strong evidence of discounting in foreign-earned credentials. Comparing to the other three China-born earnings curves, migrants with China-based education trajectory have disadvantaged wage regardless of gender. Their earnings disadvantages persist from early career to later ages. Despite that some of them have advanced degrees, they even earn lower starting and peak wage than China-born US college graduates. Noting that women are much overrepresented in the China-based education trajectory, they could be more vulnerable to these earnings discount.

On the contrary, the earnings curves of China-born US college graduates display strong return to migrants' US-based degrees. Both men and women with this trajectory hold much higher starting wage compared to US-born with identical trajectories at their early career. However, there is also clear evidence of the 'bamboo ceiling', as China-born men with US college graduate trajectory earn lower peak wage than US-born men.

The high return to China-born migrants' US-based education is more evident among women. While the earnings curves of US-born workers display a strong and persistent gender wage gap especially at the peak earnings ages, such gender gap among China-born migrants is much smaller and less persistent, particularly among those with US college graduate trajectory. China-born US college graduates not only show the smallest gender gap, but also evidence of breaking the gendered 'glass ceilings'. China-born women not only out-earn US-born women through all ages, but catch up with China-

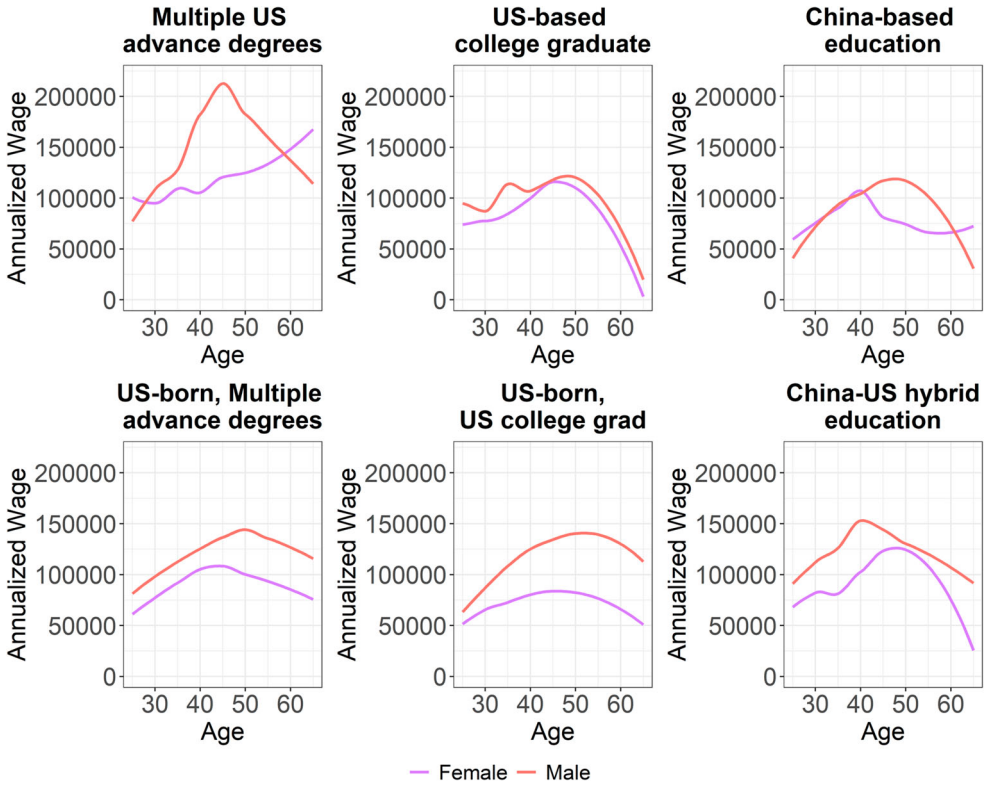

Figure 4. Local regression models between annualised wage in STEM and age. Local regression models between annualised wage in STEM and age. The nine models summarise the effect of different education trajectories on China- and US-born, male and female STEM workers, aged between 25 and 65.

born men with similar trajectory. While the selective nature of STEM education and employment might contribute to the high wages of China-born female US college graduates, women are not necessarily underrepresented in this group, further showing that they could benefit from exposure to US-based education.

I finalise the analysis with a set of OLS models estimating the effect of education trajectories on income, controlling for employer, citizenship and legal status, and experience in the US. I present these results in Table 2. Column 1 presents a baseline model 1, estimating the earnings differential among the four China-born education trajectories controlling for age and gender. I sequentially added controls over key earnings determinants in column 2–4 to test the effect of employer, visa and legal status, and experience in the US. I end the analysis with a model 5 simultaneously estimating the effect of all variables.

The baseline model 1 shows strong coefficients for each of these education trajectories. Adjusting for gender and age, the comparison of the four migration-education trajectories reveals that individuals with a China-based education trajectory experience a substantially stronger earnings penalty. These findings provide further confirmation of the patterns shown in Figure 4. In exponentiated US dollar terms, on average they earn roughly 41% lower than those with multiple US advance degrees, 23% than those with

Table 2. Log-transformed annualised wage by key determinants of intellectual capital realisation.

	1	2	3	4	5
Outcome	(Log) Annualised salary	(Log) Annualised salary	(Log) Annualised salary	(Log) Annualised salary	(Log) Annualised salary
Age	0.010***	0.008***	0.0004	−0.001	−0.004*
	(−0.001)	(−0.001)	(−0.002)	(−0.002)	(−0.002)
Women	−0.138***	−0.069***	−0.211***	−0.142***	−0.116***
	(−0.027)	(0.025)	(−0.026)	(−0.026)	(−0.025)
Education trajectories (ref = Multiple US advance degrees)					
China-based	−0.520***	−0.438***	−0.400***	−0.413***	−0.243***
education	(−0.046)	(−0.043)	(−0.044)	(−0.047)	(−0.050)
US college	−0.254***	−0.234***	−0.367***	−0.343***	−0.174***
graduate	(−0.051)	(−0.048)	(−0.05)	(−0.052)	(−0.064)
China–US hybrid	−0.218***	−0.199***	−0.197***	−0.207***	−0.171***
education	(−0.043)	(0.040)	(−0.041)	(−0.043)	(−0.038)
Employer (ref = education institutions)					
Industry and		0.640***			0.502***
business		(−0.031)			(−0.031)
Public Sector		0.389***			0.251***
		(−0.064)			(−0.06)
Occupation (ref = STEM occupations)					
Non-STEM		−0.201			−0.259***
occupation		(0.028)			(0.027)
Citizenship and Visa status (ref = naturalised citizen)					
Permanent			−0.119***		0.157***
Residency (PR)			(−0.036)		(0.053)
Other Visas			−0.251		−0.108
			(−0.293)		(−0.272)
Spouse Visa			−0.257		−0.167
			(−0.166)		(−0.155)
Student Visa			−0.894***		−0.598***
			(−0.055)		(0.057)
Temporary Work			0.026		0.112**
Visa			(−0.048)		(0.047)
Experience in the US					
Time in the US				0.016***	0.011***
				(−0.002)	(−0.002)
Time with PR				−0.005	−0.019***
				(−0.003)	(−0.072)
Constant	11.274***	10.842***	11.785***	11.412***	11.247***
	−0.063	−0.062	−0.082	(−0.066)	(−0.005)
Observations	617,498	617,498	617,498	617,498	617,498
R^2	0.094	0.233	0.197	0.114	0.308
Adjusted R^2	0.092	0.231	0.194	0.112	0.304
Residual Std. Error	10.322	9.499	9.722	10.207	9.038
	(df = 2686)	(df = 2683)	(df = 2681)	(df = 2684)	(df = 2674)

Standard errors in parentheses: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Note: This sample is confined to China-born STEM workforce in the US, aged 25–65, employed with earnings over $1000 in the previous year. The outcome variable is the log-transformed annualised wage. Employer industry contains three groups from the NSCG's Employer sector summary codes. Occupation contains STEM/non-STEM occupation broad group codes. Time in the US is calculated as the time between 2019 and the year the respondent's first came to US for 6 months or longer. Time with permanent residency is calculated as the time between 2019 and the year when the respondent obtained permanent residency.

US college graduate trajectory, and 26% lower than those with China–US hybrid education. Surprisingly, despite not having advanced degrees, those with US college graduate trajectory earn a higher wage than China-based education trajectory, but they also catch up with those holding China–US hybrid education. The earnings differential between these two trajectories is only 3.4% in exponentiated US dollar terms, further highlighting

the high return to US-based bachelor's degrees and associated US-based intellectual capital accumulation such as language and culture dividends.

As columns 2–4 show, the earnings effects observed in model 1 persist after the addition of controls for employer sector, occupation, visa and legal status and experience in the US. Those with China-based educations continue to exhibit a strong earnings penalty due to their education trajectory. When I simultaneously model the effect of education trajectories and other determinants, the earnings penalty associated with China-based education trajectory is mitigated slightly but remains 5–24% lower in exponentiated US dollars than workers with other education trajectories. More importantly, as model 5 demonstrates, the education trajectories displayed a much larger magnitude in their coefficients comparing to legal status and experience in the US. While it is unclear whether unobserved factors such as school quality and non-cognitive skills played any role in determining the economic effect of education trajectories, the controls over legal status and experience in the host labour market indicate that these factors are not significantly hindering the transferability of skills and experience earned in China. More nuanced data on personal cognitive abilities, school qualities, employer preference and the regional labour market will be needed to further explore such possibilities.

Discussion and conclusion

Intellectual migrants are important because they make a great contribution to the innovation and advancement in the Science, Technology, Engineering and Mathematics fields of the US. However, they face persistent income deficits even if they hold similar occupations, education level and location of employment as their US-born peers (Wright, Ellis, and Townley 2017; Xie and Connor 2022). While scholars observe a prevalent discount to foreign-earned human and social capital in many Global North countries such as Canada and Australia, relatively little is known about the devaluation of foreign-gained intellectual capital in the STEM fields of the US by using direct measures. In this article, I address this issue with respect to intellectual migrants in the STEM fields of the US. I apply an innovative sequence analysis technique to China-born migrants in the STEM-focused NSCG data and to document and evaluate the role of educational background, and experience gained in different regional labour markets in accounting for the labour market performance of intellectual migrants.

This article has three main contributions. First, it provides an analytic framework for studying migration-education trajectories among intellectual migrants in the US. Second, using the empirical case of China-born migrants in the STEM fields of the US, this study documents that these trajectories play important and lasting roles in shaping the earnings prospect of migrants. Given this work has shed new insights into economic inequality with respect to foreign-born STEM workers, this framework could be applied to many other contexts and groups. Third, the findings of this analysis bear policy implications and highlight the importance of mutual qualification recognition and inclusive STEM education.

My first major finding identifies four multi-dimensional migration-education trajectories among China-born intellectual migrants in the STEM fields of the US. They extend our understanding of human capital and migrants' economic outcomes using more static measurements such as years of schooling, years of migration and degree

location (Mattoo, Neagu, and Özden 2008; Wang and Lysenko 2014; Zhen and Xie 2004) and highlight the effect of the accumulation and transfer of multi-dimensional intellectual capital at different locations and life stages. These China-born trajectories are largely determined by the location of education and degree types. Most of them have STEM degrees from China-based institutions or US-based major research universities. Compared to US-born with similar levels of education, most of them have very high wage at early career and high job-skill matching scores, reflecting the selective nature of STEM and immigration in the US (Hunt and Xie 2019). However, as they progress towards mid-career, their lower earnings peak also reveal evidence of the 'bamboo ceiling' in the workplaces of the US (Tan 2008; Yu 2020). The descriptive profiles of these trajectories show more preliminary evidence of discounting of foreign-earned credentials and experience, as China-born migrants with only China-based education trajectory face large earnings deficit comparing to those with US-based education experiences.

Analysis of economic prospect strengthens the preliminary findings of the discount, confirming the lack of transferability of foreign-gained intellectual capital can substantially jeopardise migrant's economic prospect (Lancee and Bol 2017). Regardless of age, gender, legal status, employer type, occupation, or experience in the US, those with only China-based education face the strongest earnings penalty, earning 5–25% lower wage than China-born intellectual migrants with some US-based education. These initial earnings deficits do not dissipate even when they spend more time in the US. Even those with some US-based education tend to face a bamboo ceiling, earning lower peak wage in their mid-career compared to similarly educated US-born (Yu 2020; Tan 2008). These findings suggest that the discounting of foreign intellectual capital in the US is likely to have a lasting impact on the economic fortunes of highly skilled foreign-born workers, and this lasting earnings deficit is rarely compensated by longer experience in the US. These findings also confidently conclude that factors such as gender, experience, and legal status are not the most significant barriers to the transfer of foreign-gained intellectual capitals. Other factors such as qualification recognition, tertiary education quality in China and employer bias may play more important roles here. Investigations into these factors would require more detailed microanalysis and different international data sources.

On the other hand, this study finds that there is potentially high return to intellectual capital gained in the US, especially for women. Unsurprisingly, women are more likely to face discount to their China-based education and experience, resembling the double-disadvantage observed by other scholars (Donato, Piya, and Jacobs 2014; van Veelen, Derks, and Endedijk 2019). However, while a gender wage gap is prevalent among STEM workers in the US, China-born female migrants benefit from higher return to their US-based bachelor's degrees, earning higher wage than US-born women and catch up with China-born men with similar trajectory as they both progress towards mid-career in the US. What's surprising is that women are not necessarily underrepresented in this high-earning US college graduate trajectory. This suggests that China-born women could enjoy a lasting high return to their US-based education, and this reward is further strengthened by their accumulation of experience in the labour market of the US, reflecting the interaction effect of multi-dimensional intellectual capital (Li, Lo, and Lu 2023; Tan et al. 2023). While this study cannot provide conclusive evidence

on why foreign-born women experience such wage premium, it presents strong evidence that it is not due to nativity, education trajectories nor the gender-selective nature of STEM education in the US. Unobserved factors such as immigration unit, selective nature of China-to-US immigration system, school quality or gender-ethnic networks could be at work here (Waters and Leung 2013; Pascarella and Terenzini 2005; Alegria and Branch 2015; Hunt and Xie 2019; Grove, Hussey, and Jetter 2011; Zhou and Lee 2017).

This study bears two major policy implications. Firstly, it reveals that factors such as legal status and experience in host country hardly alleviate the long-lasting effect of the discounting of foreign qualifications. Thus, to help migrants better utilise their intellectual capital and economic contributions, it is necessary for policy makers to answer the UN's call for facilitating mutual recognition of skills, qualifications and competences (United Nations 2018). Secondly, this study observes a high return to migrant women's early exposure to US-based STEM education. This initial reward is further reinforced as they gain more experience in the labour markets of the US. Consequently, to improve gender equity in the STEM fields, it is important for government agencies and education institutions to provide inclusive STEM education, strengthen the gender-based mentorship in STEM education and workplace and encourage the participation of women and racial minority in STEM.

Although this study sketches out a framework for studying the impact of migration-education trajectories on earnings, it is confined to relative coerced geographical and school quality information in the public-use version of the NSCG data. Further studies with different methods and data will be needed for nuanced explanation of these migration-education trajectory patterns and their economic effects. Firstly, we know that school location and access to the corresponding local labour market could affect economic outcomes of STEM workers (Lysenko 2017). Incorporating this information would improve my ability to explain the earnings differentials along these lines but would require the use of restricted data. Secondly, for the interpretability of results, this study is limited to relatively coarse definitions of STEM field of study and occupations. The use of more detailed industry, occupation and field of study codes would improve the understanding of earnings differences along these lines. In addition, the inclusion of macro-level factors and samples of different countries of origin could further advance the field. As various scholars have noted, macro-level international relations and local policies both affect intellectual migrants' employment experience (Li et al. 2015; Kemeny and Cooke 2017; McDaniel, Rodriguez, and Wang 2019). My future work should therefore address these dimensions and further investigate how changes in international relations and local policies shape the economic trajectories of intellectual migrants.

Notes

1. College educated, either with STEM-related education or work in a STEM occupation.
2. NSCG takes a stratified sampling strategy to maximize its coverage of different demographic, education and occupation groups (National Center for Science and Engineering Statistics 2019)
3. Due to the extremely small sample size, the fifth highest degree is omitted in the analysis.

4. Job-Skill Match is derived from the 'OCEDRLP' variable in the NSCG dataset, measuring to what extent is the respondent's work is related to their highest degree. Higher score denotes a closer match.
5. Due to data compression in the public-use NSCG dataset, the geographic unit in this analysis is limited to countries and census divisions; the institution identifier is limited to the 1994 Carnegie classification codes; citizenship and visa type are restricted to citizen/non-citizen/naturalized citizen, and temporary/permanent visas.
6. Age 25–65 is selected to capture working age population with college education per ACS standard; see US Census Bureau (2020) for detail.
7. To reduce the complication in the optimal-matching distance calculation and trajectory clustering process, this study has adopted country code as the indicator of education location, STEM/STEM-related/non-STEM broad group codes for field of study, and 1994 Carnegie code for institution identifier.
8. I have tested multiple sequence analysis fit statistics such as the silhouette score and elbow method, and the results all point to the four-type solution.
9. The details of the five US-born trajectories will not be discussed here since they are not the main point of this analysis. See appendix 1 for additional detail and visualization of US-born sequences.
10. I use non-linear curves here because STEM worker's wages don't necessarily follow the traditional age-earnings profiles. See Deming and Noray (2018) for details.
11. The NSCG data provide a retrospective education history of the respondent that dates back from the person's highest to fifth highest higher education degrees. The fifth highest degree is omitted in the sequence analysis due to the limited sample size. Hence, the starting point of these visualizations should be interpreted as the respondent's fourth highest degree instead of first degree, as they may have more than four degrees.

Disclosure statement

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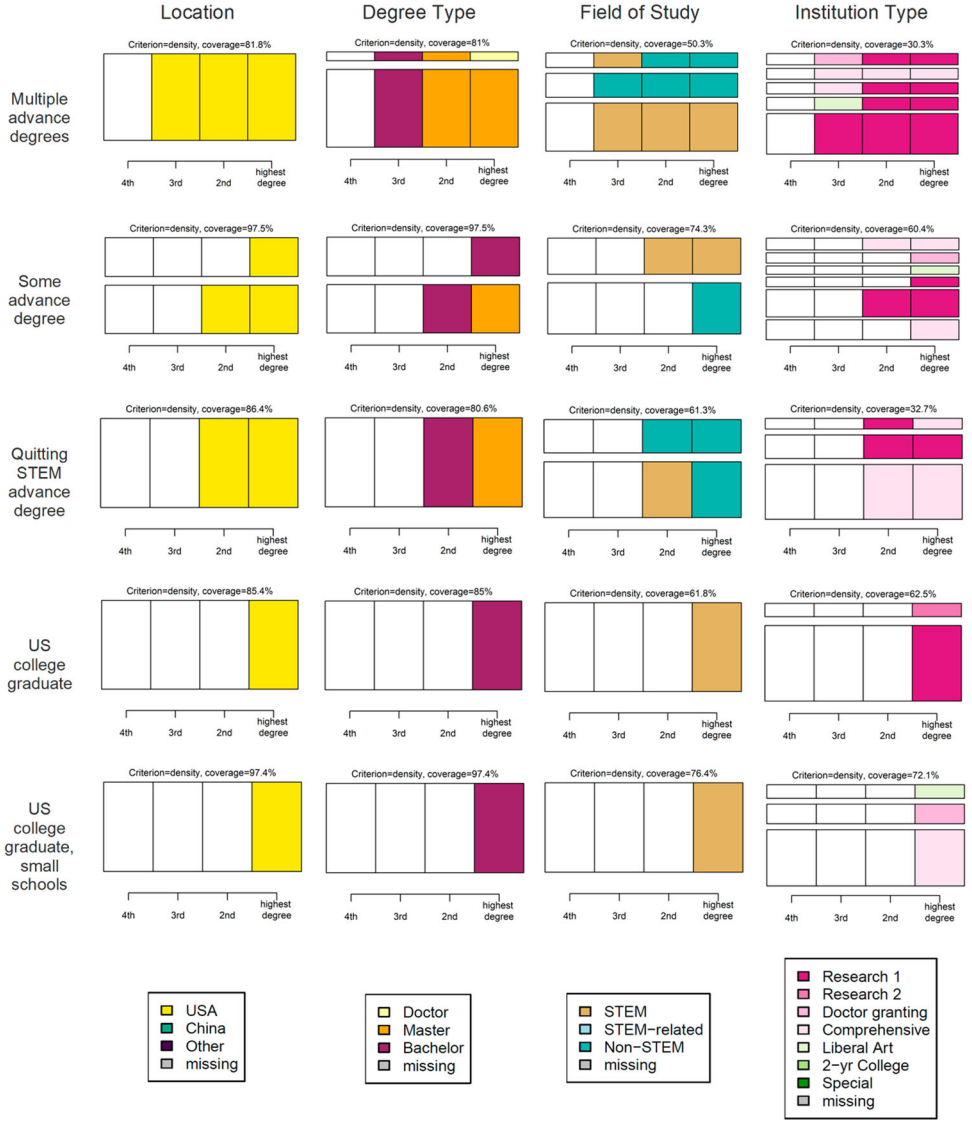
Appendices

Appendix 1. Representative trajectories of US-born college-educated STEM workforce, aged between 25 and 65.



Appendix 2. Average demographic profiles of education trajectory members.

	Estimate population	Share of women (%)	Age	Time in the US	Annualised wage	Job-skill match	Advanced degree (%)
China 1	73,422	40.2	40.1	19.4	131,171	0.91	100.0
China 2	185,838	57.7	38.3	11.9	79,274	0.84	41.8
China 3	132,808	51.6	31.2	18.1	79,220	0.81	1.2
China 4	272,888	52.8	38.6	17.8	105,950	0.87	100.0
US 1	1,869,267	50.9	48.6	48.6	105,494	0.87	100.0
US 2	12,778,157	54.4	41.7	41.7	74,111	0.63	30.2
US 3	9,182,659	59.2	43.5	43.5	94,055	0.79	100.0
US 4	6,314,924	48.0	41.0	41.0	89,595	0.68	16.9
US 5	11,537,934	49.9	41.0	40.9	73,277	0.57	0.5