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The impact of broadband on poverty reduction in rural Ecuador

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ABSTRACT

This study examines the impact of broadband deployment on labor income and employment (in both level and composition) in rural Ecuador. The analysis spans the 2011 to 2019 period, during which the share of rural households covered by high-speed broadband increased from 14.5% to 83%. The empirical strategy exploits variations in the timing of network deployment, as well as the fact that several rural areas remained unserved by 2019. To estimate impact, the study uses a semi-parametric alternative to the standard two-way fixed-effects (TWFE) estimator proposed by Callaway and Sant'Anna (2021). Overall, the findings indicate that broadband deployment in rural areas is associated with measurable gains in labor income and employment. Our income model estimates range from an increase of 14% to 21% above the expected level had broadband not been deployed in these areas. The impact estimates on employment are more modest, ranging from 3% to 5% (depending on the specification) above the mean employment level over the study period. Additionally, our results corroborate that ICTs help diversify employment opportunities, as the share of agricultural employment falls in the connected areas. The findings also suggest that the economic benefits associated with broadband favor younger workers, presumably because their skills better match the newly created jobs.

1. Introduction

Despite modest gains in recent decades, rural poverty remains an intractable problem in developing countries. In 2019, the rural poverty rate in Latin America stood at 45.7 percent, about double the rate of urban poverty (ECLAC, 2021). Further, early evidence suggests that the Covid-19 pandemic has erased some of the gains made in recent years, pushing the more vulnerable households back into poverty. In Ecuador alone, rural poverty climbed from 43.8 in 2019 to 49.2 percent in 2021.[1] Rural poverty disproportionately affects women and children, thus complicating efforts to break the intergenerational transmission of poverty.

The roots of rural poverty in Latin America are historically complex and include both lack of endowments (such a land and human capital) at the household level as well as broader institutional factors that result in high transaction costs and limited income-generating opportunities for rural dwellers (López and Valdés, 2000). At the same time, several studies suggest that the diffusion of information and communication technologies (ICTs) can help address some of these root factors, potentially mitigating rural poverty (Chong et al., 2009; Bahia et al., 2020). For example, studies offer evidence that mobile phones can help raise agricultural productivity by facilitating access to time-sensitive information about weather, crop prices, fertilizers, and new farming techniques (Cole and

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[1] Source: Central Bank of Ecuador.

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Fernando, 2012). Others demonstrate that new ICTs reduce transaction costs and information asymmetries in input and output agricultural markets (Aker, 2010; Jensen, 2010). Yet others suggest that ICTs can promote economic diversification and create nonfarm employment opportunities through forward and backward linkages with traditional agricultural activities (Nakasone and Torero, 2016).

This study contributes to this literature by examining the impact of high-speed (fixed) broadband deployment on labor incomes and employment in rural Ecuador. The analysis spans the 2011 to 2019 period, during which the share of rural households covered by high-speed broadband increased from 14.5 to 83 percent. This rapid increase in broadband availability was driven by a set of policy initiatives and regulatory reforms as part of Ecuador's "*Plan Nacional de Desarrollo de la Banda Ancha*" (National Plan for Broadband Development). Among the key goals of the plan was to promote investments in areas where incumbent operators had minimal presence.

The empirical strategy of the study exploits temporal variations in network deployment and market entry, as well as the fact that several areas remained unserved in 2019. Using alternative difference-in-difference specifications, the study estimates the impact of broadband deployment on labor incomes and employment (in both level and composition) at the parish level.[2]

Overall, the findings indicate that broadband deployment is associated with measurable gains in labor income and employment in areas that received high-speed broadband (the "treatment"). Additionally, our results corroborate the hypothesis that ICTs help diversify employment opportunities, as the share of agricultural employment falls in the newly connected parishes relative to those that remained unconnected. The findings also suggest that the benefits associated with broadband favor younger (mostly male) workers. This last finding is particularly relevant to efforts to reduce gender inequality in rural contexts, and point to the need to complement broadband deployment with initiatives that address human capital and demand gaps.

2. The contribution of broadband to economic activity and poverty reduction in rural areas

2.1. ICTs and economic growth

As conduits of information and enablers of service delivery, telecommunication services have long been recognized as a catalyst of economic growth (Leff, 1984; Roller and Waverman, 2001). Following the increase in network rollout and service adoption in developing countries in the 1990 s, scholars began to pay closer attention to the economic implications of ICTs in rural areas, exploring questions such as nonfarm employment, new business formation and transaction costs in agricultural markets. These studies shed light on a number of impact mechanisms associated with the rollout of ICTs.

For example, the introduction of mobile phones has been shown to improve market efficiency by reducing information asymmetries in agricultural markets, resulting in less price dispersion and long-term income gains for producers (Jensen, 2007; Aker, 2010; Goyal, 2010). Mobile phones have also been shown to improve the delivery of agricultural extension services, and as a result to promote the adoption of new agricultural practices and farm management techniques (Cole and Fernando, 2012).

In addition, numerous studies have examined how the introduction of mobile banking services in rural areas facilitates transactions and increases access to credit for those with limited access to traditional banking. This has been shown to smooth consumption patterns and protect rural households from external shocks (Jack and Suri, 2014). M−banking also provides an efficient mechanism to deliver government cash transfers, reducing both program costs and costs for recipients. Further, Aker et al. (2016) find evidence of health and nutrition gains among beneficiaries associated with mobile cash transfers.

Given the characteristics of rural areas, much of the existing literature is centered on mobile phones and mobile broadband services, with fewer studies exploring the impact of traditional (fixed) telephony and residential broadband. A notable exception is the study by Chong et al. (2009), which examines changes in per capita incomes in rural towns where public payphones were installed after the privatization of the state-owned incumbent in Peru. Using a matching strategy and exploiting the fact that towns receiving payphones were randomly selected, the authors find payphones to be associated with significant increases in both farm and nonfarm average incomes. A similar study by Beuermann (2015) explores an intervention that deployed satellite payphones in isolated villages in rural Peru. Using a village-level panel and exploiting variations in the timing of deployment, the author finds increases in agricultural profitability of about 20 percent as well as significant reductions in child labor.

There is also evidence that links ICT rollout with increases in rural employment and new business formation, although mainly from advanced economies. For example, Whitacre et al. (2014) find that broadband adoption is associated with lower rural unemployment in U.S. counties, but the availability of broadband services (regardless of adoption) shows no effects on employment. By contrast, Atasoy (2013) finds small but significant positive impacts of broadband availability on employment at the county level, and report that effects are larger in rural counties because broadband facilitates the integration of isolated communities into global markets for goods and labor. This is corroborated by Isley and Low (2022), who examine the linkages between broadband and rural employment during the early days of the Covid-19 pandemic. Using a two-stage least-squares approach, the authors find that broadband availability helped mitigate the employment impact of Covid, though the results for broadband adoption are less conclusive.

[2] After *provincias* and *cantones*, *parroquias* (parishes) are the third and lowest administrative level in Ecuador. There are 1,049 parishes in Ecuador, of which 828 are considered rural by the national statistics office (INEC).

2.2. Heterogeneous effects by quality of service

Another strand of literature examines whether differences in the quality of broadband services (rather than simply availability) help explain variations in the economic impact of broadband. This is of particular relevance to the present study given our focus on the deployment of high-speed (fixed) broadband. However, most studies come from advanced economies, and thus findings must be carefully evaluated in terms of relevance to rural Ecuador.

Using a panel of counties in the state of Tennessee, Lobo et al. (2020) find that unemployment rates are lower in counties where higher-speed services (above 100Mbps) are available, and that effects are larger in rural counties. Using a similar panel data strategy, Deller et al. (2021) find that broadband availability generally boosts new business formation in non-metro U.S. counties, and that the effect increases with faster broadband speeds (above 50Mbps). Worden and Hambly (2022) find that demand for high-speed broadband in Canada is higher for rural than for urban users. Other studies suggest that the availability of high-speed broadband is an important determinant of rural firm location (Mack, 2014). Taken together, these studies point to potentially important variations in the linkages between broadband and economic activity that is explained by differences in the quality of services available to rural communities.

2.3. ICTs and poverty reduction

The studies discussed so far examine potential associations between ICTs and economic activity in broader terms. We now turn to a subset of studies that investigate the potential mechanisms through which ICTs are linked to poverty reduction in rural areas in developing countries. An example is Beuermann et al. (2012), who exploit variations in the timing of mobile phone service deployment to estimate poverty impacts in rural villages in Peru. The findings show that mobile service availability is associated with increases in household consumption (about 11 percent) and a reduction in household poverty (about 8 percent). Interestingly, the results suggest strong spillover effects at the village level, as these impacts are not conditional on mobile phone ownership.

In a unique study that randomly selects areas for mobile service deployment in the Philippines, Blumenstock et al. (2020) find that the availability of mobile service is associated with a 17 percent increase in household income and 10 percent increase in household expenditure. Similarly, Bahia et al. (2020) exploit a unique household-level dataset to estimate the impacts increases in mobile broadband coverage on household consumption and poverty in Nigeria. Their findings show that mobile broadband availability is associated with a drop in household poverty (about 4.3 percent) and an increase in household consumption (about 6 percent). Interestingly, the authors note that the effects of mobile broadband on poverty reduction increase over time, manifesting progressively after a year of exposure.

2.4. Heterogeneous effects across subpopulations

Another subset of this literature examines heterogeneities in impact across subpopulations. Given the context of this study, our primary interest lies in examining whether the impact of high-speed broadband rollout in rural Ecuador vary across age and gender lines.

There are two main hypotheses related to gender differences in the broadband impact literature (Galperin and Arcidiacono, 2021). The first states that Internet access facilitates remote work arrangements that favor women with care responsibilities, thereby promoting labor force participation. For example, Dettling (2017) finds evidence for the U.S. that high-speed broadband availability increased labor force participation among college-educated, married women. The second hypothesis, more relevant to developing countries but more difficult to test, is that Internet access promotes women's employment by challenging social norms about gender roles.

Using an instrumental variable strategy that captures the location of 3G towers, Viollaz and Winkler (2021) find that increased Internet adoption in Jordan promoted labor force participation (but not actual employment) among women. In the Bahia et al. (2020) study described above, the authors find that the positive impact of mobile broadband coverage in Nigeria was largely driven by an increase in employment among women.

The literature on heterogeneous impacts by age builds on the common premise that broadband availability will favor younger workers due to more familiarity with digital devices and online services (Akerman et al., 2015; Barrantes and Cozzubo, 2019). Kaila and Tarp (2019) examine the impact of broadband deployment on agricultural output over the 2008–2012 period in rural Vietnam. Using a difference-in-difference strategy similar to the present study, the authors find that the rollout of broadband in an area is associated with an increase of about 7 percent in total agricultural output. In addition, the results indicate that younger farmers benefited more from broadband availability, which the authors attribute to younger heads of households being more familiar with digital technology and being more open to technological innovations. In a similar study, Kusumawardhani et al. (2021) construct a village-level panel that tracks Internet availability in Indonesia for the 2007–18 period. The authors report only modest overall impacts on employment, but heterogeneity analysis reveals significant impact among younger (in particular female) workers (under 45 years old).

2.5. Technological innovation and paths out of poverty

This study also draws on the broader theorization and historical examination of the linkages between technological innovation and poverty reduction in rural Latin America. In particular, we draw on the foundational study by de Janvry and Sadoulet (2000). After reviewing the available evidence, the authors identify-three alternative paths out of rural poverty that can be promoted by technological change: 1) an "agricultural path" that involves productivity gains and lower transaction costs in input and output agricultural markets; 2) a "pluriactive path" based on the diversification of income-generating activities; and 3) an "assistance path" premised on significant improvements in the delivery of safety net and support programs to families in rural areas.[3]

This study evaluates the impact of broadband deployment in rural Ecuador through the lenses of each of these potential poverty-reduction paths. First, it explores whether broadband availability in a parish is associated with higher levels of labor income and employment, relative to a control group of parishes where broadband has not been deployed. Second, it examines changes in the composition of employment, seeking evidence that broadband favors nonfarm activities. Third, the study explores the "assistance path" by evaluating the impact of broadband availability on the coverage of social protection programs.

3. The expansion of broadband in rural Ecuador

As in most countries, the rollout of fixed broadband in rural Ecuador has lagged significantly relative to urban areas. Studies point to differences in demographic factors such as population density, wealth and education, as well as higher network construction costs, as the key contributors to the rural–urban gap in broadband availability (Grubesic and Murray, 2004; James, 2010; Prieger, 2013; Hambly and Rajabiun, 2021). In 2011, high-speed (fixed) broadband services were available to only 14.5 percent of rural households in Ecuador, compared to 97.7 percent of urban households.

To address this gap, in 2011 the government of Ecuador launched the *Plan Nacional de Desarrollo de la Banda Ancha*, an ambitious initiative aimed at promoting broadband infrastructure investments and adoption with particular attention to rural areas. One of the core objectives of the plan was to facilitate market entry by lowering regulatory burdens and simplifying licensing procedures. The plan combined with a set of reforms to the administration of radio frequencies that allowed new entrants to quickly deploy competitive services in low-density areas. In particular, these reforms enabled ISPs to deploy wireless point-to-point links over unlicensed spectrum (in the 900 MHz, 2.4HGz and 5 GHz bands), which reduced deployment costs in rural areas by several orders of magnitude.

These changes promoted the entry of small and medium-size network operators in markets where the incumbents – in particular the state-owned Corporación Nacional de Telecomunicaciones (CNT) – had limited presence. According to the telecommunications regulator ARCOTEL, the total number of fixed broadband providers jumped from 150 in 2011 to 682 in 2020, and most new entrants held licenses to operate wireless point-to-point links under the new frequency administration regime.

The reforms resulted in a rapid increase in the availability of broadband services across Ecuador, with the largest impact on rural areas. The share of rural households covered by fixed broadband increased from 14.5 in 2011 to 85.2 percent in 2020. This can be visualized in Fig. 1, which shows the expansion in high-speed (fixed) broadband availability at the parish level (blue indicates availability).

Source: ARCOTEL.

Despite the increase in broadband availability during the study period, about a third of rural parishes remained unserved by 2020. In addition, the deployment of services across parishes was staggered over the years. Our empirical strategy exploits this temporal variation in service deployment, as well as the fact that many parishes remained without service at the end of the study period, to estimate the contribution of broadband to economic activity and poverty reduction.

4. Data and empirical strategy

4.1. Data sources

The data used in this study is drawn from two sources. First, the administrative records of ARCOTEL, which contains information about the availability of high-speed (fixed) broadband services at the level of parish/year. Second, the *Encuesta de Empleo, Desempleo y Subempleo* (ENEMDU), a large-scale household survey administered by the national statistics office of Ecuador (INEC). ENEMDU contains information on a variety of demographic and employment variables at the individual level, and location information allows for aggregating individual responses to the parish level.

We begin by restricting ENEMDU to respondents located in rural parishes. Next, we filter out responses from individuals located in the small number of rural parishes (24) where fixed broadband was already available at the start of the study period in 2011 (in other words, we drop individuals for whom pre-treatment information is not available). We then aggregate variables at the parish level, thus obtaining a pseudo panel of 804 parishes for the 2011–2019 period based on a total sample size of 242,911 ENEMDU individual records.

Descriptive statistics for the variables used in the study are presented in Table 1. The table distinguishes between dependent variables, control variables and the main covariate of interest (fixed broadband availability), and presents data for the starting year (2011) and the end year (2019) of the study period, as well as aggregate statistics over the entire study period (2011–19). Each of the variables is further discussed in the corresponding results section.

[3] de Janvry and Sadoulet (2000) identify an additional path that involves rural-to-urban migration. Since our data is at the parish (and not the individual or household) level, we are unable to examine rural-urban migration patterns. At the same time, while this path remains of critical importance to understand changes in rural poverty in the region, there is evidence that it results in only modest contributions to aggregate poverty reduction, as it often shifts the locus of poverty from rural to urban areas (see Ravallion, 2002).

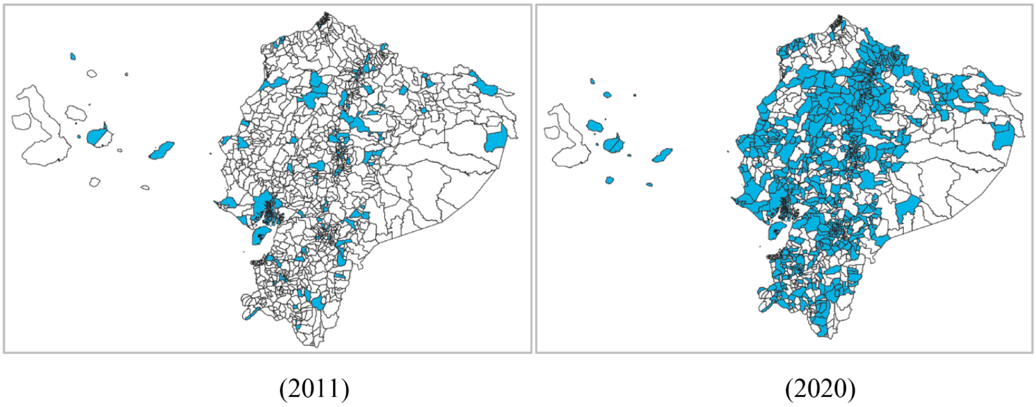

Fig. 1. Fixed broadband availability by parish in Ecuador.

Table 1
Summary statistics (mean and standard deviation).

Variable	2011	2019	2011–19
Dependent variables			
Labor income (in USD)	223	321	303
	(103)	(188)	(170)
Employment	0.54	0.55	0.56
	(0.12)	(0.12)	(0.11)
Agricultural employment	0.45	0.49	0.46
	(0.22)	(0.28)	(0.24)
Social security coverage	0.28	0.33	0.33
	(0.29)	(0.30)	(0.28)
Healthcare coverage	0.17	0.19	0.16
	(0.38)	(0.39)	(0.37)
BDH coverage	0.33	0.16	0.22
	(0.47)	(0.37)	(0.42)
Covariates			
Gender (male = 1)	0.50	0.50	0.50
	(0.07)	(0.07)	(0.06)
Age	34.7	35.1	32.1
	(8.62)	(8.40)	(7.35)
Years of education	4.48	4.97	4.80
	(0.68)	(0.63)	(0.59)
Internet use	0.14	0.40	0.29
	(0.12)	(0.17)	(0.18)
Independent variable			
Fixed broadband (yes = 1)	0	0.76	0.46
	0	(0.43)	(0.50)
Number of parishes	804	804	804

Note: Employment, education, social security and BDH coverage based on the population above 18 years of age. Standard deviation in parenthesis.

4.2. Empirical strategy

Our empirical strategy is based on the generalization of the difference-in-difference (DiD) approach to the case where the "treatment" (in our case, the deployment of high-speed broadband) is staggered over different time periods. Recall that our unit of analysis is the parish, for which we can observe variation over time in high-speed broadband availability as well as variations in income and employment indicators. Because we observe availability at the parish level and not broadband adoption at the individual or household level, the general interpretation of the ATETs (average treatment effect on the treated) presented in this study is within an intention-to-treat (ITT) framework. As a robustness check, we also examine impacts that condition on Internet use.

Parishes in our pseudo panel are either treated in different time periods (heretofore called treatment cohorts) or remain untreated throughout the study period (never-treated group). In this setup, the ATET is often recovered using the following two-way fixed effects (TWFE) specification:

$$Y_{it} = \alpha_t + \delta_i + \beta D_{it} + X_{it} + \mu_{it} \quad (1)$$

where Y_{it} is the outcome variable of interest for parish i in period t, α_t are year fixed effects, δ_i are parish fixed effects, D_{it} indicates whether fixed broadband was available in parish i at year t, X_{it} is a vector of parish-level covariates, and μ_{it} is the error term.

Now, if all treated units were treated in the same time period, the coefficient β in equation (1) would reasonably approximate the ATET of interest. However, as Goodman-Bacon (2021) notes, this is not necessarily true when treatment is staggered over different periods, and is particularly not the case when treatment effects evolve over time. Further, Sun and Abraham (2021) demonstrate that adding treatment lead and lag indicators to the TWFE specification also introduces biases to the recovered DiD parameter.

A key problem in the standard TWFE specification when treatment is staggered over time is that units treated at time t ("early" treatment cohorts) are used as controls for units treated at $t+k$ ("later" treatment cohorts). Using units treated in earlier periods as controls for units treated in later periods is inappropriate when treatment effects manifest over time, as is likely the case with the deployment of broadband in a previously unserved parish. These comparisons contaminate the aggregate TWFE estimator.

As an alternative, we use the semi-parametric approach proposed by Callaway and Sant'Anna (2021). The key insight in Callaway and Sant'Anna (CS) is that multiple cohort-time ATET estimators are possible, which correspond to different treatment cohorts evaluated at different points in time after treatment (or before treatment in placebo tests). For each treatment cohort, there are T-g estimators, where T is the final panel period and g indicates the treatment period for the cohort. The ATET for outcome variable Y can be expressed in two different ways, depending on the units used as controls. If never-treated units (denoted as group C) are used as controls, then the ATET for the cohort treated at time g evaluated at time t is:

$$ATET(g,t) = E\left[Y_t - Y_{g-1}|G_g = 1\right] - E\left[Y_t - Y_{g-1}|C = 1\right] \quad (2)$$

This recovers the ATET for outcome variable Y at time t for units in the cohort first treated at time g by comparing the expected change in Y for these units to the change among those that are never treated. Heretofore we refer to this specification as the CS-NT estimator.

An alternative estimator proposed by Callaway and Sant'Anna uses the units not yet treated at time t as controls. In this case the ATET is expressed as:

$$ATET(g,t) = E\left[Y_t - Y_{g-1}|G_g = 1\right] - E\left[Y_t - Y_{g-1}|Dt = 0, Gg = 0\right] \quad (3)$$

This recovers the ATET for outcome variable Y at time t for units in the cohort first treated at time g by comparing the expected change in Y for these units to those that are eventually treated but are yet to be treated at time t (thus $D_t = 0$). Heretofore we refer to this specification as the CS-YT estimator.

When the parallel trends assumption is conditional on covariates, the CS estimators use the propensity score approach for DiD proposed by Abadie (2005). In our case, the control vector includes parish-level averages for education (completed schooling in years), age and gender. Because population totals at the parish level are only updated every 10 years with the decennial census, parish size and population density cannot be included. To obtain a summary ATET from the multiple cohort-time combinations, we use the weighted average alternative proposed by Callaway and Sant'Anna with weights proportional to group size.

To recap, for each of the outcome variables of interest we present ATET estimators based on six different model specifications: the standard TWFE specification (with and without covariates), the CS-NT estimator (with and without covariates), and the CS-YT estimator (with and without covariates). However, for the reasons noted above, our interpretation of results favors the CS estimators.

5. Results

5.1. Labor income

Table 2 presents results for the six different model specifications on the natural log of labor income. Models 1 and 2 present the standard TWFE estimator (with/without covariates), models 3 and 4 present the CS-NT estimator (with/without covariates) which uses never-treated parishes as controls, and finally models 5 and 6 present the CS-YT estimator (with/without covariates) which uses yet-to-be treated parishes as controls. All other tables in the paper follow a similar presentation.

The results suggest that the deployment of high-speed broadband in a previously unserved parish is associated with an increase in aggregate labor income. The magnitude of the effect ranges from 14.6 to 21.8 percent over and above the expected change had broadband not been deployed in the parish. This magnitude is in line with similar studies. For example, Chong et al. (2009) find that the deployment of payphones in rural Peru is associated with an increase of about 20 percent (depending on the specification) in per capita income. Beuermann (2015) finds effects of a similar magnitude for a payphone intervention in rural Peru. Blumenstock et al. (2020) find that the introduction of a new mobile telephony tower in the rural areas of the Philippines is associated with an increase in household income of 17 percent.

Fig. 2 presents a disaggregation of the CS-NT estimator (model 4) recentered on relative time of exposure to treatment. The horizontal axis represents the length (in years) relative to the period of broadband deployment in the parish, with zero being the average ATET for treatment cohorts in the year of exposure. The plot presents two important results: first, it suggests that, conditional on covariates, the parallel trends assumption holds, as there are no observable impacts in pretreatment periods; second, it indicates that the effects of broadband on labor income increase with length of exposure. The latter finding validates the use of alternatives to the standard TWFE specification in the presence of dynamic effects.

Next we test for heterogeneous effects. Fig. 3 summarizes the ATET estimators (model 4) for different age groups. The results corroborate that the impact of broadband on labor income is larger for younger workers (ages 18–25), decreasing slightly for those aged 26 to 39 before turning indistinguishable from zero for workers 40 and above.

Table 2
Impact of broadband availability on labor income (log).

	(1)	(2)	(3)	(4)	(5)	(5)
	TWFE	TWFE	CS-NT	CS-NT	CS-YT	CS-YT
Broadband	0.053	0.038	0.168***	0.218***	0.146**	0.200***
	(0.039)	(0.039)	(0.062)	(0.079)	(0.057)	(0.067)
Observations	3,329	3,329	3,329	3,329	3,329	3,329
Mean income (USD)	303	303	303	303	303	303
Covariates	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Bootstrap standard errors in parenthesis.

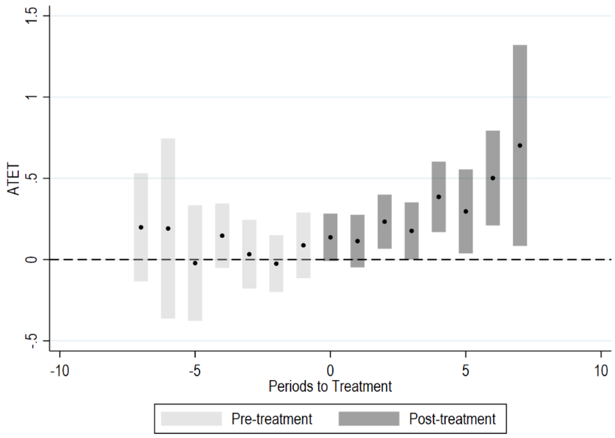

Fig. 2. Broadband availability impact on labor income by relative time to treatment (95% CI).

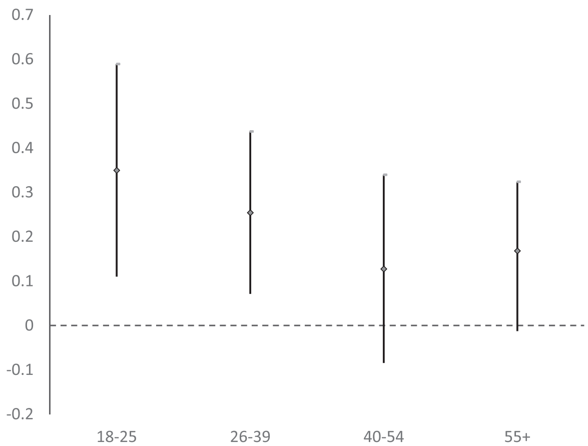

Fig. 3. Broadband availability impact on labor income by age group (95% CI).

Finally, we test for different effects across gender. The findings, reported in Tables A1 (men) and A2 (women) in Appendix A, indicate that labor incomes among male workers increase significantly following the availability of high-speed broadband in a parish. However, this is not the case for female workers, whose labor incomes remain unaffected by broadband availability.

5.2. Employment

Table 3 presents results about the impact of broadband rollout on parish employment levels. The presentation of the alternative

Table 3
Impact of broadband availability on employment.

	(1)	(2)	(3)	(4)	(5)	(5)
	TWFE	TWFE	CS-NT	CS-NT	CS-YT	CS-YT
Broadband	−0.005	0.042	0.018*	0.031**	0.018*	0.029**
	(0.008)	(0.040)	(0.010)	(0.014)	(0.010)	(0.012)
Observations	3,329	3,329	3,329	3,329	3,329	3,329
Mean employment	0.56	0.56	0.56	0.56	0.56	0.56
Covariates	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Bootstrap standard errors in parenthesis.

specifications is analogous to Table 2. While the results are somewhat less robust than in Table 2, they suggest that the deployment of high-speed broadband in a previously unserved parish is associated with an increase of between two and three percentage points above the expected level of employment had the service not been deployed. Calculated over the average employment level for the study period, this represents an increase of between 3 and 5 percent (depending on the specification).

Fig. 4 presents an event study plot based on relative time to treatment for our preferred model specification (CS-NT with covariates in model 4). The results show no pretreatment effects, suggesting that the parallel trends assumptions holds. They also suggest that the impact of broadband rollout on aggregate employment is only observable two years after treatment, and that the effect magnitude increases over time.[4] Theoretically, this is consistent with the expectation that the short-term employment effects of investments in broadband infrastructure (associated for example with network construction and customer acquisition) are small and short-lived, while potential impacts on agricultural productivity and the diversification of economic activities are only observable in the medium to long term.

A key hypothesis that underpins the pluriactive path out of poverty is that broadband availability creates opportunities for nonfarm employment. While the ENEMDU survey does not contain disaggregated information about labor income sources, it does provide information about primary employment sector. Based on this information, we construct a variable that captures the share of agricultural employment for each parish over the study period. Following the diversification hypothesis, the expectation is that the share of farm employment will be lower than expected after the deployment of high-speed broadband in a parish, relative to never treated or yet-to-be treated parishes.

The results in Table 4 corroborate that agricultural employment falls as broadband extends to rural parishes. The availability of high-speed broadband is associated with a decrease of between six and nine percentage points in the expected share of farm employment had the service not been deployed. Calculated over the average share of farm employment for the study period, this represents a drop of between 13 and 19 percent (depending on the specification). This indicates that the impact of broadband on employment composition (in favor of non-agricultural activities) is significantly larger than the overall effect on employment.

Next, we investigate differences in the employment impact of broadband across age groups. Fig. 5 presents the ATET estimators based on the CS-NT with covariates specification (model 4) for different age groups. The results indicate, as predicted, that the impact of broadband is concentrated among younger workers (ages 18–25).

Finally, we explore heterogeneous employment impacts by gender. Contrary to results in previous studies, we do not find evidence that broadband favors female employment (Tables A3 and A4 in Appendix A). It must be noted that the ENEMDU survey only captures paid employment, and thus omits unpaid female work within the household or subsistence agriculture, which are common activities for women in rural areas.

5.3. *Social protection*

This section explores the hypothesis that the availability of high-speed broadband helps improve the delivery of safety net and support programs to families in rural areas. As outlined by de Janvry and Sadoulet (2000), the “assistance path” out of poverty is premised on the expansion of social assistance programs to rural families in poverty.

We first examine coverage for Bono de Desarrollo Humano (BDH), a conditional cash transfer program for families living in extreme poverty. Overall, about 15 percent of households report income from BDH during the study period. Second, we examine healthcare coverage from either private insurance or a variety of public programs, the most relevant being Seguro Campesino, a public healthcare and social security program for rural workers. About a third of respondents report healthcare coverage, of which slightly over half are covered by Seguro Campesino. Finally, we evaluate whether broadband availability is associated with changes in the share of the working population that reports social security contributions, a commonly used indicator of labor informality. About a third of workers report making contributions to social security, which is consistent with high levels of labor informality in rural Latin America.

Overall, the results do not support the hypothesis of an increase in the coverage of safety net programs associated with the

[4] It is worth noting that large effects and uncertainty intervals at both ends of the event study plot partly reflect the small number of ENEMDU records for these periods.

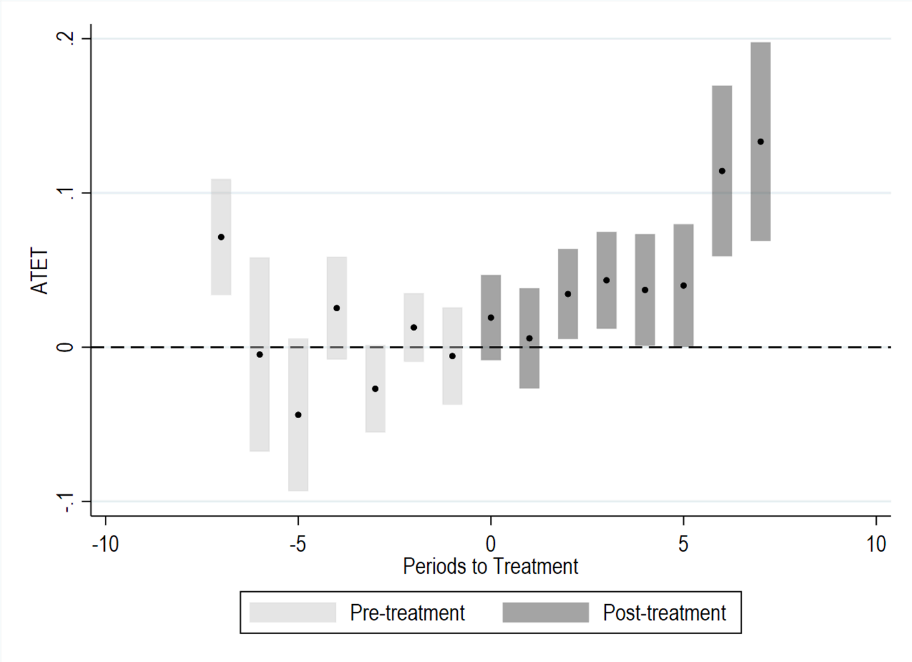

Fig. 4. Broadband availability impact on employment by relative time to treatment (95% CI).

Table 4
Impact of broadband availability on agricultural employment.

	(1)	(2)	(3)	(4)	(5)	(5)
	TWFE	TWFE	CS-NT	CS-NT	CS-YT	CS-YT
Broadband	−0.025**	−0.0150	−0.068**	−0.092**	−0.064**	−0.087**
	(0.012)	(0.011)	(0.030)	(0.037)	(0.029)	(0.034)
Observations	3,329	3,329	3,329	3,329	3,329	3,329
Mean farm employment	0.46	0.46	0.46	0.46	0.46	0.46
Covariates	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Bootstrap standard errors in parenthesis.

expansion of broadband. First, there is no evidence that more families receive income from the BDH program in parishes where broadband services were deployed. A possible interpretation is that the combined effect of income and employment gains helped lift some households over the extreme poverty threshold required to qualify for BHD, thus offsetting improvements in program coverage. However, since we lack panel data at the household level, we are unable to test this interpretation.

The results also indicate that broadband availability is not associated with changes in healthcare coverage in general, or in the coverage of Seguro Campesino in particular. Finally, in terms of social security coverage, only the standard TWFE specifications suggest an increase (of about 4 percentage points) in the share of workers that contribute to social security associated with broadband rollout (Table 5). However, this is not corroborated in any of the CS specifications. Overall, the takeaway is that there is no evidence linking the deployment of high-speed broadband in a rural parish with improved delivery of social assistance programs.

5.4. Robustness checks

A key threat to the validity of the results presented is the fact that the deployment of high-speed broadband in rural Ecuador was not randomized across parishes. We therefore rely on the assumption that, in the absence of treatment, differences over time in the variables of interest between parishes that received broadband and those that remained unserved (or that received broadband at a later time period, depending on the specification) would have remained constant. We test this parallel trends assumption in a number of ways.

First, Appendix B provides density plots for the main outcome variables at the start of the study period (year 2011). The graphs show that, at the baseline, the distribution of income and employment in treated units is comparable to that of never-treated units.

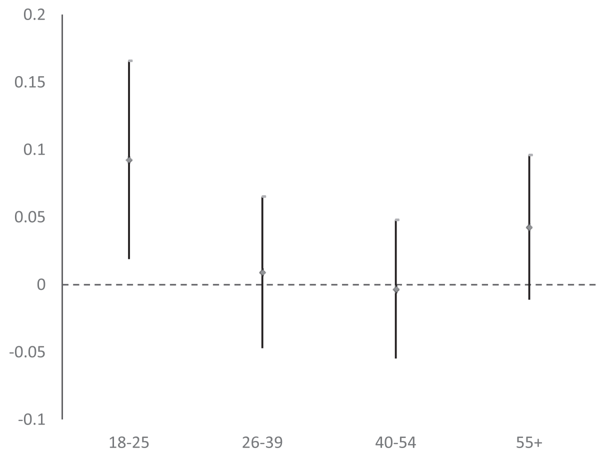

Fig. 5. Broadband availability ATET on employment by age group (95% CI).

Table 5
Impact of broadband availability on social security contributions.

	(1)	(2)	(3)	(4)	(5)	(5)
	TWFE	TWFE	CS-NT	CS-NT	CS-YT	CS-YT
Broadband	0.044**	0.035*	0.001	0.013	0.009	0.000
	(0.020)	(0.019)	(0.035)	(0.038)	(0.034)	(0.036)
Observations	3,329	3,329	3,329	3,329	3,329	3,329
Mean coverage	0.33	0.33	0.33	0.33	0.33	0.33
Covariates	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Bootstrap standard errors in parenthesis.

Further, a simple regression exercise shows that, taking baseline values, income and employment do not predict selection into treatment (Table B1).

Second, recall the presentation of event study plots recentered on relative time to exposure based on our preferred specification (the CS-NT with covariates estimator) in Fig. 2 (labor income) and Fig. 4 (employment). While not a direct test of the parallel trend assumption, in practice this represents a placebo test that examines differences between treated and nontreated units in pre-treatment periods. The absence of impact in pre-treatment periods validates the findings presented.

Finally, we extend the analysis beyond an intent-to-treat (ITT) framework by conditioning results on Internet use within the past 12 months. In other words, if changes in labor income and employment result from the availability of high-speed broadband in a previously unserved parish, this effect should be larger among individuals that report Internet use. This robustness check is closely related to the triple difference approach initially proposed by Gruber (1994). Over the study period, only about 29 percent of respondents report Internet use in the past 12 months, a level that shows how deficits in broadband infrastructure in rural areas are correlated with low levels of Internet use.

To implement this check, we divide the sample between Internet users and nonusers before aggregating at the parish level. The implicit assumption is that Internet use can only be observed after high-speed broadband is deployed in a parish, which effectively ignores the fact that respondents can also access the Internet through slower mobile connections or travel to neighboring parishes where the service may be available. However, this assumption is required because the ENEMDU survey does not contain information about type of Internet connection or location of use. Despite this limitation, this strategy offers a more targeted estimate of the treatment effect by evaluating changes among the population most likely to benefit from the deployment of high-speed broadband in a parish.

Table 6 contains two panels. Panel A (above) shows TWFE and CS estimators for Internet users, while panel B (below) shows the same estimates for individuals that do not report Internet use even after high-speed broadband is made available in the parish.

The results suggest that parish-level changes in labor income are entirely driven by workers that report Internet use in the past 12 months. In fact, the table shows that labor incomes for nonusers remain essentially unaffected by the availability of broadband. Due to the small number of units in several parish-years combinations, the point estimates are noisier than the aggregate results reported in Table 2. Regardless, this robustness check corroborates the validity of our main results.

Table 6
Impact of broadband availability on labor income (log) by Internet use.

	(1)	(2)	(3)	(4)	(5)	(6)
	TWFE	TWFE	CS-NT	CS-NT	CS-YT	CS-YT
PANEL A (users)						
Broadband	0.393***	0.165**	0.347***	0.429***	0.301***	0.428***
	(0.055)	(0.065)	(0.088)	(0.096)	(0.082)	(0.086)
Observations	2,763	2,763	2,763	2,763	2,763	2,763
Mean income (USD)	328.6	328.6	328.6	328.6	328.6	328.6
PANEL B (nonusers)						
Broadband	−0.119***	0.139**	−0.047	−0.035	−0.093	−0.064
	(0.044)	(0.056)	(0.086)	(0.121)	(0.078)	(0.100)
Observations	2,806	2,806	2,806	2,806	2,806	2,806
Mean income (USD)	273.1	273.1	273.1	273.1	273.1	273.1
Covariates	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Parish FE	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Note: Bootstrap standard errors in parenthesis.

6. Discussion and conclusions

As a general-purpose technology, broadband supports a variety of applications and uses that can spur economic activity and improve wellbeing in rural areas. This is of particular relevance to countries like Ecuador, where about half of rural households live in poverty. In this study, we build on the theorization by de Janvry and Saudolet (2000) about alternative paths out of poverty to investigate the impact of high-speed broadband deployment in rural Ecuador.

Our results demonstrate positive impacts on key determinants of rural poverty, including labor income and employment. Further, they indicate that the availability of broadband promotes economic diversification, a key factor in the mitigation of poverty among landless families and small-plot holders. As Reardon et al. (2007) argue, nonfarm activities are critical to rural households as they counterbalance the cyclical nature of agricultural incomes. One potential interpretation that links these findings is that the reduction in transaction costs in agricultural activities brought about by broadband creates opportunities (e.g., time and resources) for small-scale farmers - which account for over 75 % of agricultural activity in Ecuador (Córdova et al., 2018) - to diversify into nonfarm activities. This hypothesis deserves further exploration in future studies, particularly in contexts where small-scale, family-based farming prevails.

Our results align with previous findings about the importance of investments in basic infrastructures for broadening economic linkages that spur economic activity and create new income-generating opportunities in rural areas (Escobal, 2001). At the same time, there are notable differences between investments in roads, sanitation and electricity and those associated with broadband. Studies have consistently shown that digital skills and attitudes toward new technologies moderate the potential benefits of ICT infrastructure investments (Akerman et al., 2015; Wamuyu, 2017). The finding that benefits are disproportionately appropriated by young (male) workers likely reflects differences in digital abilities and attitudes towards new technology adoption that deserve policy attention.

The study also corroborates that the positive impacts of broadband availability are increasing in time, a finding that is consistent with the theorization about investments in general-purpose technologies (Helpman, 1998; Jovanovic and Rousseau, 2005). This underlines the need to assess the impact of broadband over the long term, as short-term evaluations (while methodologically more robust when true panel data is available) may fail to identify impacts that materialize over several years. For example, this may explain why our findings fail to identify impacts on the coverage of safety net programs, which may materialize in future years as government agencies adapt program delivery mechanisms and services to the availability of high-speed broadband in previously unserved areas.

Finally, the study shows that regulatory reforms can be a critical lever to maximize the economic contribution of broadband. In Ecuador's case, facilitating access to unlicensed spectrum bands significantly lowered market entry barriers, spurring a wave of investments in previously unserved rural areas. This strategy is not unique to Ecuador, as studies show increased investments in fixed wireless last-mile solutions in many developing countries.[5] Overall, our findings reinforce the need to promote the deployment of high-speed broadband as part of poverty reduction and economic diversification strategies in rural areas.

There are various limitations to this study that call for further research to validate the findings. For example, while our results are broadly in line with similar studies that examine the impact of wireless service deployment in rural areas (e.g., Bahia et al., 2020), a joint impact analysis of fixed and mobile broadband would provide much needed guidance to policymakers. Further research could also point to potential spatial externalities and spillover effects, as studies in developed economies suggest that broadband deployment in one area affects outcomes in neighboring areas (e.g., Briglauer et al., 2021). Finally, a better understanding of the impact heterogeneities associated with rural broadband and its root causes would provide valuable input for the design and implementation of rural development programs in emerging countries.

[5] For example, in South Africa fixed wireless ISPs already accounted for about 20% of the fixed broadband market in 2020 (ICASA, 2021).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tele.2022.101905.

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