Broadband as a Complement to Institutional Access: Evidence from Education Deserts

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Received: 05/01/2026
Accepted: 08/31/2026

Abstract

In this study, we examine whether household broadband access moderates spatial barriers to human capital investment in education deserts, defined as areas located more than 50 miles from a broad-access public institution. While prior research has examined education deserts and broadband access independently, relatively little is known about how household broadband access influences the perceived returns to human capital investment within education deserts. Using survey data and a discrete choice experiment administered to workers employed throughout the agricultural and food system across the United States (n = 321), we estimate individual-level valuation measures for a full, industry-recognized, stackable certificate. We then evaluate how valuation varies across combinations of education desert status and household broadband access using regression and predictive margins. The results indicate a significant interaction between education desert status and high-speed household broadband access. Among respondents residing in education deserts, predicted valuation is \$31,074 for those with high-speed access compared with \$6,290 for those with low access, a difference of approximately \$24,800 ($p < 0.001$). Outside education deserts, the corresponding difference is substantially smaller and only marginally significant. Among respondents with high-speed access, valuation does not differ significantly between education-desert and non-desert. Subgroup and formal heterogeneity analyses provide no evidence that the education desert × broadband association differs systematically by gender, age, or household income. These findings suggest that household broadband access is associated with higher workforce credential valuation within education deserts, consistent with the broader hypothesis that digital access complements institutional proximity in shaping human capital investment decisions.

Keywords: education deserts, broadband access, workforce credentials, human capital investment
JEL Codes: I23, J24, R11, R58

1 Introduction

Persistent geographic disparities in access to postsecondary education continue to influence regional patterns of human capital development in the United States. Although expansion in higher education has raised overall attainment levels, access to broad-access public institutions remains uneven across regions. Regional research consistently emphasizes that educational attainment and institutional presence are central components of long-run regional economic performance (Mykerezi and Mills, 2004). At the same time, migration dynamics and state funding decisions interact with higher education systems in ways that reinforce spatial inequality (Dunn, 2015). These dynamics underscore that educational opportunity is embedded within broader regional structures rather than determined solely by individual choice. In recent years, digital infrastructure has also emerged as an important component of these regional opportunity structures. Household broadband access

can expand opportunities for education, training, and labor market participation in geographically isolated areas and has been linked to broader rural economic development outcomes (Whitacre et al., 2014), and subsequent work has demonstrated heterogeneous economic and labor market impacts across rural regions (Lee and Whitacre, 2017). Together, these institutional and infrastructural conditions shape the spatial distribution of human capital investment.

Workers employed throughout the agricultural and food system provide an informative empirical setting for examining how physical and digital access conditions shape human capital investment decisions. The agricultural and food system extends beyond primary agricultural production to include processing, manufacturing, transportation, distribution, retail, food service, and related support industries, creating a geographically dispersed workforce that spans both rural and urban communities. Across these sectors, technological change, evolving regulatory requirements, and changing employer expectations have increased demand for continuing education, workforce development, and lifelong learning. As a result, alternative educational pathways, including industry-recognized certificates, stackable credentials, and other competency-based programs, have become increasingly important mechanisms through which workers acquire and demonstrate new skills (Maxwell and Gallagher, 2020; Braxton, 2023; Thorpe et al., 2024). Because many of these occupations are distributed across regions with varying levels of institutional access and household broadband connectivity, the agricultural and food system provides a useful context for examining how place-based access conditions influence the perceived value of workforce credential investments.

An increasing body of research highlights "education deserts" as commuting zones or regions that lack reasonable proximity to public two- or four-year institutions, especially those that offer broad admissions access (Klasik et al., 2018). These spatial gaps are not randomly distributed and are disproportionately found in rural and structurally disadvantaged regions (Dache-Gerbino, 2018). From a regional science perspective, such institutional scarcity represents a structural feature of place, reflecting historical investment patterns, demographic shifts, and spatial development trajectories. As Deller (2015) discusses in his presidential address, regional development outcomes are deeply shaped by the institutional arrangements embedded within specific geographic contexts.

Spatial frictions such as distance, transportation costs, and institutional scarcity directly affect educational participation and investment decisions. Students tend to prefer proximity and frequently enroll in institutions near their homes when possible (Klasik et al., 2018). In rural areas, where institutions are fewer and farther apart, these geographic constraints can restrict both enrollment and the types of credentials individuals pursue (Koricich et al., 2020). Spatial modeling approaches further demonstrate that education deserts can be quantitatively assessed using commuting zone and accessibility frameworks, reinforcing the role of geographic structure in shaping opportunity sets (Solís and Aljaddani, 2021).

Digital infrastructure has increasingly been promoted as a mechanism to reduce spatial inequality in educational access. Broadband expansion is often framed as a substitute for physical proximity, enabling remote learning and online credential attainment. However, the extent to which broadband mitigates the economic consequences of living in an education desert remains insufficiently understood. Existing research documents persistent disparities in broadband access, digital inclusion, and educational participation, particularly in rural and underserved regions (Reddick et al., 2020; Robinson et al., 2020), but offers limited evidence on how infrastructure conditions shape individuals' valuation of educational investment, especially in workforce-oriented credential markets. While broadband is often framed as a substitute for geographic proximity, recent evidence suggests that its economic value may depend on underlying spatial conditions. For example, studies examining willingness to pay for broadband services find that valuation varies substantially across rural and underserved populations, reflecting differences in both access and perceived utility. This raises a related but understudied question: whether broadband similarly alters how individuals value investments in education, particularly in regions where physical access to institutions is limited.

Despite a growing body of work on education deserts and broadband access, relatively little empirical evidence exists on how these spatial factors jointly shape the *perceived economic returns* to human capital investment. Most studies focus on participation outcomes such as enrollment or attainment, while fewer examine how individuals value educational opportunities under differing access conditions. This distinction is particularly relevant in workforce-oriented credential markets, where participation decisions are closely tied to perceived costs, benefits, and feasibility. This study addresses this gap by evaluating how household broadband access conditions the relationship between education desert status and willingness to invest in

workforce credentials. Using a discrete choice experiment administered to agricultural and food system workers across the United States (n = 321), we derive individual-level valuation measures for a full, industry-recognized, stackable certificate and examine how these valuations vary across combinations of physical and digital access constraints.

By focusing on economic valuation rather than participation alone, this study contributes to the regional science literature in three ways. First, it extends the education desert framework by demonstrating that spatial constraints influence not only access to education but also the perceived returns to human capital investment. Second, it evaluates household broadband access as a conditioning factor that may complement, rather than fully substitute for, proximity to educational institutions. Third, it situates workforce credential demand within a broader place-based framework in which infrastructure and institutional access jointly shape opportunity structures in rural regions. Together, these contributions provide new evidence on how spatial inequality influences human capital investment decisions and offer policy-relevant insights for workforce development in underserved areas.

2 Conceptual Framework

Human capital investment decisions are shaped by spatially structured opportunity sets. In regional science, three related areas of literature inform this relationship: 1) research linking human capital and regional economic development, 2) work on education deserts and institutional access constraints, and 3) studies examining broadband and digital infrastructure as enabling conditions for participation in education and labor markets. Taken together, the literature suggests that both physical and digital access conditions jointly shape the feasibility and perceived returns to human capital investment.

Human capital investment is spatially conditioned. Educational decisions occur within geographically structured opportunity sets shaped by distance, institutional presence, migration patterns, and local economic structure. Regional research has consistently shown that proximity to higher education institutions influences income growth and regional economic performance. For example, Mykerezi and Mills (2004) demonstrate that counties with greater exposure to higher education institutions experience stronger income growth, particularly in rural areas. Dunn (2015) further shows that migration flows and higher education funding are interrelated across states, underscoring the spatial interdependence between human capital investment and regional fiscal conditions. Deller (2015) emphasizes that place-based institutional arrangements are central to understanding regional development processes. Together, this work contributes to the literature by situating education within a regional systems framework in which institutional presence shapes both investment behavior and long-run economic outcomes.

The education desert framework provides a more focused lens for examining institutional scarcity. Hillman (2016) conceptualizes education deserts as commuting zones lacking access to broad-access public institutions, particularly two-year and nonselective four-year colleges. Subsequent empirical work operationalizes this framework and documents how limited local options alter application and enrollment behavior (Klasik et al., 2018). Students residing in education deserts, defined as areas without public institutions offering programs relevant to a student's academic interests, are more likely to apply to institutions farther from home and face greater geographic barriers to participation in postsecondary education. Geographic scarcity, therefore, modifies decision environments rather than merely constraining observed outcomes. These spatial disparities are closely tied to broader patterns of regional inequality. Dache-Gerbino (2018) documents that limited local college access reflects underlying spatial stratification, while Koricich et al. (2020) highlight the structural constraints faced by rural-serving institutions. Within this framework, education deserts represent persistent regional characteristics that shape long-run human capital accumulation.

This study extends the education desert framework from participation outcomes to economic valuation. Rather than examining whether individuals enroll in postsecondary education, this study focuses on how spatial context shapes the perceived returns to human capital investment. In regions with limited institutional access, individuals may discount high-commitment credentials if perceived access costs, coordination barriers, or delivery constraints are substantial. Spatial constraints may therefore reduce the economic value assigned to education even when underlying demand for skill acquisition remains strong.

Broadband infrastructure introduces a second spatial dimension. If physical proximity limits access,

digital connectivity may expand the feasible set of opportunities. However, digital infrastructure is unlikely to function as a complete substitute for institutional presence. Solís and Aljaddani (2021) model education deserts using accessibility measures that incorporate spatial and transportation dynamics. Extending this logic, broadband can be viewed as a modifying condition within the accessibility function: it may reduce effective distance, but only where credential design and delivery modalities are compatible with online or hybrid formats.

At the same time, recent work highlights that the economic value of broadband itself varies across populations and contexts. For example, Boyce (2024) shows that willingness to pay for broadband services depends on service quality, reliability, and household characteristics, suggesting that the benefits of digital infrastructure are not uniform across space. Complementary research by Lee and Whitacre (2017) demonstrates that broadband access is associated with heterogeneous economic and labor market outcomes across rural regions, reflecting differences in how digital infrastructure is utilized and integrated into local economies. Taken together, this evidence suggests that broadband operates as a context-dependent input, with effects that depend on underlying spatial and economic conditions.

This perspective motivates a conditioning hypothesis: the economic value of household broadband access should be greatest where spatial barriers are most binding. In regions with local institutional access, broadband may have limited marginal influence on perceived returns to credentials. In contrast, within education deserts, broadband may alter the effective opportunity set and therefore modify willingness to invest in human capital. The empirical strategy that follows evaluates this spatial interaction by modeling individual-level willingness to pay for a full, industry-recognized certificate as a function of both education desert status and household broadband access.

3 Data and Methods

3.1 Study Population and Survey Administration

The target population for this study consisted of workers employed throughout the agricultural and food system, including occupations spanning agricultural production, food processing, manufacturing, transportation, distribution, retail, food service, and related support industries. This workforce provides an appropriate empirical setting for examining human capital investment because continuing education, employer-recognized credentials, and other competency-based educational pathways are becoming increasingly important components of workforce development in response to technological change, evolving regulatory requirements, and changing labor market demands (Maxwell and Gallagher, 2020; Braxton, 2023; Thorpe et al., 2024). Moreover, the geographic dispersion of the agricultural and food system workforce creates meaningful variation in proximity to postsecondary institutions and household broadband access, making it well suited for examining how place-based access conditions influence the perceived value of workforce credential investments.

Data were collected through an online survey administered using Qualtrics Panels, a commercial survey platform that recruits respondents meeting predefined eligibility criteria. At the beginning of the survey, respondents were screened to verify that they were currently employed within one of the agricultural and food system occupations or industries identified for this study. Individuals not meeting this eligibility criterion were screened out and did not continue with the survey. Eligible respondents then completed questions measuring demographic characteristics, household broadband access, workforce experiences, and preferences for alternative postsecondary credentials, followed by a discrete choice experiment designed to estimate individual-level valuation of workforce credential attributes. The study protocol was reviewed and approved by the University of Arkansas Institutional Review Board (IRB# 2507614107), and informed consent was obtained from all respondents prior to participation. Consistent with the study's objectives, the analysis is intended to characterize relationships between household broadband access, institutional proximity, and workforce credential valuation within this workforce rather than to estimate nationally representative preferences for all U.S. workers.

3.2 Survey Instrument and Question Development

The survey instrument was designed to capture digital access conditions, workforce characteristics, and preferences for alternative postsecondary pathways, with particular emphasis on evaluating how individuals value workforce credentials under varying combinations of physical and digital access constraints. This focus allows the analysis to move beyond participation outcomes to examine how access conditions shape the perceived economic returns to human capital investment. Question development drew from established federal, international, and workforce assessment instruments to ensure content validity and comparability with prior research in labor force participation and adult learning. Table 1 presents the sample statistics.

Table 1: Sample Characteristics

Variable	Category	Freq.	%
Gender	Male	152	47.4
	Female	169	52.7
Age	18–24	56	17.5
	25–34	92	28.7
	35–44	78	24.3
	45–54	66	20.6
	55–64	22	6.9
	65+	7	2.2
Household Income	Less than $15,000	32	10.0
	$15,000–$24,999	44	13.7
	$25,000–$34,999	55	17.1
	$35,000–$49,999	45	14.0
	$50,000–$74,999	80	24.9
	$75,000–$99,999	34	10.6
	$100,000 or more	31	9.7
Primary Industry	Agriculture, Forestry, Fishing, Hunting	57	17.8
	Manufacturing	43	13.4
	Wholesale Trade	8	2.5
	Retail Trade	53	16.5
	Transportation and Warehousing	12	3.7
	Finance and Insurance	4	1.3
	Professional, Scientific, Technical	1	0.3
	Management of Companies	6	1.9
	Educational Services	5	1.6
	Arts, Entertainment, Recreation	8	2.5
	Accommodation and Food Services	118	36.8
	Public Administration	6	1.9
Primary Role	Farming/Production	42	13.1
	Agricultural Services	14	4.4
	Agribusiness/Input Supplier	9	2.8
	Processing/Manufacturing	44	13.7
	Food Retail/Distribution	199	62.0
	Finance/Insurance	3	0.9
	Education/Extension/Government	6	1.9
	Agricultural/Natural Resource Law	4	1.3
Years of Experience	Less than 1 year	29	9.0
	1–4 years	101	31.5
	5–9 years	83	25.9
	10–14 years	50	15.6
	Over 15 years	58	18.1

Table 1: Sample Characteristics (continued)

Variable	Category	Freq.	%
Education Desert Status	Non–education desert	276	85.98
	Education desert ($\geq$ 50 miles)	45	14.02
Household Broadband Access	No high-speed internet	10	3.12
	Basic/Standard broadband	55	17.13
	High-speed/Gigabit broadband	256	79.75
Education Desert x Household Broadband Access	Non–desert/Low Access	54	16.82
	Non–desert/High-Speed Access	222	69.2
	Desert/Low Access	11	3.43
	Desert/High-Speed Access	34	10.60

Demographic and employment items were aligned with question formats used in the Current Population Survey and the USDA Farm Labor Survey, both of which provide standardized measures of age, employment status, occupational experience, and industry classification (U.S. Bureau of Labor Statistics and U.S. Census Bureau, 2023; U.S. Department of Agriculture, National Agricultural Statistics Service, 2022). Digital access and device availability measures were informed by Pew Research Center broadband surveys and the National Telecommunications and Information Administration Digital Nation framework, which distinguish between high-speed broadband, basic service, and lack of reliable internet access (Pew Research Center, 2021; National Telecommunications and Information Administration, 2022). These classifications are also consistent with broadband speed thresholds used in federal infrastructure reporting (Federal Communications Commission, 2023). Questions measuring digital comfort and technology use were conceptually adapted from the OECD Programme for the International Assessment of Adult Competencies (PIAAC), which provides validated measures of adult digital proficiency and technology use in learning and work environments (OECD, 2019).

Items related to skills, training preferences, and learning modalities were informed by national workforce competency models, including ACT WorkKeys and the U.S. Department of Labor O*NET Content Model. These frameworks provided structure for questions regarding perceived skill gaps, training needs, and modality preferences. Questions concerning credential recognition, stackability, and sponsorship were grounded in the literature on alternative credentials and micro-credentials in higher education and workforce development. Micro-credentials are typically defined as competency-based, verifiable credentials that may be credit-bearing and stackable toward larger qualifications (Oliver, 2019; Clements et al., 2020; McGreal and Olcott, 2022). Stackability indicated whether the credential could be applied toward a higher-level certificate or degree, consistent with research emphasizing cumulative learning pathways and modular credential design (Oliver, 2019; McGreal and Olcott, 2022). A recent synthesis of definitions emphasizes their workforce alignment, issuer credibility, and modular structure (Galindo and Gauthier, 2025). These conceptual features directly informed the construction of attributes in the discrete choice experiment described below.

3.3 Discrete Choice Experiment Design

To estimate preferences for workforce credentials, the survey incorporated a discrete choice experiment structured around five attributes: price, credential type, delivery mode, institutional recognition, and stackability. The full set of attributes and levels is presented in Table 2. These attributes reflect dimensions consistently identified in the micro-credential literature as salient to learners and employers, including credential length, modality, issuer credibility, and the ability to build toward larger qualifications (Oliver, 2019; Clements et al., 2020; McGreal and Olcott, 2022; Galindo and Gauthier, 2025).

Price levels were selected to reflect realistic tuition benchmarks observed in workforce-oriented undergraduate programming. The lower-bound price levels were anchored to the per-credit tuition rates charged by the University of Arkansas for undergraduate coursework, providing a regionally relevant public-university reference point. At the time of instrument development, tuition rates implied that an 18-credit certificate

Table 2: Discrete Choice Experiment Attributes and Levels

Attribute	Level 1	Level 2	Level 3	Level 4
price (4)	$900	$6,600	$12,300	$18,000
credential (3)	Course Badge	Micro certificate	Full Certificate	
delivery (3)	Online	Mixed-Mode	In-Person	
recognition (4)	Industry	University	Government	None
stackable (2)	Yes	No		

would cost approximately $5,760, establishing a realistic baseline for short-term certificate pricing (University of Arkansas). The higher-end price levels were calibrated to reflect comparable tuition costs at peer public institutions and alternative credential providers. This approach ensured that the experimental price vector spanned a plausible range of observed market costs while preserving sufficient variation to identify WTP parameters. Anchoring price levels to observed institutional tuition rates enhances external validity and interpretability of valuation measures derived (Louviere et al., 2000).

Credential type included three levels corresponding to increasing program intensity: a 3-credit course badge, a 9-credit micro certificate, and an 18-credit full certificate. Delivery mode included online, mixed-mode, and in-person formats to capture modality tradeoffs that frequently arise in adult and workforce education. Recognition levels are distinguished between industry, university, government, or no formal recognition, reflecting evidence that issuer credibility and external validation influence perceived labor market value. The discrete choice experiment follows random utility theory and established stated preference methodology (Louviere et al., 2000; Train, 2009). Under this framework, individuals select the choice alternative that maximizes utility, where utility is modeled as a function of observed credential attributes and a stochastic component. Because preferences for credential attributes are likely to vary across individuals embedded in different occupational and spatial contexts, a mixed logit model was estimated to allow for random preference heterogeneity and to relax the independence of irrelevant alternatives assumption (Train, 2009).

The experimental design was programmed in Ngene (Choicemetrics, 2021) using an Optimal Orthogonal Design (OOD) design algorithm to maximize statistical efficiency subject to attribute and level constraints. The final design achieved a D-efficiency of 97.98 percent, indicating near-optimal parameter identification given the attribute structure. D-optimality minimizes the determinant of the covariance matrix of the estimated parameters and is widely used in efficient experimental design for stated-preference models (Scarpa and Rose, 2008). The OOD design generated 36 choice tasks, and we applied block techniques to divide them into three blocks of 12 choice questions each in order to reduce the number of tasks per respondent and minimize potential fatigue effects (Bradley and Daly, 1994). Choice sets were randomized across respondents to mitigate ordering effects (Carlsson et al., 2012), and a cheap talk script was presented to each respondent before they answered choice questions to mitigate the hypothetical bias (Tonsor and Shupp, 2011). Figure 1 displays a sample choice task. Note that in each of the 12 choice tasks, respondents were presented with the definitions of the attribute levels to ease the cognitive burden associated with recalling this information as the levels changed across choice tasks.

3.4 Spatial Classification: Education Deserts and Broadband Access

Education desert status was operationalized using a 50-mile proximity threshold consistent with the framework introduced by Klasik et al. (2018). Following this approach, a respondent is classified as residing in an education desert if no broad-access public two- or four-year institution is located within a 50-mile radius of their residence. The 50-mile rule serves as a commuting-distance approximation commonly used in education desert research to represent the outer bound of feasible in-person access, particularly in rural contexts where institutional density is low. While any distance threshold represents a simplification of heterogeneous commuting costs, the 50-mile criterion provides a transparent and replicable measure of structural institutional scarcity. Although the 50-mile threshold is widely used as a proxy for feasible commuting distance in education desert research, actual willingness to travel varies across individuals and regions. As such,

Figure 1: Example Choice Task

	Certificate 1	Certificate 2	Certificate 3
Price	$900	$6,600	$18,000
Credential Type	Course Badge	Microcertificate	Full Certificate
Delivery Mode	Online	Mixed-Mode	In-Person
Recognition	Industry	None	University
Stackable	Yes	No	No

◯ Certificate 1
◯ Certificate 2
◯ Certificate 3
◯ None of these

Course Badge: One course showing a specific skill.
Micro Certificate: 2–4 related courses showing focused skills.
Full Certificate: 5–7 courses showing advanced training.

Online: Fully online, no set meeting times.
Mixed-Mode: Online with some required in-person sessions.
In-Person: Traditional classroom setting.

Industry: Endorsed by a trade group or commodity board.
University: Issued by an accredited university.
Government: Approved by a state or federal agency.

Stackable: Smaller credentials can build toward a larger certificate or degree.

this measure should be interpreted as a stylized representation of institutional access rather than a precise behavioral cutoff. The proportion of the sample in an education desert is presented in Table 1.

This distance-based definition treats institutional presence as a spatially distributed regional asset. In a regional science framework, institutional proximity reduces transportation costs, commuting time, and informational frictions that influence human capital investment decisions. Areas exceeding the 50-mile threshold represent structurally constrained educational environments where physical attendance requires substantially higher time and financial costs. Classifying respondents using this rule allows the analysis to capture geographic barriers in a transparent and replicable manner.

Household broadband access was measured using respondent self-reports across three categories: no high-speed internet, basic or standard broadband, and high-speed or gigabit broadband. For the second-stage analysis, the no high-speed internet and basic/standard broadband categories were combined into a low-access category and compared with high-speed/gigabit broadband. This binary classification preserves the primary distinction in household digital access while avoiding inference from sparsely populated interaction cells when broadband access interacts with education desert status. In this context, household broadband access serves as a proxy for the level of digital access available to respondents, conditioning the feasibility of online credential delivery. As shown in Table 1, the resulting classification yields 54 non-desert and 11 education-desert respondents with low access, compared with 222 non-desert and 34 education-desert respondents with high-speed access.

This spatial classification framework allows the subsequent regression analysis to estimate how WTP for a full, industry-recognized, stackable (FIS) certificate varies across combinations of physical and digital access conditions. By treating household broadband access and education desert status as interacting regional characteristics, the empirical design reflects a regional science perspective that emphasizes infrastructure complementarities and spatially conditioned opportunity structures. Rather than assuming that household

broadband access uniformly offsets geographic constraints, the interaction framework allows the analysis to identify whether high-speed household broadband access moderates the economic valuation of credential investment in regions defined by the 50-mile education desert threshold.

3.5 Econometric Specification

This study uses a two-stage empirical strategy to evaluate whether household broadband access moderates spatial barriers to human capital investment in education deserts. In the first stage, a mixed logit model is estimated using discrete choice experiment (DCE) responses to recover preference parameters for credential attributes and to derive individual-level WTP measures. In the second stage, the derived WTP outcome, FIS (full certificate, industry-recognized, stackable), is regressed on education desert status, broadband access, and their interaction, controlling for demographic and workforce characteristics. This approach allows the analysis to move from stated choice behavior to interpretable valuation outcomes that can be analyzed in relation to regional access conditions. The FIS specification was selected to represent a high-commitment credential pathway combining depth, recognition, and stackability, allowing for a consistent benchmark across respondents. The FIS measure captures the economic valuation of the most comprehensive credential pathway and serves as the primary dependent variable in assessing how education desert status and broadband access condition perceived returns to human capital investment.

Preferences are estimated using a mixed logit specification in preference space, with correlated random parameters, and an error component (MXL-EC) implemented in NLOGIT 6. Respondents face repeated choice tasks, and the model is estimated as a panel specification with 321 individuals, each contributing 12 choice tasks (N = 3,852). Utilities are specified for three credential alternatives relative to an opt-out alternative (NONE), where the opt-out is represented by an alternative-specific constant. A latent error component is included for the credential alternatives, allowing additional correlation across the non-opt-out options beyond the random coefficients. This approach is well established in the stated preference literature and has been applied in prior research examining attribute processing and behavioral mechanisms in discrete choice settings (e.g., Kemper et al., 2020; Train, 2009; Gao et al., 2023). For respondent i, alternative j, and choice occasion t, utility is modeled as:

$$\begin{aligned} U_{ijt} = {} & \beta_0 None_{ijt} + \beta_1 Price_{ijt} + \beta_2 MICR_{ijt} + \beta_3 FULL_{ijt} + \beta_4 ONLI_{ijt} \\ & + \beta_5 MIX_{ijt} + \beta_6 RIND_{ijt} + \beta_7 RUNI_{ijt} + \beta_8 GOV_{ijt} + \beta_9 STCK_{ijt} + \eta_{ij} + \varepsilon_{ijt} \end{aligned} \tag{1}$$

where $None_{ijt}$ is an alternative-specific constant equal to 1 for the opt-out option and 0 otherwise. The parameter β_1 represents the marginal utility of price, treated as fixed across respondents. All other attribute parameters were specified as random and allowed to vary across individuals to capture preference heterogeneity. Price was included as a continuous variable corresponding to the experimentally assigned tuition levels. Price was treated as fixed to facilitate estimation of WTP through coefficient ratios and to avoid instability associated with dividing by a random price parameter (Train and Weeks, 2005). Credential attributes were represented using effects coding. Under this coding structure, attribute levels take a value of 1 when present, -1 when the alternative level is present, and 0 for the opt-out alternative. Effects coding imposes a zero-sum restriction across attribute levels, allowing coefficients to be interpreted as deviations from the overall mean utility of the attribute rather than relative to a single omitted reference category. Because the opt-out alternative is coded as 0 on all attribute variables, inclusion of the alternative-specific constant does not induce perfect collinearity and the model remains properly identified. The term η_{ij}represents the individual-specific random component associated with the correlated random parameters, which is assumed to have a mean of zero and to follow a normal distribution to capture the potential heteroskedasticity, and $\varepsilon_{ijt}$is the independently and identically distributed Type I extreme value error term.

Following estimation of the MXL-EC model, WTP measures were derived for each credential attribute level using the ratio of the individual-specific attribute coefficient to the fixed price coefficient. Because price entered utility as a fixed parameter, WTP for attribute k for individual i is computed as:

$$WTP_{ik} = -\frac{\beta_{k,i}}{\beta_p} \tag{2}$$

where $\beta_{k,i}$ represents the posterior mean of the random coefficient for attribute k conditional on respondent i's sequence of observed choices, and β_p is the estimated price coefficient. This transformation yields respondent-level dollar valuations for each credential attribute. The outcome used in the second-stage regression, FIS, is defined as the sum of the individual-level WTP components corresponding to a full certificate, industry recognition, and stackability compared to course badge only, no formal recognition and not stackable pathway:

$$FIS_i = WTP_{i,FULL} + WTP_{i,RIND} + WTP_{i,STCK} \tag{3}$$

Full credentials were preferred over micro and badge levels, and industry recognition was selected for inclusion because it was the type of recognition that respondents most preferred among recognition categories in the mixed logit results. The resulting FIS measure therefore represents the economic valuation of a full, industry-recognized, stackable certificate pathway.

Alternative composite credential bundles were also constructed using different combinations of significant attribute levels. Regression results using these alternative constructions yielded similar patterns for the spatial access variables, supporting the robustness of the primary FIS specification. For clarity and brevity, the analysis presented in this paper focuses on FIS as the representative high-commitment credential pathway.

3.6 Regression Model and Predictive Margins

In the second stage, WTP for FIS is regressed on education desert status, high-speed household broadband access, and their interaction, along with demographic and workforce controls:

$$FIS_i = \alpha_0 + \alpha_1 Desert_i + \alpha_2 Broadband_i + \alpha_3 (Desert_i \times Broadband_i) + \mathbf{X}_i^{'}\delta + u_i \tag{4}$$

where $Desert_i$indicates residence in an education desert (50-mile proximity rule), $Broadband_i$represents high-speed household broadband access, and $\mathbf{X}_i$is a vector of demographic and employment controls including gender, age category, years of occupational experience, and household income category. These covariates are included as indicator variables, with reference (base) categories reported in the regression tables. Heteroskedasticity-robust standard errors are used. To present the interaction effects, predictive margins are computed for each combination of education desert status and household broadband access category (low access or high-speed access). Margins are evaluated at observed covariate distributions, allowing direct comparison of expected FIS across access environments.

To assess whether the estimated education desert × broadband association is concentrated within demographic groups, we conduct additional heterogeneity analyses by gender, age, and household income. We separately estimate the primary specification for male and female respondents, respondents under age 35 and age 35 or older, and respondents with household incomes below $50,000 and $50,000 or more. Each subgroup model retains the primary specification's control variables except for the characteristic used to define the subgroup. Because differences in statistical significance across separate subgroup models do not establish that coefficients differ across groups, we also estimate full-sample models interacting education desert status and household broadband access with each demographic characteristic. These triple-interaction models formally test whether the education desert × broadband association differs by gender, age, or income. Finally, we estimate a joint model containing all three demographic interactions and jointly test whether the education desert × broadband association varies across these observed demographic dimensions. These analyses directly assess whether the primary relationship is robust to demographic composition and whether observable socioeconomic characteristics systematically moderate the estimated association.

4 Results

4.1 Mixed Logit Results

Mixed logit results are reported in Table 3. The model was estimated using 1,000 Halton draws with correlated random parameters and a fixed price coefficient. The final log-likelihood is -4,320.23, yielding a

McFadden pseudo R-squared of 0.191, indicating substantial improvement over the restricted model. The price coefficient is highly statistically significant and negative (-0.050, $p < 0.01$), confirming that respondents respond systematically to tuition levels. The alternative-specific constant (ASC) for the opt-out option is negative and statistically significant (-2.483, $p < 0.01$), indicating that respondents generally prefer selecting one of the credential options rather than choosing the opt-out alternative. These results support the validity of the derived WTP measures.

Table 3: Mixed Logit (MXL-EC) Results

Attribute	Parameter		Coefficient	S.E.	p-value
Certification Level (Course Badge Base)	Microcertificate (MICR)	μ	-0.108	0.070	0.123
	Microcertificate (MICR)	σ	0.344***	0.108	0.001
	Full Certificate (FULL)	μ	0.500***	0.109	0.000
	Full Certificate (FULL)	σ	1.061***	0.146	0.000
Delivery Mode (Base:In-Person)	Online (ONLI)	μ	0.047	0.078	0.549
	Online (ONLI)	σ	0.602***	0.164	0.000
	Mixed (MIX)	μ	-0.073	0.093	0.431
	Mixed (MIX)	σ	0.922***	0.225	0.000
Recognition (Base=None)	Industry (RIND)	μ	0.472***	0.099	0.000
	Industry (RIND)	σ	0.707***	0.137	0.000
	University (RUNI)	μ	0.238**	0.098	0.015
	University (RUNI)	σ	0.844***	0.141	0.000
	Government (RGOV)	μ	0.401***	0.102	0.000
	Government (RGOV)	σ	1.007***	0.191	0.000
Stackability (Base=None)	Stackable (STCK)	μ	0.195***	0.060	0.001
	Stackable (STCK)	σ	0.376	0.266	0.158
Price	Price (Fixed)	μ	-0.050***	0.002	0.000
ASC	None (Opt-Out)	μ	-2.483***	0.278	0.000
EC	Error Component (η)	σ	-2.807***	0.241	0.000
Model diagnostics					
Respondents (n)			321		
Observations			3,852		
Restricted Log Likelihood			-5,340.01		
Log Likelihood			-4,320.23		
LR χ^2 (47 df)			2,039.56 ($p < 0.001$)		
McFadden pseudo R^2			0.191		
AIC/N			2.268		

Note: *,**, and *** indicate statistical significance at the $p < 0.10$, 0.05, and 0.01 levels, respectively. The model includes an error component (η_{ij}) that captures correlation across the experimentally designed credential alternatives (PRODA, PRODB, PRODC) relative to the opt-out option. The estimated standard deviation of the error component is reported.

Among credential type attributes, the coefficient on Full Certificate (FULL) is statistically significant and positive (0.500, $p < 0.01$), indicating a strong preference for full certificates relative to course badge only. Stackability (STCK) is also statistically significant and positive (0.195, $p < 0.01$), suggesting respondents value credentials that can build toward future qualifications. Recognition type plays an important role in credential valuation. Industry recognition (RIND) is significant and positive (0.472, $p < 0.01$), government recognition (RGOV) is significant and positive (0.401, $p < 0.01$), and university recognition (RUNI) is significant at the 5 percent level and positive (0.238, $p = 0.015$). Among these, industry recognition generates the largest mean preference effect, indicating that respondents place the greatest value on credentials with direct employer relevance.

Delivery format attributes are not statistically significant at the mean level. Online delivery (ONLI) (0.047) and hybrid delivery (MIX) (-0.073) do not differ significantly from the in-person delivery level. In terms of standard deviations estimates, several random parameter standard deviations are statistically significant, including FULL (sd = 1.061, $p < 0.01$), ONLI (sd = 0.602, $p < 0.01$), MIX (sd = 0.922, $p < 0.01$), RIND (sd = 0.707, $p < 0.01$), RUNI (sd = 0.844, $p < 0.01$), and GOV (sd = 1.007, $p < 0.001$). These results indicate heterogeneity in preferences across respondents, particularly for credential depth and recognition attributes.

The correlated random parameter structure provides insight into relationships among preference dimen-

sions. The estimated correlation matrix indicates positive associations between recognition and stackability parameters, suggesting that respondents who value formal credential recognition may also place greater value on stackable credential pathways. This pattern supports the construction of FIS as a composite credential reflecting high depth, formal recognition, and stackable structure. Overall, the mixed logit results indicate strong average preferences for full, industry-recognized, stackable credentials, substantial heterogeneity across individuals, and price sensitivity consistent with economic theory. These estimates provide the basis for constructing respondent-level WTP measures used in the regression analysis.

The strong preference for industry recognition relative to university or government recognition likely reflects the applied nature of workforce credential markets in agriculture and food systems. Respondents may perceive industry-recognized credentials as more directly aligned with employer expectations and job-relevant skills, providing clearer labor market signaling than institutionally or government-issued credentials. This interpretation is consistent with research on alternative credentials, which suggests that perceived value depends not only on credential content but also on the credibility of the issuing body and its relevance to specific occupational pathways (Oliver, 2019; McGreal and Olcott, 2022; Galindo and Gauthier, 2025). The lack of statistically significant differences across delivery modes further suggests that respondents do not systematically prefer online or in-person formats on average, but rather may evaluate delivery modality in conjunction with other constraints such as time, cost, and access. This pattern is consistent with the broader framework of this study, in which household broadband access and institutional proximity shape the feasibility and perceived value of educational investments rather than driving uniform preferences across individuals.

4.2 Regression Results: FIS and Spatial Access

Table 4 reports regression estimates of WTP for FIS compared to course badge only, no formal recognition, and a non-stackable pathway on education desert status, household broadband access, and their interaction, controlling for gender, age category, years of experience, and household income. The omitted broadband category is Low Access, which combines respondents reporting no high-speed internet or basic/standard broadband, and the omitted spatial category is residence outside an education desert. The coefficient on education desert status is negative and statistically significant. Among respondents with low household broadband access, residence in an education desert is associated with a \$11,778 decrease in WTP for FIS ($p = 0.014$). High-speed household broadband access is associated with a \$6,529 increase in WTP outside education deserts, although this association is only marginally significant ($p = 0.099$).

Because the model includes an interaction between education desert status and high-speed household broadband access, the coefficients must be interpreted jointly. The education desert × high-speed access interaction is positive and statistically significant (\$18,254; $p = 0.005$), indicating that the association between high-speed household broadband access and credential valuation is substantially larger within education deserts than outside them. Among respondents residing in education deserts, high-speed household broadband access is associated with a \$24,784 increase in WTP for FIS relative to low access ($p < 0.001$). Conversely, among respondents with high-speed household broadband access, predicted WTP does not differ significantly between education-desert and non-desert respondents (\$6,476; $p = 0.121$). These results indicate that the association between household broadband access and credential valuation is concentrated in education deserts, where physical access constraints are greatest.

To evaluate whether the estimated education desert × broadband association is concentrated within particular demographic groups, we re-estimated the primary model separately by gender, age, and household income. The substantive relationship persists across all six subgroup specifications. Among education-desert respondents, High-Speed Access is associated with \$30,544 higher WTP for males ($p = 0.042$) and \$22,115 higher WTP for females ($p = 0.001$); \$16,443 higher WTP for respondents under age 35 ($p = 0.029$) and \$28,382 higher WTP for respondents age 35 or older ($p = 0.001$); and \$16,907 higher WTP for respondents with household incomes below \$50,000 ($p = 0.021$) and \$26,337 higher WTP for respondents with household incomes of \$50,000 or more ($p = 0.001$). Thus, despite differences in model explanatory power and precision across the smaller subsamples, the within-education-desert association between High-Speed Access and credential valuation remains positive and statistically significant in every demographic subgroup examined.

Table 4: Regression Results for WTP for FIS

Variable	Level	Coefficient	Robust S.E.	*p*-value
Gender (Base: Male)	Female	1,196.42	2,854.09	0.675
Age (Base: 18–24)	25–34	-1,172.91	4,051.79	0.772
	35–44	7,544.83	4,606.80	0.103
	45–54	1,054.42	4,543.74	0.817
	55–64	275.44	6,282.57	0.965
	65+	18,305.06	12,063.67	0.13
Experience (Base: <1 year)	1–4 years	4,792.34	5,234.55	0.361
	5–9 years	4,992.17	5,644.28	0.377
	10–14 years	9,011.67	6,686.42	0.179
	Over 15 years	-2,358.96	5,972.25	0.693
Income (Base: < $15,000)	$15,000–$24,999	-1,759.26	6,249.21	0.779
	$25,000–$34,999	1,419.73	6,214.08	0.819
	$35,000–$49,999	12,349.67*	7,019.98	0.08
	$50,000–$74,999	1,730.63	5,713.09	0.762
	$75,000–$99,999	-576.95	6,556.20	0.93
	$100,000+	4,094.71	6,366.91	0.521
Education Desert (Base: Non-Desert)	Education Desert	-11,778.38**	4,774.58	0.014
Broadband Access (Base: Low Access)	High-speed/Gigabit	6,529.23*	3,940.31	0.099
Interaction Effect	Education Desert × High-speed	18,254.41***	6,446.01	0.005
Intercept	Constant	9,031.74	6,527.03	0.167
Model statistics				
Observations	321			
R^2	0.118			
Root MSE	24,689			

Note: *,**, and *** indicate statistical significance at the $p < 0.10$, 0.05, and 0.01 levels, respectively. Final model covariates were selected via a backward stepwise approach. Dependent variable FIS is an individual-level WTP measure derived from significant attributes in the MXL-EC model. Low Access combines respondents reporting no high-speed internet or basic/standard broadband; High-Speed Access includes respondents reporting high-speed/gigabit broadband.

We further tested whether the education desert × High-Speed Access interaction differs statistically across these demographic groups rather than relying on comparisons of subgroup-specific significance. Full-sample triple-interaction tests provide no evidence that the interaction differs by gender (p = 0.374), age group (p = 0.634), or household income group (p = 0.996). A joint model containing all three demographic moderators likewise fails to reject the joint null that the interaction does not differ across these dimensions (F(3, 301) = 0.26; p = 0.857). These results, reported in Appendix Table A1, provide no evidence that the interaction varies systematically across the observed gender, age, or household income groups.

Most demographic and workforce characteristics included as control variables are not statistically significant at conventional levels. The age category 35–44 is positive but not statistically significant at the 5 percent level (p = 0.103), while the income category $35,000–$49,999 is marginally significant (p = 0.080). Overall model fit yields an R-squared of 0.118 with 321 observations. The demographic and workforce controls are included to account for observable respondent characteristics rather than to develop a comprehensive predictive model of individual educational investment behavior. The subgroup and formal heterogeneity analyses provide additional evidence that this pattern is not explained by concentration of the estimated broadband × education-desert association within particular observed demographic groups.

4.3 Predictive Margins

To clarify the interaction effects, predictive margins were computed for each combination of education desert status and household broadband access. Table 5 reports the adjusted mean FIS values. Among respondents outside education deserts, predicted WTP for FIS is $18,069 under low household broadband access and $24,598 under high-speed access. This $6,529 difference is only marginally significant (p = 0.099), indicating relatively limited evidence of a broadband-access difference in credential valuation where physical access to institutions is less constrained.

In contrast, among respondents residing in education deserts, predicted WTP for FIS is $6,290 under

Table 5: Predictive Margins for WTP for FIS, by Education Desert and Broadband Access

Education Desert	Broadband Access	Predicted WTP ($)	S.E.	95% CI Lower	95% CI Upper
Non-desert	Low Access	18,068.79	3,473.72	11,232.94	24,904.64
	High-Speed Access	24,598.02	1,733.24	21,187.23	28,008.81
Education desert	Low Access	6,290.41	3,421.24	-442.18	13,023.00
	High-Speed Access	31,074.05	3,792.91	23,610.07	38,538.03

Notes: Predictive margins were calculated using post-estimation marginal effects from the linear regression model of FIS. Predicted values represent the adjusted mean WTP for each combination of education desert status and broadband access, holding all other covariates at their observed values. Standard errors and confidence intervals are computed using the delta method with robust variance estimates. Low Access combines respondents reporting no high-speed internet or basic/standard broadband; High-Speed Access includes respondents reporting high-speed/gigabit broadband.

low household broadband access and $31,074 under high-speed access. The $24,784 difference is statistically significant ($p < 0.001$), indicating substantially higher credential valuation among education-desert respondents with high-speed household broadband access. Moreover, among respondents with high-speed access, predicted WTP does not differ significantly between education-desert and non-desert respondents ($6,476; $p = 0.121$).

Taken together, the predictive margins reinforce the regression results: the association between household broadband access and workforce credential valuation is substantially larger within education deserts than outside them. This pattern is consistent with the broader hypothesis that digital access complements institutional proximity where physical access constraints are greatest. Because household broadband access is measured at the respondent level, these findings should be interpreted as associations with the digital access experienced by workers rather than as estimates of the effects or returns to regional broadband infrastructure.

5 Conclusion

This study examined how WTP for a full, industry-recognized, stackable certificate varies across spatially defined opportunity structures characterized by broadband access and proximity to higher education institutions. By integrating discrete choice–derived WTP estimates with a regression framework that explicitly models the interaction between digital and physical access constraints, the analysis adopts a regional science perspective that treats infrastructure and institutional access as jointly conditioning economic opportunity.

The results indicate substantial heterogeneity in WTP for FIS across place-based access contexts. Among respondents residing in education deserts, high-speed household broadband access is associated with substantially higher credential valuation than low access, while the corresponding difference outside education deserts is considerably smaller. Moreover, among respondents with high-speed household broadband access, credential valuation does not differ significantly between education-desert and non-desert respondents. These findings suggest that the relationship between digital access and human capital investment preferences is spatially contingent and are consistent with the broader hypothesis that household broadband access complements institutional proximity where physical access constraints are greatest.

These findings align with a growing body of regional science research emphasizing that economic outcomes vary systematically across place-based opportunity structures. The Carlino–Mills framework, which models the interdependence of population and employment dynamics, provides early empirical evidence that jobs follow people and people follow jobs, underscoring the spatially embedded nature of economic adjustment processes (Carlino and Mills, 1987). More recent place-based development scholarship similarly argues that regional trajectories depend on localized configurations of infrastructure, institutions, and governance arrangements, rather than national aggregates alone (Hicks and Faulk, 2024). Our results extend this perspective to the domain of human capital investment, showing that the valuation of credentials is associated with spatially structured access conditions. In particular, the findings bridge the literature on education deserts and broadband by demonstrating that these factors interact to shape economic decision-making, rather than operating as independent constraints.

The intended scope of inference for this study follows directly from its research design. Rather than

estimating nationally representative preferences for all U.S. workers, the analysis examines how household broadband access and institutional proximity are associated with workforce credential valuation among workers employed throughout the agricultural and food system. This workforce provides a theoretically appropriate setting because workforce credentials represent an increasingly important mechanism for ongoing human capital investment within geographically dispersed labor markets. Accordingly, the findings should be interpreted as evidence regarding the relationship between place-based access conditions and credential valuation within this workforce and, more broadly, within occupational settings sharing similar characteristics. Future research should examine whether comparable relationships emerge in other geographically dispersed industries where workforce credentials play a similar role in lifelong learning and workforce development.

The findings also resonate with arguments that contemporary economic development strategy is increasingly place-based and people-centered. Deller (2021) describes a "fourth wave" of economic development in which communities shift emphasis from firm recruitment toward investments that enhance community attractiveness and opportunity structures for residents. The present study suggests that household broadband access and institutional accessibility are related components of such opportunity structures. In regions where physical institutional access is limited, household broadband access is associated with substantially higher valuation of workforce credentials, highlighting the potential importance of digital access within place-based human capital development strategies.

Importantly, the results have distributional implications. Education-desert respondents with low household broadband access exhibit substantially lower WTP for FIS than those with high-speed access, suggesting that overlapping physical and digital access constraints may be associated with differences in perceived educational opportunity. This reinforces concerns in economic geography regarding the balance between efficiency and spatial equity in regional development policy (Storper, 2011). Although the present analysis does not estimate the effects of broadband infrastructure investment, the findings suggest that understanding household broadband adoption and access may be particularly important in geographically isolated regions where institutional access is limited.

Several limitations warrant consideration. First, the discrete choice experiment framework elicits stated preferences in a hypothetical setting; as with most stated-preference methods, although a cheap talk script was used to mitigate hypothetical bias, estimated valuation levels may not correspond directly to observed market prices. The average sample valuation for a full, industry-recognized, stackable certificate ($23,558) exceeds the current tuition cost of comparable programs (approximately $5,760). However, this difference should not be interpreted as a literal willingness to pay for tuition alone. Instead, the estimated values reflect preferences for a bundled set of credential attributes, including program depth, industry recognition, and stackability, which respondents may associate with longer-term career advancement, skill acquisition, and earnings potential. Prior research indicates that the returns to alternative credentials vary substantially by field, employer recognition, and labor market conditions, suggesting that respondents may be valuing expected future benefits rather than current program costs alone.

Despite these limitations, the study contributes to regional science by demonstrating that preferences for human capital investments are not spatially neutral. Infrastructure complementarities, specifically between broadband access and institutional proximity, shape the valuation of credentials in ways that are consistent with broader place-based development theory. Future research should extend this analysis using revealed preference data, longitudinal migration patterns, and spatial econometric approaches that explicitly model spillovers across adjacent regions. Evaluating whether improvements in household broadband access in education deserts translate into realized enrollment, completion, and mobility outcomes would further clarify the policy relevance of these findings. Finally, while the sample includes meaningful representation from education desert regions (n = 45; 14 percent), the majority of respondents reside outside education deserts (n = 276; 86 percent). This imbalance reflects the underlying geographic distribution of access conditions but limits statistical power for within-desert subgroup comparisons, particularly when interacting desert status with broadband categories. As a result, estimated effects for education desert respondents should be interpreted with appropriate caution. At the same time, additional subgroup and formal heterogeneity analyses indicate that the estimated education desert × broadband association is not concentrated within a particular gender, age, or household income group, although the relatively small number of education-desert respondents continues to warrant caution in interpreting the magnitude of the estimated differences.

This study provides empirical evidence that WTP for FIS varies systematically across combinations of

digital and physical access conditions. By situating human capital valuation within a place-based opportunity structure framework, the results identify household broadband access and institutional proximity as related components of regional opportunity structures associated with workforce credential valuation. The findings do not estimate the returns to broadband infrastructure investment, but they suggest that household broadband access may be particularly relevant to workforce credential valuation in geographically isolated areas. More broadly, integrating spatial access, digital access, and workforce development perspectives can improve understanding of human capital investment decisions in geographically dispersed labor markets and provide a foundation for future research linking broadband adoption and infrastructure investments to realized educational and labor market outcomes.

Funding Acknowledgment

This research was supported by the Southern Risk Management Education Center (SRMEC) through its Education Program under the project "Strengthening Rural Resilience: Agricultural Workforce Development in Risk Management." This material is based upon work supported by USDA/NIFA under Award Number 2024-70027-42471.

AI Disclosure

Generative AI tools were used to assist with editing and improving the clarity of the manuscript text. All analysis, results, and interpretations are the sole work of the authors.

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Appendix

Table A1: Robustness of Education Desert × Broadband Association Across Demographic Subgroups

Subgroup	N	Desert × High-Speed	Robust S.E.	Within-Desert High-Speed Difference	Robust S.E.	p-value
Male	152	24,485.59	16,113.59	30,543.85	14,892.13	0.042
Female	169	13,316.29	8,413.95	22,114.99	6,495.88	0.001
Under age 35	148	16,957.99	9,150.14	16,443.01	7,467.18	0.029
Age 35+	173	12,101.29	9,494.39	28,381.62	8,124.55	0.001
Household income < $50,000	176	13,034.61	8,317.02	16,906.57	7,242.05	0.021
Household income ≥ $50,000	145	11,368.08	9,783.20	26,336.89	7,775.77	0.001

Tests of demographic heterogeneity	p-value
Gender triple interaction	0.374
Age triple interaction	0.634
Household income triple interaction	0.996
Joint test (gender, age, income)	$F(3, 301) = 0.26;\ p = 0.857$

Note: The dependent variable is individual-level willingness to pay for FIS. High-Speed Access is compared with Low Access. Gender-specific models control for age, years of workforce experience, and household income; age-specific models control for gender, years of workforce experience, and household income; and income-specific models control for gender, age, and years of workforce experience. Robust standard errors are reported. The within-desert High-Speed Access difference is the estimated difference in WTP between High-Speed Access and Low Access among respondents residing in education deserts. Triple-interaction tests evaluate whether the Education Desert × High-Speed Access association differs across each demographic characteristic. The joint test evaluates the null hypothesis that the interaction does not differ collectively by gender, age group, or household income group.