EL COLEGIO DE MÉXICO, A.C.
CENTRO DE ESTUDIOS ECONÓMICOS

THE DIGITAL REVOLUTION AND DEVELOPMENT:
BRIDGING THEORY AND EVIDENCE

TESIS PRESENTADA POR

FERNANDO GARCÍA MORA

PROMOCIÓN 2022-2025

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DIRECTOR DE TESIS

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CIUDAD DE MÉXICO

SEPTIEMBRE DE 2025

EL COLEGIO DE MÉXICO

CENTRO DE ESTUDIOS ECONÓMICOS

CONSTANCIA DE APROBACIÓN

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Tesis: *The Digital Revolution and Development: Bridging Theory and Evidence*

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Ciudad de México, 18 de septiembre de 2025

A mi esposa Rocio y mi hijo Carlos.

Gracias por acompañarme y apoyarme en este largo camino.

A mi hijo Gabriel.

Gracias por recordarme lo frágil que es la vida y lo mucho que hay que disfrutarla cada día.

Agradecimientos

A mi tío, mentor, colega y amigo, el doctor Jorge Mora Rivera, por todo el apoyo y acompañamiento brindado. Esta tesis es un reflejo de todas las enseñanzas adquiridas durante más de 15 años.

A mis padres, Sofía y Cristóbal por estar siempre a mi lado apoyándome incondicionalmente. No hay cómo agradecer el que sean los magníficos padres que son.

Al doctor, colega y amigo, Edwin van Gameren, por todo el acompañamiento, los comentarios, las sugerencias y los cuestionamientos realizados durante estos tres años. Gracias por ser un asesor que realmente se involucra en la formación de los tesistas.

A los doctores, Raymundo Campo y Owen Ceballos, por su lectura y valiosos comentarios y sugerencias.

A mi abuela Sara, por confiar siempre en mí e insistirme en que debía terminar este reto.

A mi familia, por estar siempre cuando los necesito. Ustedes son parte fundamental de este logro en mi vida.

A El Colegio de México por haberme acogido todos estos años. Gracias por ser una gran institución y apoyarme para culminar este proyecto de vida.

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Introduction

Over the past fifteen years, the global expansion of Information and Communication Technologies (ICT) has been nothing short of remarkable, fundamentally reshaping the way individuals, businesses, and governments interact. According to the International Telecommunication Union (ITU), the number of Internet users worldwide increased by 3.4 billion between 2010 and 2023. In 2010, only 29% of the global population had access to the Internet; by 2023, this figure had more than doubled to 67%. While Internet adoption continues to correlate strongly with a country's level of economic development, even low-income countries have experienced substantial progress in bridging the digital divide. Since 2020, Internet use in these countries has increased by 44.1%, including a 14.3% rise in the last year alone. This rapid growth reflects both the increasing availability of digital infrastructure and the growing recognition of the Internet as a vital tool for socioeconomic inclusion. As connectivity improves, more people are gaining access not only to information and communication channels but also to new opportunities in education, employment, and public services, laying the foundation for broader development gains.

In response to this rapid technological expansion, numerous international organizations have turned their attention to the potential of ICT as a catalyst for achieving the Sustainable Development Goals (SDGs). These goals, established by the United Nations, encompass a broad range of global priorities, including poverty reduction, improved healthcare, expanded access to quality education, increased employment opportunities, and the promotion of gender equality. Agencies such as the ITU, the Economic Commission for Latin America and the Caribbean (ECLAC), and the World Bank have emphasized that leveraging ICT effectively can accelerate progress toward these objectives. Beyond providing new tools for communication and data access, ICT can help reduce inequalities by connecting underserved populations to essential services, markets, and information, thereby playing a transformative role in advancing inclusive and sustainable development. Consequently, scholarly interest in constructing a theoretical framework and empirically examining the relationship between ICT and key development

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indicators has grown significantly. Despite this increasing attention, important gaps persist in the literature, particularly in efforts to establish robust conceptual and empirical linkages between ICT and development outcomes.

These gaps in the literature provide the basis for a research question that frames the development of this thesis: How is the ICT for Development (ICT4D) approach theoretically linked to the digital divide approach, incorporating a clear definition of development, and how can this theoretical connection be empirically tested? Addressing these questions allows for the formulation of the central objective of this thesis along two main lines, first, to develop a theoretical framework that clearly connects the ICT4D approach with the digital divide approach–understood as the unequal access to, use of, and impact of ICT across different populations–while also incorporating a clear definition of what is meant by development; and second, to conduct two empirical exercises to validate the proposed theoretical framework. To our knowledge, this thesis constitutes the first effort to simultaneously integrate a formal theoretical model of the ICT–development nexus with empirical tests on both poverty and gendered labor outcomes at the local level in Mexico. Therefore, structured in three chapters, this thesis seeks to contribute to the field by addressing the aforementioned gaps through both theoretical refinement and empirical analysis.

To achieve the central objective of this thesis, a comprehensive methodological strategy is proposed, structured in two main stages. The first stage involves the development of a robust theoretical framework that integrates three key conceptual approaches: the ICT4D, the digital divide, and Amartya Sen's capability approach. This interdisciplinary framework provides a solid foundation for understanding the complex ways in which access to and use of ICT can influence development outcomes, particularly by shaping opportunities and expanding individual capabilities.

The second stage of the methodological strategy consists of the application of two complementary empirical methodologies aimed at testing the theoretical propositions derived in the first stage. Specifically, instrumental variable techniques are employed to address potential endogeneity and establish credible causal relationships between ICT access and multidimensional poverty. In addition, a trivariate recursive model is used to

simultaneously estimate interrelated binary outcomes and account for potential correlations among unobserved factors. This dual-method approach not only strengthens the empirical rigor of the study but also allows for a more nuanced validation of the theoretical model by examining its applicability to real-world scenarios. Together, these two stages ensure a coherent alignment between theory and empirical analysis, contributing to a more comprehensive understanding of the ICT–development nexus.

Specifically, the first chapter addresses a theoretical void: the lack of an integrated framework that clearly connects the ICT4D perspective with the digital divide approach while incorporating a well-defined concept of development based on Amartya Sen's capability approach. Although some studies acknowledge the interrelation between these perspectives, none have explicitly proposed how the digital divide fits within the broader ICT4D framework. This chapter seeks to bridge that gap and contribute to the construction of a more robust theoretical foundation linking ICT and development. Furthermore, existing theoretical work tends to overlook the mechanisms through which ICT impacts development outcomes. This research contributes by identifying and conceptualizing those transmission channels and offers an initial formalization through a mathematical representation, an aspect largely missing in current theoretical discussions.

Building on the theoretical framework developed in Chapter One, Chapter Two presents the first empirical investigation of the thesis. It focuses on assessing the potential impact of mobile Internet access on multidimensional poverty among Mexican localities, with particular emphasis on labor markets as a key transmission mechanism. The chapter employs one of the most internationally recognized development indicators to analyze the effects of mobile Internet on the third level of the digital divide, that is to say, the capacity of ICT, particularly mobile Internet, to generate tangible benefits for the population. Despite the persistent and multidimensional nature of poverty in Mexico and the growing body of international evidence linking mobile Internet access to poverty alleviation, no previous study has empirically examined this relationship in the Mexican context. Moreover, existing research has largely overlooked the differentiated effects of various mobile technologies, such as 3G, 4G, or their combined implementation, as well as the role of exposure time and technological evolution in shaping poverty outcomes. This chapter

seeks to address these research gaps by offering novel empirical evidence on the interplay between mobile Internet access, labor market dynamics, and multidimensional poverty.

Several considerations highlight the significance of Chapter Two. First, although mobile Internet coverage in Mexico has expanded rapidly in recent years, it remains essential to evaluate whether this increased availability has translated into measurable improvements in multidimensional poverty outcomes. Second, to date, no empirical study has simultaneously assessed the differentiated effects of distinct mobile technologies (3G, 4G, and combined) alongside the role of exposure or adaptation time in shaping poverty dynamics. Third, this chapter contributes methodologically by employing a rigorous econometric framework to estimate the potential impact of mobile Internet access as a mechanism for poverty alleviation in the Mexican context. Fourth, it extends the existing literature by explicitly examining labor markets as a key transmission channel through which mobile Internet may influence multidimensional poverty. Understanding this mechanism is essential for a more comprehensive analysis of the socioeconomic implications of digital connectivity. Fifth, the findings presented in this chapter offer valuable insights into the design of evidence-based public policies aimed at leveraging mobile Internet adoption to reduce poverty and promote inclusive development.

In particular, we find that, regardless of the specific technology used, expanding mobile Internet coverage to the entire population contributes to reducing multidimensional poverty. However, the impact varies significantly across localities. In areas with very low levels of multidimensional poverty, mobile Internet access helps maintain favorable conditions, while in those with very high levels of poverty, it supports efforts to overcome adverse circumstances. We also find suggestive evidence that the effect is more pronounced in localities with lower rates of labor market informality–our proxy for labor market development. These results reinforce the rationale behind current Mexican government initiatives aimed at achieving universal mobile Internet access. From a policy perspective, we recommend complementing coverage expansion with initiatives to promote digital literacy, particularly in rural areas.

The final chapter presents a second empirical analysis, examining the relationship between Internet access, rural migration, and female labor force participation in Mexico.

Specifically, it investigates whether increased Internet availability contributes to greater out-migration from rural areas and how these migratory flows subsequently affect women's participation in the labor market within the communities of origin. This research focus is particularly pertinent for three main reasons. First, migration remains a central and multifaceted phenomenon in Mexico. A significant number of individuals continue to migrate to the United States in pursuit of improved employment opportunities, largely driven by persistent regional economic disparities. Second, a pronounced digital divide persists between urban and rural areas. This disparity underscores the importance of analyzing whether access to digital infrastructure in rural communities influences critical household decisions, particularly those related to migration. Third, women's participation in the labor force has increased markedly since the early 2000s. However, substantial gender gaps in labor market participation persist in rural areas. Despite these broader trends, limited research has examined the mechanisms that shape women's labor decisions in rural contexts. This chapter seeks to address this gap by analyzing the intersection of digital connectivity, migration, and gendered labor outcomes in a developing economy.

The findings from this chapter provide suggestive evidence that Internet access is a key driver of migration among rural households. Specifically, it strengthens migratory networks by facilitating communication between migrants and their families during the journey and after arrival, while also enabling new connections between current and potential migrants, thereby reducing information and transportation costs. Moreover, Internet access and migration jointly contribute to the integration of rural women into both salaried employment and self-employment in non-agricultural activities. However, there is no evidence that they promote women's participation in agricultural work. These results suggest that expanding Internet access could serve as a powerful tool for improving rural women's access to labor market opportunities.

Collectively, the chapters aim to deepen our understanding of how Information and Communication Technologies (ICT), and the Internet in particular, can function as a catalyst for development. By integrating theoretical frameworks with empirical analysis, this research provides both conceptual insights and evidence-based findings with important implications for public policy and inclusive digital development strategies.

Chapter 1

Information and Communication Technologies (ICT) for Development (ICT4D) and the Digital Divide: A Unified Theoretical Framework

1.1 Introduction

In the last fifteen years, the expansion of Information and Communication Technologies (ICT) worldwide has been remarkable. The International Telecommunication Union (ITU) points out that from 2010 to 2023, the number of Internet users in the world rose by 3.4 billion; while in 2010 just 29% of the world population used the Internet, in 2023 this figure increased to 67% (ITU, 2024). While Internet use remains closely linked to a country's development level, low-income countries have also advanced in incorporating their population into the digital era. In these countries, the number of Internet users has grown by 44.1 percent since 2020, and by 14.3 percent in the past year alone. In response to this technological boom, several international agencies have been interested in understanding how ICT can be used to achieve Sustainable Development Goals (SDG), such as reducing poverty, improving health, increasing employment levels, providing quality education, and promoting gender equality (ITU, 2022; ECLAC, 2022; World Bank, 2016). The World Bank highlighted that raising Internet penetration to 75% of the population in all developing countries could add as much as US$2 trillion to their collective gross domestic product (GDP) and create more than 140 million jobs worldwide.

As a result, researchers have become increasingly interested in empirically analyzing the way ICT (potentially) impacts development indicators like welfare (Apeti, 2023; Melaine and Nonvide, 2023; Masaki, et al., 2020; Tadesse and Bahiigwa, 2015; Bahia, et al., 2024), poverty (Bahia, et al., 2023; Galperin et al., 2022; Afzal, et al., 2022; Nguyen et al., 2022; Zhang et al., 2022; Yang, et al., 2021), labor outcomes (Chiplunkar

and Goldberg, 2022; Bhuller et al., 2020), GDP (Mensah, 2021), and political outcomes (Donati, 2023; Guriev, et al., 2021). However, despite recent empirical evidence regarding the effects of ICT on development, there are still gaps concerning the theory that links the ICT-development nexus (Sein et al., 2018), and even more so, about the channels through which ICT could potentially impact a region's, community's, household's, or individual's development.

Several studies have addressed from a theoretical perspective the ICT-development link under different conceptual frameworks (see Table 1) such as the livelihoods approach (Chapman et al., 2003; Duncombe, 2006; Parkinson and Ramirez, 2006; Parkinson and Lauzon, 2008), the actor-network theory (ANT) (Stanforth, 2006; Rubinoff, 2008; Rhodes, 2009, Teles and Joia, 2010; Thapa, 2011), the diffusion of innovation theory (Roman, 2003; Chigona and Licker, 2008), the capability approach (Alampay, 2006; Zheng, 2009; Zheng and Stahl, 2011; Bass et al., 2013; Kleine, 2013), the rights-based approach (Gurumurthy, 2008), the competitive advantage theory (Heeks, 2006), or the choice framework (Kleine, 2010). Heeks (2006) offers guidance on when, why, and how to apply Porter's competitive advantage theory to the analysis of IT sectors in developing countries. Particularly, he applies this theory to the case of India's software industry, which he finds to have a competitive advantage, based on variables such as ever-increasing advanced skills, domestic rivalry, clustering, and government policy/vision. Applying a livelihoods approach, Duncombe (2006) analyzes the role of ICT in microenterprises, assuming that they represent a viable route out of poverty through increased and more diversified income streams for poor households. Along the same vein, Parkinson and Ramirez (2006) describe the sustainable livelihoods framework as a useful tool in assessing the contribution of ICT to development projects, arguing that this framework can help to broaden the ICT scope in a manageable way and prove more analytically rigorous than other available approaches.

Stanforth (2006) presents actor-network theory (ANT) as a framework for understanding the processes of implementing e-government in developing countries. Similarly, Rubinoff (2008) argues that ANT helps to conceptualize ICT beyond the

technological systems of the conventional "digital divide[1]." ANT supports thinking about the sociotechnical networks that incorporate humans, hardware, institutions, and policies into ICT networks. Chigona and Licker (2008) analyze how well the diffusion of innovations (DoI) theory explains the adoption of communal computing facilities operating among the urban poor of Cape Town, in South Africa. They conclude that DoI explains most of the adoption patterns of communal computing facilities.

Drawing on the capability approach, Zheng (2009) provides some theoretical reflections on e-development. He argues that the capability approach, being a normative and evaluative framework, provides a different "space" to assess e-development and allows sensitizing and considering various important issues surrounding ICT adoption for development. Zheng and Stahl (2011) investigate how critical theory can enhance and fortify Sen's capability approach concerning technology and human progress. They pinpoint three key areas for improvement: First, on a conceptual level, by offering a nuanced critique of individual agency and broadening the understanding of technology beyond mere goods and resources. Second, from a methodological perspective, by raising awareness of the dominance and objectification associated with scientific methodologies. Third, by advocating for reflexivity among researchers in their analysis.

Despite these efforts, literature lacks a theoretical framework that clearly connects the ICT for Development (ICT4D) approach and the digital divide approach, while also incorporating a clear definition of what is meant by development. Although some studies acknowledge their interrelation, no one explicitly proposes how the digital divide approach fits within the broader ICT4D framework. This research aims to fill that gap and, in doing so, contribute to the development of a stronger theoretical framework that more effectively links ICT with development. Similarly, theoretical work on the relationship between ICT and development tends to address only briefly the transmission channels through which ICT affects development outcomes. This investigation seeks to contribute by proposing how such effects are transmitted. It also introduces an initial formalization of these ideas

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[1] The digital divide refers to the gap between individuals, households, businesses, or geographic areas at different socio-economic levels in terms of their access to, use of, or familiarity with ICTs. This concept is further elaborated later in the chapter.

through a mathematical representation—an element largely absent from existing theoretical discussions.

Table 1. Studies addressing the ICT-development nexus from a theoretical point of view

Authors (year)	Theory
Chapman et al., 2003	
Duncombe, 2006	
Parkinson and Ramirez, 2006	Livelihoods approach
Parkinson and Lauzon, 2008	
Stanforth, 2006	
Rubinoff, 2008	
Rhodes, 2009	Actor-network theory (ANT)
Teles and Joia, 2010	
Thapa, 2011	
Roman, 2003	Diffusion of innovation
Chigona and Licker, 2008	
Alampay, 2006	
Zheng, 2009	
Zheng and Stahl, 2011	Capability approach
Bass et al., 2013	
Kleine, 2013	
Gurumurthy, 2008	Rights-based approach
Heeks, 2006	Competitive advantage theory
Kleine, 2010	Choice framework

Source: By author.

The main aim of this research is to develop a theoretical framework that helps better explain the relationship between ICT (specifically the Internet) and development, as well as to analyze two (potential) transmission channels by which this technology can positively affect an individual's degree of development. To achieve these goals, we aim to answer the following questions: In the first instance, how can the concept of development be more

effectively integrated into the ICT literature? To do so, we proposed to use and broaden the capability approach introduced by Sen (1985). According to this perspective, ICT can be considered a particular resource that generates new opportunities and thus improves people's well-being. Secondly, what are the mechanisms through which ICT allow the creation of new opportunities that enhance the degree of development? To address this question, we suggest using the concepts of social and human capital. Thirdly, how can the widely used digital divide approach be introduced into the theoretical framework that links the capability approach with ICT? Although international researchers have not yet addressed this last question, we propose an initial pathway to link our empirical framework with the digital divide approach.

The answer to these questions contributes to different branches of literature on the ICT-development nexus. First, while several studies have analyzed this relationship, only a few incorporate a clear definition of the concept of development, and hardly any include a formal explanation of the way ICT can be linked to it. In this context, we build a theoretical framework that clearly explains the main concepts and definitions that underlie the ICT-development linkage and mathematically describe how they interact. Second, although international research has made a substantial effort to analyze empirically the relationship between ICT and development (Apeti, 2023; Bahia, et al., 2023; Galperin et al., 2022; Chiplunkar and Goldberg, 2022), showing the positive impacts of technology on different dimensions of people's well-being, almost no one theoretically describes the possible channels through which this effect is transmitted. Third, an increasing number of researchers are using the digital divide approach as a basis to examine the role of ICT on various economic, socio-demographic, and sociological aspects (Mignamissi and Djijo, 2021; Pérez-Castro, et al., 2021; van Dijk, 2020; Ye and Yang, 2020; Mariscal, et al., 2019), yet we found no evidence of the incorporation of this approach as an element of a theoretical framework that explains the ICT-development link.

The rest of the chapter is divided as follows. Section 1.2 presents the central concepts and definitions used to outline the ICT-development nexus. In section 1.3, we developed the mathematical model to explain the relationship between ICT and development, as well as the conditions that allow human capital and social capital to act as

transmission mechanisms of this link. Finally, we summarize our findings and present the conclusions.

1.2 Central concepts and definitions underlying the ICT-development relationship

To build up a theoretical framework that helps explain the transmission channels through which Information and Communication Technologies potentially affect development, we must start by defining two central concepts: (i) the digital divide, and (ii) development.

1.2.1 Digital divide

The *digital divide* approach provides useful elements to assess the effects of the dispersion and the penetration of ICT in different dimensions of society (van Deursen and van Dijk, 2019; Nishijima et al., 2017; van Dijk, 2013). The concept was coined during the mid-1990s and initially documented in a publication released by the US Department of Commerce's National Telecommunications and Information Administration; however, it was not until the 2000s that it became a topic of interest for research in other disciplines, such as communication sciences, sociology, psychology, economics, and educational sciences (van Dijk, 2006). In the early years, the digital divide focused on a narrow meaning of access, particularly *physical access*; thus, scholars concentrated on analyzing the correlation between physical access and general demographic characteristics such as income, level of education, age, gender, employment status, and race.

Later, researchers called attention to issues *beyond physical access*, especially necessary skills needed for users (Hargittai, 2002), different uses of the Internet (Bonfadelli, 2002), as well as the complex nexus between access and the appropriation of technology (van Dijk and Hacker, 2003). As a result of the broader conceptualization of the digital divide, in 2002, Hargittai proposed the term *second-level divide*. From 2005 to 2015, most digital divide research focused on the second-level divide; however, an important drawback was that the causes of access were not studied, let alone the effects, which were completely ignored. In this regard, van Dijk (2017) recognizes the importance of

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investigating the impacts of having greater or lesser access, which entails examining the advantages and disadvantages of equal or unequal ICT availability. Therefore, a third level of the digital divide emerged, aimed at analyzing the benefits in social, economic, or cultural aspects, related to connectivity (Castells and Himanen, 2014; van Deursen and Helsper, 2015; Mansell, 2017).

1.2.2 Development

In terms of *development*, several approximations have been used over the years to define the concept. Traditional economics tends to link individuals' well-being with their command over goods and services (Basu and López-Calva, 2011). This approximation often views each individual as being endowed with a utility or welfare function, and their income as a fundamental variable in influencing the utility level they enjoy. According to this approach, social welfare can be represented as the aggregation of the utility levels of all individuals in society (Basu and López-Calva, 2011). Other perspectives on development focus on increasing different kinds of resources, recognizing the fundamental importance of commodities and material goods to our well-being in the short and long term (Alkire and Deneulin, 2009).

An alternative route that has been widely used among researchers to define the term development is the one proposed by Amartya Sen in his *capability approach* (Sen 1980, 1985). According to Sen, the conceptualization of development goes beyond an economic growth perspective. He argues that the enhancement of living conditions must be an essential – if not the essential – object of the entire economic exercise and that enhancement is an integral element of the concept of development (Sen, 1988).[2] The fundamental difference between Sen's approach and traditional welfare economics is the distinction between *goods* (*commodities*) and *functionings*. Functionings are those valuable

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[2] Alternative approaches to development challenge Sen's capabilities framework by emphasizing relational, environmental, and structural dimensions. Relational development focuses on the social and power dynamics that shape wellbeing, highlighting the importance of collective agency, community ties, and institutions. The sustainability approach critiques development models that ignore ecological limits, advocating for intergenerational justice, environmental stewardship, and holistic wellbeing beyond economic growth. Meanwhile, the data justice perspective interrogates the role of digital technologies and data systems in development, calling for equitable access, representation, and governance of data to prevent new forms of exclusion or surveillance. These frameworks broaden the definition of development by embedding it in social, ecological, and political contexts, rather than viewing it solely through individual capabilities.

activities and states that make up people's well-being – such as a healthy body, being safe, being educated, or having a good job. It is worth noting that some functionings focus on survival, work, and material well-being, and others on empowerment or self-expression. On the other hand, goods (commodities) can *enable* functionings, but they are distinct from them; for example, a vehicle is a good, whereas being able to transport oneself rapidly to work is a functioning. Although the capability approach can be developed without reference to utility, it is not incompatible with the idea of individuals striving to achieve a certain level of or even aiming to maximize utility (Basu and López-Calva, 2011). However, if we are willing to use the idea of utility in conjunction with that of functionings, then we should consider that just as goods (commodities) come before functionings, functionings come before utility.

While functionings *achieved* by an individual are essential, they may not be sufficient in the process of determining a person's degree of development. The alternative combinations of things a person could do or be – the various functionings an individual could achieve – are called capabilities (Sen, 1985); therefore, the concept of capabilities is closely related to the idea of *freedom*. It is worth clarifying that capabilities include only possibilities that people value; activities or states that people do not value or have reason to value cannot be called capabilities. Thus, the focus of development evolves into increasing a person's capability set (Sen, 1999). It should be noted that the capability approach makes an important distinction between *means*, such as ICT services (e.g., Internet connectivity) or income, and *ends*, such as education, healthcare, employment, inequality, and poverty; thus, Sen's approach, unlike other approaches, does not attach direct importance to the means of living but to the ends.

1.2.3 Linking development with ICT: towards a better unified framework connecting ICT4D and the digital divide

Once we have defined the concept of development, the next step consists of linking Sen's capability approach with ICT in general, and the digital divide approach in particular. To do so, we must realize that ICT are an individual and collective resource; therefore, the benefits derived from the access to and use of ICT have an individual and collective dimension. To incorporate the collective nature of ICT in the concept of development, it is

necessary to extend (as far as possible) Sen's capability approach to one that includes collective functionings (Evans, 2002; Ibrahim, 2006)[3]. The notion of collective functionings refers to the opportunity of a group of individual agents to perform a set of distinct actions in a cooperative way. Collective functionings are not simple aggregates of individual functionings; rather, they are distinct in the sense that an individual can attain them only as a group member; thus, collective functionings influence the enhancement and exercise of individual functionings (Ibrahim, 2006).

Hence, converting ICT into functionings is not exclusively determined at an individual level but also at a collective one. Nonetheless, two questions remain unanswered: What could be the mechanism(s) through which ICT allow the creation of collective and individual functionings? And how can the digital divide approach be incorporated into the theoretical framework that links the capability approach to ICT?

1.2.3.1 Social and human capital as mechanisms through which ICT creates collective and individual functionings

To answer the first question, we propose using two concepts: *social capital* and *human capital*. The former would be linked mainly with the notion of collective functionings, while the latter with that of individual functionings; however, as will be pointed out later, there is a complementary relationship between the two.

Social capital can be defined as "the value of those aspects of social structure to actors as resources that can be used by them to realize their interest" (Coleman, 1994). The theory of social capital recognizes two forms in which this type of capital manifests itself: *bonding social capital* and *bridging social capital*. Bonding social capital refers to the ties between family and close friends. Bridging social capital represents the extended but

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[3] While the capabilities approach offers a valuable normative framework for assessing human development and individual agency, its application in contexts of digital structural inequality has faced criticism. Scholars argue that it often presumes individuals can convert capabilities into functionings without fully accounting for systemic barriers such as gender norms, limited digital infrastructure, or unequal access to education. In rural and marginalized settings, the mere provision of digital access does not ensure meaningful use or empowerment. Without addressing structural constraints—including digital literacy gaps or patriarchal control over technology—the capabilities approach risks individualizing responsibility for disadvantage and overlooking the broader social conditions that shape real freedoms. A more grounded application requires integrating a structural and intersectional analysis to avoid reinforcing existing inequalities under the guise of opportunity.

generally weaker social ties between individuals of different groups that, for example, help people to find work, or cooperatively solve shared problems. Additionally, bridging social capital is broken down into two veins: intra-community, associated with local community ties, and inter-community (also known as *linking social capital*), associated with ties across borders of the local community. Like other forms of capital, social capital is *productive*, enabling the achievement of certain ends (Coleman, 1988). Social relations are considered a form of capital that contributes to the well-being of a community or *directly to an individual's welfare* (Lin, 2001).

With this perspective in mind, ICT can be considered to create or extend social capital which helps build collective functionings and thus enlarge individuals' capability set. For example, knowledge gained from access to the Internet about market prices strengthens the social capital among small farmers, who can share up-to-date information with other (small) farmers; this process helps them create collective functionings such as group protection from abuse by external buyers. Also, employment search websites like LinkedIn or Indeed strengthen intra-community social relationships (bridging social capital) but also inter-community social nexus (linking social capital). The expansion in social capital arising from the adoption of ICT creates new collective functionings such as access to digital labor networks (especially for job seekers), thus enlarging their capability set.

Another example could be international migration, in which case ICT (especially the Internet and smartphones) have become essential tools that help preserve and strengthen the migrants-relatives nexus (bonding social capital) but also encourage international migration by linking the migrant with other members of their community of origin who intend to migrate (bridging social capital). This expansion of social capital within the home community creates new collective functionings, such as access to migration networks, which in turn broadens individuals' capability set. Chapter 3 empirically examines the relationship between Internet access and international migration in rural Mexico. The analysis focuses on how access to the Internet contributes to the expansion of migration networks—primarily by preserving and strengthening ties between migrants and their families, but also by facilitating the sharing of information about migration routes and

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opportunities in destination areas with other family or community members. Both of these mechanisms are directly linked to social capital. The chapter also explores how the Internet, through its influence on migration, affects patterns of women's participation in the rural labor force, potentially contributing to expanding their human capital.

On the other hand, *human capital* refers to the "activities that influence future income by increasing resources in people" (Becker, 1975). While Becker's approach focused exclusively on the returns of investments in education on future income, other authors have defined complementary ways of thinking about human capital, pointing out that it also includes the skills individuals acquire throughout their lives and gives them an advantage over others (Gathmann and Schönberg, 2024; Kottelenberg and Lehrer, 2019; Goldin, 2016). Also, Grossman (1972, 2000) connects the human capital framework to health, arguing that individuals view health as a durable capital stock that produces both direct utility and economic returns. In this view, people invest in their health—through medical care, nutrition, physical activity, and education—not only because being healthy is valuable in itself, but also because better health increases their productivity, reduces time lost to illness, and enhances their capacity to generate income. Thus, health investments are comparable to other forms of human capital accumulation, such as education, in that they improve an individual's ability to participate in the labor market and contribute to long-term economic outcomes. Thus, if ICT are considered a source of human capital, it is reasonable to assume that access to and use of ICT can significantly contribute to human capital formation. Individuals who access or use ICT may develop specific skills that give them an advantage over those without such access. Considering the above, we could argue that the accumulation of human capital through accessing and using ICT expands people's achievable functionings from an individual dimension, thus broadening their capability set, enlarging individuals' freedom to do and to be (Chiappero-Martinetti and Sabadash, 2014).

It should be highlighted that a close relationship exists between social capital and human capital. According to Coleman (1988), social capital is a fundamental element to enhance the impacts derived from human capital. Therefore, individuals can make better use of the skills they have learned throughout their lives if social relations are stronger. In the case of ICT, under the premise that they are an individual and collective resource, we

can argue that the positive effect on an individual's level of human capital gained from ICT access and use is enhanced at the same time by the stronger social capital in their community derived also from ICT access and use (social capital effect), which allows individuals to use their newly acquired skills more efficiently. Hence, ICT should be understood as a particular kind of resource that enables a reinforcing nexus between human and social capital.

1.2.3.2 Incorporating the digital divide into the ICT4D framework

Regarding the second question (how the digital divide can be incorporated into the theoretical framework that links the capability approach with ICT), it is worth noting that to the best of our knowledge, international literature has not yet addressed this particular nexus. Ragnedda and Ruiu (2017) analyze the link between social capital and the three levels of the digital divide, but they do not examine the potential relationship with the capability approach. Therefore, we integrated the digital divide approach into two stages of the theoretical framework, as illustrated by the orange boxes in the diagram in Figure 1. First, levels one and two of the digital divide approach (physical access and skills) are directly related to what Urquhart et al. (2008) defined as the implementation stage of an *ICT intervention*. Even though Urquhart et al. (2008) define this implementation stage, they do not connect it to the digital divide approach. Second, the *results achieved* by the ICT intervention across various dimensions of well-being are linked to the third level of the digital divide (impacts). This last proposal represents a unique contribution of our research, as, to the best of our knowledge, no existing studies explicitly connect the third level of the digital divide with an approach that links ICT and development.

Having defined the most important concepts to outline a theoretical framework that allows explaining the ICT-development nexus, below we present a scheme illustrating the way these concepts work together. The particular steps describing the Figure are the following:

1. At the beginning, the inhabitants of a community do not have access to ICT services, reflecting the first level of the digital divide. At this initial stage, we assume that the community members possess an inherent endowment of social capital, such as networks, relationships, trust, and human capital, including skills,

education, and health. They also have access to an initial endowment of commodities, from which they select those that best serve their interests. However, access to ICT is not yet included among the available commodities.

2. Given the backward conditions faced by the population living in the community, an *ICT intervention* is implemented, such as a public policy aimed at expanding broadband Internet coverage or a commercial venture designed to increase the diffusion of high-speed Internet. These interventions are typically introduced to address the gaps in access and ensure that underserved communities can benefit from the opportunities offered by digital technologies. At this stage, Internet access emerges as a new commodity available to all members of the community.

Ideally, as part of its design, the ICT intervention will consider two main components: ICT infrastructure and ICT capacity-building. The former is a fundamental part of all ICT projects, while the latter refers to the human capacity to employ ICT properly, but also can be seen as the acquisition of human capital by attaining new skills (Urquhart et al., 2008). It should be highlighted that ICT infrastructure is mainly associated with the first level of the digital divide (access), while ICT capacity-building is associated with the second level (skills for efficient use).

3. When the community's inhabitants gain access to and begin using ICT, they become more connected with other members of their community, fostering bonding social capital, while simultaneously expanding their networks to interact with individuals from other communities, thereby developing bridging social capital. This increased connectivity allows them to share resources, information, and support within the community, strengthening local ties. Moreover, as individuals connect with people beyond their immediate environment, they gain access to broader networks of knowledge, opportunities, and collaborations that transcend geographic and social boundaries. In addition to these social benefits, the use of ICT enables individuals to learn new skills, acquire knowledge, and engage with educational resources, thus

enhancing their human capital. This accumulation of knowledge and skills leads to improved personal and professional outcomes.

Because social capital and human capital are mutually reinforcing, the growth of one tends to stimulate the other. As individuals strengthen their social connections through ICT, they often encounter new opportunities for learning and skill development, while the acquisition of new knowledge increases their capacity to engage more effectively with others. This synergy creates a virtuous cycle where increased social interaction and enhanced human capital mutually strengthen one another, contributing to the overall development and resilience of the community.

4. The increase in social and human capital enhances both collective and individual functionings, thereby broadening people's capability set, or their freedom to choose and act. As individuals and communities accumulate social capital through stronger networks and relationships, as well as human capital through improved skills and knowledge, they gain greater access to opportunities that enable them to lead more fulfilling lives. This expansion of functionings means that individuals are not only able to engage more actively in their personal lives and communities, but they can also exercise greater control over their economic, social, and cultural choices.

In other words, their expanded capability set means that they are empowered to pursue a diverse array of alternative combinations of "beings" (what they can be or achieve) and "doings" (what they can do or participate in), thereby increasing their overall well-being and freedom of choice. This greater freedom reflects a shift from a constrained existence to one in which individuals and communities can actively shape their own lives based on their preferences, values, and aspirations.

5. Finally, if individuals have a wider capability set, they can enjoy a higher degree of development across all dimensions that ICT can influence, such as education, employment, health, and social mobility. With greater access to information, resources, and opportunities through ICT, individuals can improve their educational outcomes by accessing online courses, digital learning tools, and global knowledge networks. In the realm of employment, ICT enables individuals to acquire new

skills, explore job opportunities beyond their immediate locality, and engage in remote work, which leads to better income prospects and career advancement. Moreover, access to ICT improves healthcare by allowing individuals to access medical information, telemedicine, and health services that would otherwise be out of reach, particularly in rural or underserved areas. Thus, inequality and poverty are reduced in a multidimensional way.

6. Ideally, to empirically assess our theoretical framework, it would be preferable to have data on Internet access and usage at the household or individual level. Moreover, access to longitudinal data would be particularly valuable for examining the dynamics of key development indicators—such as inequality, migration, and poverty—resulting from the ICT intervention. While this represents the ideal in terms of data requirements, it is important to note that no such dataset currently exists for Mexico. Consequently, the empirical analyses presented in the following two chapters rely on cross-sectional data and employ alternative methodological strategies to identify causal effects.

Figure 1. Diagram of the theoretical framework underlying the ICT-development nexus
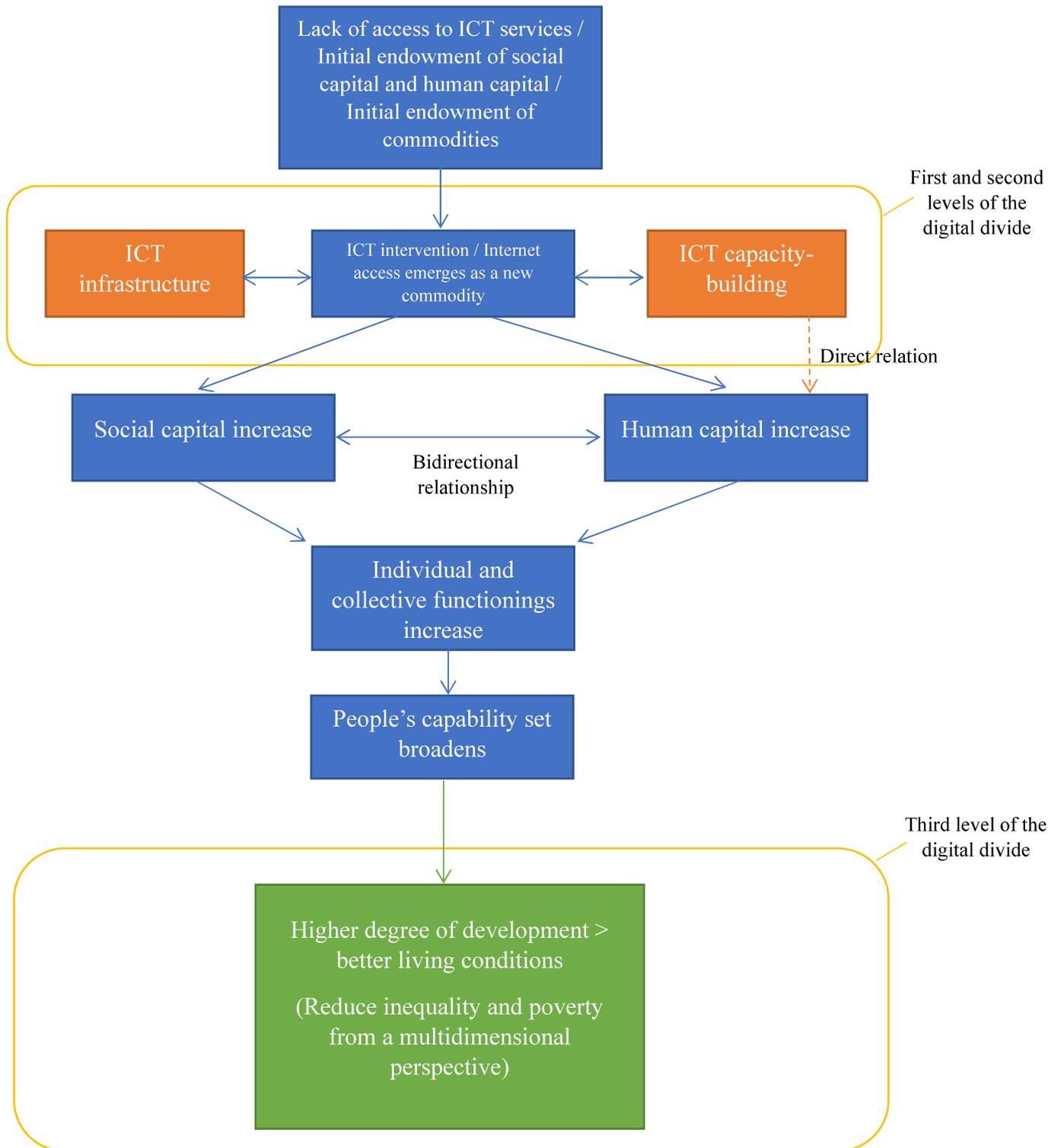
Source: By author, based on Urquhart et al. (2008) and Thapa et al. (2012).

1.3   Mathematical model

1.3.1 Base model

Once the theoretical framework has been depicted and the central concepts have been defined, the next step consists of formalizing these ideas through an initial mathematical representation, and subsequently, diving into particular relationships shown in Figure 1. We start defining a community in which n individuals live (assume n is fixed). The community lacks the infrastructure to provide ICT services (in particular Internet connectivity) to its inhabitants; thus, no member of the community has Internet access. Let $\mathbf{L}$ be the vector denoting said community, and l_i person i who lives in it, with $i = 1, \ldots, n$; therefore, $\mathbf{L} \equiv (l_1, \ldots, l_i, \ldots, l_n)$.

Following Sen (1985), we shall consider that goods (commodities) have an *instrumental* value in that they allow individuals to *function*. We define the commodities vector $\mathbf{x}_i$ as the array of all commodities possessed by person i of the community $\mathbf{L}$, and $\mathbf{X}_i$ the set of all commodity vectors to which person i can access, so $\mathbf{x}_i \in \mathbf{X}_i$.[4] Initially, given the backward conditions faced by the community, none of the $\mathbf{x}_i$ vectors include Internet connectivity as one of their components.[5] Next, let $f_i(\cdot)$ be an individual *i's personal utilization function*, that is to say, a function that transforms commodities into functionings (Basu and López-Calva, 2011; Sen, 1985). To explain the way the utilization function works, we can use the pioneering approach of Gorman (1956) and Lancaster (1966). According to these authors, commodities can be seen in terms of their characteristics, which are the various desirable properties of the commodities in question. If a person has access to a secure amount of these commodities, then they can command the corresponding characteristics. Hence, f_i could be considered a vector-valued function, which directly converts a commodity vector into a functionings vector.[6] We can also think of f_i as a function that enables social and human capital to act as mechanisms in the creation of new functionings. In this sense, the function serves as a bridge between commodities and

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[4] Sen (1985) argues that $\mathbf{X}_i$ is person *i's* entitlements.

[5] According to Yan et al. (2020), the economic view of the Internet characterizes it as a special kind of virtual commodity. The Internet is considered a commodity because it has a functional value as a technical space that can meet certain needs for people. Also, as a social space, it has exchange value and can be used for trade.

[6] Sen states that f_i is partly a matter of person *i's* choice.

functionings, with social and human capital acting as the pillars that support it. If $\mathbf{F}_i$ is defined as a feasible set of utilization functions, then, each person i chooses a particular $f_i \in \mathbf{F}_i$. Thus, following Basu and López-Calva (2011) and Sen (1985), we can represent the vector of functionings of person i as:

$$\mathbf{b}_i = f_i(\mathbf{x}_i)$$

$\mathbf{b}_i$ represents the beings and doings that an individual has managed to accomplish by using the commodities they possess ($\mathbf{x}_i$) and choosing a particular utilization function $f_i \in \mathbf{F}_i$. Next, we can define $\mathbf{P}_i(\mathbf{x}_i)$ as the set of functioning vectors that are feasible for person i, given a particular $\mathbf{x}_i$, as:

$$\mathbf{P}_i(\mathbf{x}_i) = \{\mathbf{b}_i | \mathbf{b}_i = f_i(\mathbf{x}_i) \text{ for some } f_i \in \mathbf{F}_i\}$$

According to Sen (1985), if we use the fact that $\mathbf{X}_i$ is the set of commodity vectors accessible to person i, we can define the effective *freedom* of person i, given some $\mathbf{x}_i$ and some f_i, as:

$$\mathbf{Q}_i = \{\mathbf{b}_i | \mathbf{b}_i = f_i(\mathbf{x}_i) \text{ for some } f_i \in \mathbf{F}_i \text{ and some } \mathbf{x}_i \in \mathbf{X}_i\}$$

where $\mathbf{Q}_i$ represents person *i's capability set*.

1.3.2 Intervention

Suppose now that an external agent (the government or a commercial venture, for example) implements an ICT intervention in the community **L**. The intervention aims to tackle the digital divide by addressing both its first and second levels. At the first level, it focuses on improving physical access by providing reliable Internet connectivity[7] to the community's inhabitants, thereby ensuring that technological infrastructure is no longer a barrier to digital inclusion. Ideally, the initiative also extends to the second level of the digital divide, which involves developing the skills and competencies necessary for effective and meaningful use of digital technologies. This is pursued through complementary programs designed to enhance digital literacy, such as training workshops, community tech centers, and educational campaigns that empower individuals to navigate and utilize online

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[7] In order not to be repetitive, we shall refer to Internet connectivity also as Internet access.

resources for education, employment, and civic engagement. Since Internet connectivity is now a new commodity available for the population living in $\mathbf{L}$, we can state that there exists at least one $\mathbf{x}_i \in \mathbf{X}_i$ that includes Internet access as an available commodity for person i.[8;9]

Since $\mathbf{x}_i$ is defined as the vector of commodities chosen by person i from the set $\mathbf{X}_i$, then individual i can or cannot choose a commodity vector that includes Internet connectivity. Suppose that a subset $\widetilde{\mathbf{L}}$ of the community's population decides to take advantage of the Internet, then:

$$\widetilde{\mathbf{L}} \subseteq \mathbf{L}$$

where $\widetilde{\mathbf{L}} \equiv \left(l_1, \dots, l_j, \dots, l_m\right)$ with $m \leq n$,[10] and thus, for all $l_j \in \widetilde{\mathbf{L}}$, the chosen commodity vector $\left(\tilde{\mathbf{x}}_j \in \mathbf{X}_j\right)$ includes Internet connectivity. Generically, the vector $\tilde{\mathbf{x}}_j$ of h commodities (components) can be thought as:

$$\tilde{\mathbf{x}}_j = \left(x_{1j}, x_{2j}, \dots, Internet\ connectivity, \dots, x_{hj}\right)$$

Each person j chooses a particular utilization function $f_j \in \mathbf{F}_j$ to transform their vector of commodities into a vector of functionings $\tilde{\mathbf{b}}_j$. As before, the vector of functionings $\left(\tilde{\mathbf{b}}_j\right)$ describes the beings and doings that individual j has managed to accomplish by using their commodities, one of which is Internet access. Now, the alternative $\tilde{\mathbf{b}}_j$ achieved using different f_j constitute the set of functioning vectors that are feasible for person j when choosing a particular $\tilde{\mathbf{x}}_j$; i.e., a vector of commodities that includes Internet connectivity:[11]

$$\widetilde{\mathbf{P}}_j\left(\tilde{\mathbf{x}}_j\right) = \left\{\tilde{\mathbf{b}}_j \middle| \tilde{\mathbf{b}}_j = f_j\left(\tilde{\mathbf{x}}_j\right) \text{ for some } f_j \in \mathbf{F}_j\right\}$$

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[8] Sen (1985) states that resource allocation and public policies must address the challenge of expanding the limits of choice reflected in $\mathbf{X}_i$.

[9] Internet access is assumed to be a free and uniform individual choice, which may underestimate existing structural constraints. However, as this represents an initial effort to theoretically explore the relationships previously mentioned, it is considered a useful starting point, with the understanding that future research should build upon this foundation to incorporate a more nuanced and context-sensitive analysis.

[10] Notice that we are allowing for the possibility that all individuals in $\mathbf{L}$ access the Internet.

[11] This is because individual j previously chose to access the Internet, or in other words $l_j \in \widetilde{\mathbf{L}}$.

To define person j's capability set we need to take into consideration that $\widetilde{\mathbf{P}}_j$ is associated to a particular $\widetilde{\mathbf{x}}_j$; therefore, a family of sets $\widetilde{\mathcal{M}} \equiv \{\widetilde{\mathbf{P}}_{1j}, \widetilde{\mathbf{P}}_{2j}, \dots, \widetilde{\mathbf{P}}_{nj}\}$, exists, where each set is obtained from a different $\widetilde{\mathbf{x}}_j$ that includes Internet access. In a complementary way, there is a family of sets $\mathcal{M} \equiv \{\mathbf{P}_{1j}, \mathbf{P}_{2j}, \dots, \mathbf{P}_{nj}\}$ in which every element derives from a distinct $\mathbf{x}_j$ that does not include Internet connectivity. Simplifying, the capability set of person j could be represented as:

$$\mathbf{Q}_j \equiv \left(\bigcup_{\widetilde{\mathbf{P}} \in \widetilde{\mathcal{M}}} \widetilde{\mathbf{P}} \right) \cup \left(\bigcup_{\mathbf{P} \in \mathcal{M}} \mathbf{P} \right)$$

or alternatively:

$$\mathbf{Q}_j = \{\widetilde{\mathbf{b}}_j \,|\, \widetilde{\mathbf{b}}_j = f_j(\widetilde{\mathbf{x}}_j) \text{ for some } f_j \in \mathbf{F}_j \text{ and some } \widetilde{\mathbf{x}}_j \in \mathbf{X}_j\}$$
$$\cup \{\mathbf{b}_j \,|\, \mathbf{b}_j = f_j(\mathbf{x}_j) \text{ for some } f_j \in \mathbf{F}_j \text{ and some } \mathbf{x}_j \in \mathbf{X}_j\}$$

It is worth noting that $\mathbf{Q}_j$ captures the overall choice set, including whether to use the Internet or not.

1.3.3 Valuation of Internet connectivity

One of the challenges that emerges when evaluating a person's degree of development has to do with the decision about which functionings should be included in their capability set. Sen (1992) argues that "we may be able to go a fairly long distance with a relatively small number of centrally important functionings", especially when we are studying central social phenomena like poverty and inequality. Our interest is to show that functionings arising from Internet connectivity are a crucial element in tackling these social phenomena. Chapter 2 of the thesis presents an empirical exercise of the impact of mobile Internet access on multidimensional poverty in Mexican communities.

Considering the previous ideas, a fundamental question emerges: how can we compare two functioning vectors of person j, $\widetilde{\mathbf{b}}_j$ arising from a commodity vector that includes Internet connectivity $(\widetilde{\mathbf{x}}_j)$, and $\mathbf{b}_j$ deriving from a hypothetical commodity vector that does not include it $(\mathbf{x}_j)$, keeping all other commodities invariant? Hence, we are confronted with the problem of comparison. To address this challenge, two alternatives can

be considered. The first involves using a valuation function (Sen, 1985), which allows the assignment of a specific value to any vector of functionings $\mathbf{b}_j$. Nonetheless, we must notice that $\mathbf{b}_j$ exists in the space of functionings, such as being well nourished, being properly informed, having access to digital labor networks, being safe, or being educated. Thus, before using the valuation function proposed by Sen, the vector $\mathbf{b}_j$ has to be mapped to $\mathbb{R}_+^m$ through some correspondence relationship that assigns a positive real value to each functioning in $\mathbf{b}_j$. We can conceptualize this correspondence relationship as one that indexes each functioning in the vector $\mathbf{b}_j$ between zero and one. This allows us to value the different levels of those activities and states that make up the well-being of person j.

Armed with a vector of functionings $\mathbf{b}_j \in \mathbb{R}_+^m$, we are now able to employ the following scalar valued function $v(\cdot)$:

$$v = v(\mathbf{b}_j) \colon \mathbb{R}_+^m \to \mathbb{R}$$

Therefore, $\tilde{\mathbf{b}}_j$ will be better valued than $\mathbf{b}_j$ by person j if:

$$v(\tilde{\mathbf{b}}_j) > v(\mathbf{b}_j) \tag{1}$$

The interpretation of (1) is simple: the value reached with $v(\cdot)$ using $\tilde{\mathbf{b}}_j$ is greater than the one reached using $\mathbf{b}_j$; thus, if this condition is satisfied, we could argue that person j obtained more well-being under $\tilde{\mathbf{b}}_j$ than under $\mathbf{b}_j$.

Given the valuation function $v(\cdot)$, it is possible to characterize the values of well-being that person j can possibly achieve (Sen, 1985), the set $\mathbf{V}_j$:

$$\mathbf{V}_j = \left\{ v \mid v = v(\mathbf{b}_j), \text{ for some } \mathbf{b}_j \text{ in } \mathbf{Q}_j \right\}$$

The second approach to address the comparability problem is the one proposed by Herrero (1996). This perspective provides us with the necessary tools to more comprehensively analyze the relationship between Internet connectivity and development, the latter as conceptualized within Sen's capability approach. As before, let $\mathbf{x}_j$ be the vector of h commodities to which individual j has access, with $\mathbf{x}_j \in \mathbf{X}_j$; assume that $\mathbf{X}_j \subset \mathbb{R}_+^h$. Suppose that person j can access a set of relevant functionings and that we can *measure the*

achievements of these functionings through adequate *indices*; thus, the vectors of functionings belong to some space, which for simplicity is assumed to be $\mathbb{R}_+^m$. Since commodity bundles influence the vector of functionings person j can achieve, we can define the following correspondence $C: \mathbb{R}_+^h \to \mathbb{R}_+^m$, where $C(\mathbf{x}_j)$ denotes the capability set, equivalent to the set **Q** defined by Sen (1985). Contrary to Sen, Herrero's (1996) approach does not explicitly refer to a function that allows the transformation of any commodity vector into a functionings vector. However, without loss of generality, we shall assume that said function is implicitly present in the following analysis.

To make the construction operational, we consider the following assumptions defined by Herrero (1996):[12]

1. No free functioning: $C(\mathbf{0}) = \mathbf{0}$
2. Resource-monotonicity: If $\mathbf{x} > \mathbf{x'}$, then $C(\mathbf{x}) \supseteq C(\mathbf{x'})$, $\forall\, \mathbf{x}, \mathbf{x'} \in \mathbf{X} \subset \mathbb{R}_+^h$
3. Compactness: $\forall \mathbf{x}$, $C(\mathbf{x})$ is compact in $\mathbb{R}_+^m$
4. Full dimension: $\exists\, \mathbf{x} \in \mathbb{R}_+^h$, $\mathbf{b} \in C(\mathbf{x})$, such that $\mathbf{b} \gg 0$

Intuitively, assumption (1) establishes that without positive amounts of commodities, individual j cannot achieve positive functionings. Assumption (2) states that if the vector of commodities available to person j increases, then its capability set is not reduced. In (3) we are assuming that achievable functionings are bounded and that limit points of achievable functionings are also achievable. Finally, assumption (4) states that by using some specific amounts of commodities we can obtain a strictly positive vector of functionings.

Now we return to the previously defined comparability problem faced by person j. Following Herrero (1996), we could assume that the utility attained by person j depends on the commodities they can access and, consequently, on the functionings they can achieve. So, similar in spirit to the valuation function proposed by Sen (1985), we assume that said utility could be represented by a scalar valued function $v: \mathbb{R}_+^h \times \mathbb{R}_+^m \to \mathbb{R}$, which intuitively tells us that, for any commodity vector $\mathbf{x}_j \in \mathbf{X}_j \subset \mathbb{R}_+^h$, individual j achieves a

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[12] We shall use the common topological operators on $\mathbb{R}^m$. For a set $\mathbf{A} \subset \mathbb{R}^m$: (i) $\partial \mathbf{A}$ denotes the boundary of $\mathbf{A}$, and (ii) $\geq$, $>$, $\gg$ stand for vector inequalities.

vector of functionings $\mathbf{b}_j^*$ (within their accessible set of functionings) that maximizes $v(\cdot)$, that is to say, $v(\mathbf{x}_j, \mathbf{b}_j^*) \geq v(\mathbf{x}_j, \mathbf{b}_j) \; \forall \; \mathbf{b}_j \in C(\mathbf{x}_j)$. Therefore, we can make the following proposition:

Proposition 1. If $v(\cdot)$ is defined as a function that maximizes the utility attained over the feasible set of functioning vectors given a particular commodity vector, then person j will value more the achieved vector of functionings $\tilde{\mathbf{b}}_j^*$ arising from $\tilde{\mathbf{x}}_j$ than the vector $\mathbf{b}_j^*$ resulting from $\mathbf{x}_j$ if:

$$v(\tilde{\mathbf{x}}_j, \tilde{\mathbf{b}}_j^*) > v(\mathbf{x}_j, \mathbf{b}_j^*) \tag{2}$$

where, as stated before, $\tilde{\mathbf{x}}_j$ and $\mathbf{x}_j$ differ only in that the former includes Internet connectivity and the latter does not $(\tilde{\mathbf{x}}_j > \mathbf{x}_j)$.

Intuitively, Proposition 1 tells us that the maximum value reached with $v(\cdot)$ using $\tilde{\mathbf{b}}_j^*$ is strictly greater than the one reached with $v(\cdot)$ using $\mathbf{b}_j^*$. This analysis allows us to compare the level of well-being of individual j under two different functioning vectors resulting from commodity vectors that vary only in that one includes Internet access and the other does not. Additionally, employing the fact that $\tilde{\mathbf{x}}_j > \mathbf{x}_j$, it follows from the resource-monotonicity assumption that:

$$C(\tilde{\mathbf{x}}_j) \supseteq C(\mathbf{x}_j) \tag{3}$$

Hence, individual j achieves at least the same degree of development by choosing $\tilde{\mathbf{x}}_j$ (with Internet access) as by choosing $\mathbf{x}_j$ (without Internet access).

Nonetheless, (3) relies on the condition that $\tilde{\mathbf{x}}_j > \mathbf{x}_j$, or stated differently, that vector $\tilde{\mathbf{x}}_j$ includes one more commodity (Internet connectivity) than vector $\mathbf{x}_j$. However, we could be interested in analyzing the case when $\tilde{\mathbf{x}}_j$ (the vector of commodities that includes Internet connectivity) has the same number of components (commodities) as $\mathbf{x}_j$. In such a scenario, Proposition 1 should not be affected since the maximum value attained with $v(\cdot)$

does not depend on the size of the vector of commodities, $\tilde{\mathbf{x}}_j$ and $\mathbf{x}_j$, but on the respective achieved vector of functionings, $\tilde{\mathbf{b}}_j^*$ and $\mathbf{b}_j^*$, that maximizes $v(\cdot)$. The same cannot be said about (3), in which case if the resource-monotonicity assumption is not satisfied, we cannot immediately conclude that $C(\tilde{\mathbf{x}}_j) \supseteq C(\mathbf{x}_j)$. Therefore, in capability terms, if $\tilde{\mathbf{x}}_j$ and $\mathbf{x}_j$ have the same number of commodities, then they are non-comparable. To sort out this issue, we shall use a *capability index* (Herrero, 1996).

If we have the capability correspondence $C: \mathbb{R}_+^h \to \mathbb{R}_+^m$, Herrero (1996) defines a capability index c as a continuous function, $c: \mathbb{R}_+^h \to \mathbb{R}$, such that $C(\mathbf{x}) \subset C(\hat{\mathbf{x}})$, which implies $c(\mathbf{x}) \leq c(\hat{\mathbf{x}})$, and $c(\mathbf{0}) = 0$.[13] Therefore, the following proposition can be made:

Proposition 2. Given any two vectors of commodities, $\tilde{\mathbf{x}}_j$ and $\mathbf{x}_j$, the condition that guarantees that individual j would achieve a greater degree of development choosing $\tilde{\mathbf{x}}_j$ than choosing $\mathbf{x}_j$ is:

$$c(\tilde{\mathbf{x}}_j) > c(\mathbf{x}_j) \tag{4}$$

That is to say, the value of the capability index when person j chooses $\tilde{\mathbf{x}}_j$ is greater than when they choose $\mathbf{x}_j$.

Propositions 1 and 2 together allow us to establish a positive relationship between Internet connectivity and an individual's level of development, where development is understood through Sen's capability approach. Furthermore, they provide a basis for formalizing the link between the third level of the digital divide and the ICT for development framework. More specifically, we argue that Internet connectivity leads to a broader capability set and, therefore, a higher level of development from Sen's perspective. This reasoning directly relates to the third level of the digital divide—that is, the social, economic, and cultural benefits derived from inclusion in digital life.

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[13] It should be noted that if C satisfies the resource-monotonicity assumption, any capability index is weakly increasing, that is to say, if $\mathbf{x} > \hat{\mathbf{x}}$, then $c(\mathbf{x}) \geq c(\hat{\mathbf{x}})$.

However, our formalization of the theoretical framework presented in Figure 1 still lacks a connection to the two proposed mechanisms—human and social capital—that explain how the relationship between Internet connectivity and development is established. In subsection 1.3.1, we introduced the personal utilization function, f_i, which acts as a conceptual bridge that maps a vector of commodities—such as resources or services derived from Internet connectivity—into a set of achieved functionings for the individual. It is at this point that social and human capital take on a more important role, as it is through them that the resources or services derived from Internet connectivity are transformed into new functionings. In other words, both enable individuals to convert available resources— such as access to information, educational platforms, or social networks—into tangible improvements in the valuable activities and states that constitute their well-being.

1.3.4 Human and social capital as mechanisms underlying the relationship between Internet connectivity and development

In section 1.2 of this chapter, we argue that there are two key transmission channels, social and human capital, through which ICT allows the creation of collective and individual functionings; in this subsection, we shall expand on these ideas.

Concerning human capital, we also draw on the previously stated condition that either the government or a commercial entity implements, in the context of the ICT intervention carried out in the community **L**, an ICT capacity-building component (see Figure 1). This component may take the form of complementary projects or programs specifically designed to improve digital literacy, thereby addressing the second level of the digital divide. Enhancing individuals' digital education not only equips them with the technical skills necessary to navigate and utilize Internet-based tools but also fosters greater confidence and autonomy in digital environments. As individuals who choose to engage with the Internet gain these new competencies, their human capital increases. This, in turn, opens the door to a broader range of opportunities, such as access to online education, better employment prospects, participation in digital markets, or more effective communication channels, which can significantly contribute to the improvement of their overall well-being. Suppose that each individual in **L** who decides to take advantage of the Internet has an endowment of human capital φ_i. This endowment integrates all the skills

that the individual possesses and employs to carry out productive activities linked to their well-being. Now, given that $\mathbf{x}$ denotes the vector of commodities that individual i can access, we can define x_k as the component of the vector $\mathbf{x}$ associated with Internet connectivity.

Considering that our ultimate goal is to formalize the conditions under which Internet connectivity as a new commodity enhances the human capital of individual i, in the following, we will work only with the component x_k of vector $\mathbf{x}$. However, this does not affect the findings discussed in the preceding subsections. Let $\varphi_{i,t+1}$ denote the human capital of individual i in period $t + 1$ (after the ICT intervention has been implemented). Let $x_{ki,t}$ represent the digital education investment of individual i in period t (at the moment when the ICT intervention begins); that is to say, the participation of individual i in digital literacy projects when the ICT intervention is implemented in community $\mathbf{L}$.

Thus, if we define the following human capital production function as:

$$\varphi_{i,t+1} = g\big(\varphi_{i,t}, x_{ki,t}, \varepsilon_i\big)$$

then, the human capital of individual i in period $t + 1$ (after the implementation of the ICT intervention) will be greater than the human capital of individual i in period t (φ_{it}; when the ICT intervention is launched) if g satisfies the following conditions:

i. Strictly increasing, $g : W \longrightarrow \mathbb{R}$ defined on a set $W \subset \mathbb{R}$, then $g(w) < g(y)$ whenever $w < y$ in W.

ii. Concave, for any w and y in an interval I and for any $\alpha \in [0, 1]$

$$g\big((1 - \alpha)w + \alpha y\big) \geq (1 - \alpha)g(w) + \alpha g(y)$$

The variable ε_i is the individual i's endowment that, unlike $\varphi_{i,t}$, is time invariant and unaffected by Internet access investment. For example, ε_i captures individual i's genes (innate talent) while $\varphi_{i,t}$ is the expression of those genes. It is important to highlight that g does not capture dynamic behavior within the model, as this lies beyond the scope of the chapter. Instead, we used it to reflect a comparative statics analysis between two periods, t and $t + 1$.

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As for social capital, relationships within community L^1 and between individuals from different communities (L^1 and L^2) are strengthened with the arrival of Internet connectivity. The enhancement of these intra- (within L^1) and inter-community (between L^1 and L^2) ties fosters greater trust, collaboration, and mutual support, all of which are key components of social capital. These stronger social networks, in turn, generate more opportunities for individuals who actively engage with Internet connectivity, for example, by facilitating access to job opportunities, community initiatives, or collective problem-solving platforms.

Importantly, the benefits of this improved connectivity are not limited to direct users. Even those who do not engage with the Internet themselves may experience indirect or spillover effects. These arise as stronger community relationships promote the diffusion of information, norms, and behaviors, ultimately broadening access to shared resources and support networks. In this way, Internet connectivity contributes to the expansion of individuals' capability sets.

Among the various factors that contribute to this process, the improvement in the flow of information plays a particularly central role. Internet connectivity enables individuals to access, share, and disseminate high-quality information more rapidly, broadly, and efficiently than before. This access enhances individuals' awareness of opportunities and services, as well as fosters informed decision-making. At the same time, digital communication tools make it easier for individuals to maintain contact across distances, coordinate collective actions, and cultivate new or existing social ties. These developments reinforce the formation, maintenance, and deepening of social bonds, transforming Internet connectivity into a dynamic driver of social capital. In turn, this enriched social capital enhances individuals' ability to pursue goals, mobilize support, and navigate complex environments, ultimately contributing to improvements in their well-being.

1.4 Discussion and Conclusions

This chapter develops a theoretical framework to explain better the relationship between ICT (specifically the Internet) and development. It also analyzes two (potential)

transmission channels through which this technology can positively influence an individual's level of development. To the best of our knowledge, no study has clearly connected the ICT for Development (ICT4D) approach with the digital divide framework while incorporating a clear definition of what development means. Moreover, existing research has not explicitly theorized the mechanisms that underpin the ICT-development relationship.

As part of our theoretical framework, we define two fundamental concepts: the digital divide and development. The digital divide approach provides crucial insights for exploring how ICT penetration affects various dimensions of society. Our proposal involves embedding this approach across two phases within the theoretical framework. Initially, we find it essential to incorporate both the first and second levels of the digital divide (namely, access and the skills for effective use) as part of the implementation phase of any initiative aimed at providing Internet connectivity. Subsequently, we suggest linking the third level of the digital divide (connectivity benefits) to the impact on individuals' living standards following the implementation of such an initiative.

Regarding development, our approach involves adopting Amartya Sen's capabilities framework as the primary method for exploring the relationship between ICT and development. We also argue for expanding this framework to include the concept of collective functionings (valuable social activities that make up people's well-being), thereby acknowledging the collective resource nature of ICT, particularly the Internet. Based on this premise, we propose and develop two transmission channels through which ICT exert their influence across various dimensions of development: human capital and social capital. Although authors like Duncombe (2006), Parkinson and Ramirez (2006), Kleine (2013), Castells and Himanen (2014), Ragnedda and Ruiu (2017), and Sein et al. (2018) have individually explored the connection between two of the four key elements of our theoretical framework (digital divide, development, human capital, and social capital), none of them has integrated these elements into a unified conceptual model. This aspect distinguishes our research from other investigations by providing a foundational analysis that incorporates interconnected elements and concepts into a single theoretical framework.

In addition, we introduce a formalization of our theoretical notions. Drawing from the seminal work of Sen (1985), and using key elements of Herrero's (1996), and Basu and López-Calva's (2011) research, we mathematically outline the central components of the capability approach and propose a model to explain how the intervention of either a public or private entity in providing Internet connectivity to a community translates into enhanced levels of development (well-being) among its inhabitants. Our research yields two main propositions. The first outlines the criteria for assessing the well-being of an individual across two distinct scenarios: one where the individual has Internet access, and another where they do not. The second proposition identifies the specific condition that guarantees an individual will experience a higher degree of well-being should they choose to access the Internet, as opposed to opting out. Moreover, our study represents an initial effort to crystallize the theoretical notions concerning the impact of human and social capital as potential mechanisms for the ICT's (in particular the Internet's) influence on an individual's degree of development. We argue that Internet access in communities strengthens both bonding social capital (connections within the community) and bridging social capital (connections beyond the community). It facilitates the sharing of resources, the flow of information, and mutual support at the local level, while also connecting individuals to broader networks and opportunities. Moreover, Internet access enhances human capital by enabling individuals to acquire knowledge, develop skills, and engage with educational resources, ultimately leading to improved personal and professional outcomes. Going further than Klein (2010; 2013) and Sein et al. (2018), who focused on theorizing from an almost entirely descriptive point of view the connection between ICT and development, our study contributes to the mathematical formalization of this link.

Despite the previously mentioned contributions, we believe that several potential areas for future research emerging from this study are important to explore. Incorporating the role of Internet access pricing into the model could be relevant, especially in terms of how it influences people's decisions to use or not to use connectivity. It would be crucial to investigate whether individuals place greater value on the internet's advantages (manifested in the enhancement of their human capital and their community's social capital) than on the costs associated with accessing it. Consequently, integrating a temporal dimension into our model becomes an attractive aspect. Incorporating the impact of internet access spillovers

could be an additional extension to our model. While we acknowledge the individual gains derived from internet usage, our model currently overlooks the communal aspect of technology, which facilitates shared access among individuals within the same living environment, such as a household. Thus, adding a network dimension to the model to account for household-level interactions would be an important step. Although the aforementioned points highlight potential areas for expanding this research, it is crucial to underline the significance of our work in shedding light on the dynamics between ICT and development. Our study represents a vital initial effort to consolidate the theoretical insights accumulated in this research domain over the last two decades. Finally, as an extension of the theoretical research presented in this chapter, chapters 2 and 3 offer two empirical applications that examine the impact of Internet access on three development-related variables, poverty, migration, and female labor force participation.

Chapter 2

The Mobile Internet, Multidimensional Poverty, and Labor Markets: Evidence from Mexican Localities

2.1 Introduction

The Internet, as the most influential Information and Communication Technology (ICT) in our era, either directly or by facilitating the operation of other technologies and enhancing their effectiveness, can substantially affect people's capability to escape from poverty (Galperin and Viecens, 2017). According to the World Bank, as a result of the COVID-19 pandemic and the Russo-Ukrainian war, by the end of 2022, approximately 685 million people worldwide were living in extreme poverty[14] (World Bank, 2022). Like many middle- and low-income countries worldwide, Mexico is also affected by this social issue. The latest figures released by the National Council for the Evaluation of Social Development Policy[15] (CONEVAL) revealed that 36.3% of Mexico's population, equivalent to 46.8 million people, were experiencing multidimensional poverty in 2022. Notably, this issue was even more pronounced in distant rural regions, where in the same year, 48.8% of the residents were living in multidimensional poverty (CONEVAL, 2023). In line with the above, in 2022, just over 60% of Mexicans living in remote (rural) zones were Internet users, while in the urban sector of the country, this figure rises to 83.8% (INEGI, 2023). Thus, there is still an important disparity in inclusion in the digital age for those who face the worst marginalization conditions, thereby hindering their ability to reap the advantages of the positive spillovers from the Internet. As a solution, unprecedented government

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[14] The poorest population in the world is often undernourished, without access to essential services such as electricity and safe drinking water, has less access to education, and suffers from much poorer health (World Bank, 2022).
[15] In Mexico, CONEVAL is the body in charge of measuring multidimensional poverty and evaluating public policies.

projects, such as the Shared Network[16] (Red Compartida, in Spanish), have been created to close the digital divide and increase the capacity of the poor population to benefit from telecommunication technologies, among which the mobile Internet is at the forefront. Despite these efforts, little is known about the effect of the Internet, especially the mobile network, as an additional mechanism to combat multidimensional poverty in Mexico. Aimed at addressing this gap, this chapter's main purpose is to explore the (potential) impact of the mobile Internet on multidimensional poverty levels in Mexican localities, focusing on the role of labor markets as a transmission mechanism. To the best of our knowledge, no research has yet undertaken this analysis, even though poverty remains one of Mexico's greatest social challenges.

Studies examining the Internet–poverty nexus have highlighted the advantages of this technology on the efficiency of public programs (Risner and Gadhavi, 2015), household income levels (Afzal et al., 2022; Galperin et al., 2022; Nguyen et al., 2022; Zhang et al., 2022), consumption patterns (Sayer, 2018), employment (Galperin et al., 2022), and the capacity of rural households to cope with risks (Zhang et al., 2023). Risner and Gadhavi (2015) employed a combination of smartphones and Internet connectivity to track changes in the poverty condition of beneficiaries of a Bangladesh program and found that real-time, comprehensive monitoring tools could strengthen the efficiency of programs targeting poverty reduction. Taking advantage of Colombia's 2015 initiative of providing free Internet access, Sayer (2018) leveraged this as an exogenous variation in potential Internet accessibility and discovered evidence indicating a positive link between Internet access and the consumption behavior of poor individuals. Recently, Nguyen et al. (2022) examined the consequences of Internet use on household income and poverty status within Thailand's rural sector. Their study reveals that employing the Internet for productive purposes elevated household income and stimulated the expansion of non-farm sectors. Also, Galperin et al. (2022) found that fixed broadband Internet deployment is associated with important gains in labor income and employment as well as a notable diversification of labor opportunities in rural Ecuador.

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[16] The Shared Network is a national project that seeks to (i) increase the coverage of telecommunications services, (ii) promote competitive prices, and (iii) improve the quality of telecommunications services (SCT, 2019).

Drawing upon data from the 2018 China Family Panel Study, Zhang et al. (2022) delved into the influence of Internet use on the vulnerability of farmers to poverty. They discovered that Internet use could significantly mitigate the poverty vulnerability of farmers, an effect that is achieved through heightened income levels, improved access to updated information, and the promotion of agricultural employment. Similarly, Zhang et al. (2023) concluded that Internet use significantly contributes to mitigating the poverty vulnerability experienced by rural households and emphasized that, when viewed from a regional standpoint, the beneficial impact of Internet use on poverty vulnerability is stronger in poorer areas. In this scenario, the underlying mechanisms reveal that the capacity to cope with risks and the strategies employed to manage risks play a pivotal mediating role between Internet use and poverty vulnerability.

In addition, taking advantage of the rapid worldwide expansion of mobile technologies, which allow more users to have the opportunity to enjoy the benefits of the digital age,[17] academics have also studied how the mobile Internet can contribute to poverty alleviation (Yang et al., 2021; Bahia et al., 2023). Bahia et al. (2023) examined the influence of expanding mobile Internet access on income poverty within Tanzania. After implementing a difference-in-differences model using panel household survey data and geospatial data on the rollout of mobile broadband coverage, their investigation revealed that being encompassed by a 3G network yields a substantial positive impact on reducing poverty and concluded that the primary driver behind the influence of the mobile Internet on poverty lies in its favorable impact on labor market dynamics. This includes enhancements in labor force engagement, wage-based employment, self-employment in non-farm sectors, and a reduction in agricultural employment. In China, Yang et al. (2021) examined the influence of mobile Internet usage on multidimensional poverty, employing primary data obtained from a household survey. To tackle endogeneity concerns, the researchers used an endogenous switching regression model and found that mobile Internet use yields a substantial and beneficial impact on multidimensional poverty alleviation.

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[17] The International Telecommunication Union (ITU), the specialized agency for information and communication technologies in the United Nations, revealed that from 2010 to 2015 the number of Internet users worldwide increased by 1 billion (50% growth rate), while from 2015 to 2022 it increased by 2.3 billion (76% growth rate). During the same period (2015-2022) the 4G mobile network coverage in the world went from 43% to 88%, thus, mobile technology stands out as the world's main driver of Internet penetration (ITU, 2022).

More precisely, being an active mobile Internet user results in experiencing fewer dimensions of deprivation, compared to non-users.

Although international literature provides suggestive empirical evidence of the positive impacts of the mobile Internet on poverty reduction, none of these studies have considered the differentiated effects of various mobile technologies (3G, 4G, or both combined) on multidimensional poverty nor the impact of exposure (adaptation) time and technological evolution on this social concern. This chapter also contributes to filling these gaps.

It is also important to note that the link between mobile Internet and multidimensional poverty is grounded in a theoretical framework developed from two key strands of international literature. The first, known as Information and Communication Technologies for Development (ICT4D), examines how these technologies influence various development indicators (Heeks, 2006; 2008; 2018). The second, centered on the concept of the digital divide, provides valuable insights into the effects of ICT penetration and dispersion across different dimensions of society (van Deursen and van Dijk, 2019; Nishijima et al., 2017; van Dijk, 2013). Furthermore, chapter one presents a specific theoretical framework that clarifies the relationship between Internet access and development, as well as offering an initial exploration of the transmission channels through which this technology can positively impact development outcomes. Achieving our main objective faces the evident challenge of endogeneity, which means that localities with a lower incidence of multidimensional poverty could also be the ones with better mobile Internet coverage; in other words, lower multidimensional poverty enables earlier connectivity. To minimize this issue, we employ an instrumental variable approach. This methodology isolates causal impacts by using exogenous variables correlated with the endogenous covariate (mobile Internet coverage) but that simultaneously does not lead to direct changes in the outcome variable (locality's multidimensional poverty level). We propose to use historical data on the ICT development in the locality before 2020; specifically, we employ three instruments: (i) the percentage of households with a landline telephone in 2000, (ii) the interaction between the percentage of households with a landline telephone in 2000 and the percentage of households with TV in 2000, and (iii) the

interaction between the percentage of households with a landline telephone in 2010 and the percentage of households with fixed Internet service in 2010. We contend that the earlier adoption of traditional technologies explains the recent expansion in mobile Internet coverage, while also suggesting that this characteristic of a locality with a ten- and twenty-year lag does not directly influence its present poverty status. The data used in this research is derived from three primary sources: information on locality-level multidimensional poverty computed with data from the 2020 National Population and Housing Census, novel and non-public spatial information about mobile Internet coverage in the last quarter of 2020, and data from three rounds of the National Population and Housing Census (2000, 2010, and 2020). Contrary to usage or access, which are determined on an individual or household basis, coverage considers a broader perspective, allowing us to gauge the direct influence of the mobile Internet on multidimensional poverty and account for spillover effects.There are several reasons this research is important. First, although mobile Internet coverage in Mexico has increased rapidly in recent years, reaching 80 mobile phone subscribers per 100 inhabitants in 2020[18] (IFT, 2023), it remains essential to analyze whether this expansion in the supply of mobile Internet services has had an impact on the multidimensional poverty conditions of the Mexican population. Second, while some studies have contributed to understanding the relationship between mobile Internet and poverty (Yang et al., 2021; Bahia et al., 2023), none have simultaneously examined the differentiated effects of various mobile technologies (3G, 4G, or both combined) on multidimensional poverty, nor have they considered the impact of exposure time (adaptation) and technological evolution on this social issue. This research constitutes an effort to highlight these underexplored areas of knowledge. Third, while some studies have advanced the understanding of the Internet–poverty nexus in Mexico (Galperin and Mariscal, 2016; Mora-Rivera and Garcia-Mora, 2021; Garcia-Mora and Mora-Rivera, 2023), none have explored the relationship between mobile network access and multidimensional poverty while addressing potential endogeneity. This study contributes to the literature by employing a robust econometric approach to assess the (potential) effect of mobile Internet as a mechanism for alleviating multidimensional poverty in Mexico. Fourth, the current study crucially extends previous papers by analyzing the role of labor

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[18] In 2010, there were just 4 mobile phone subscribers per 100 inhabitants (IFT, 2023).

markets as a transmission channel of the mobile network's impact on multidimensional poverty reduction in Mexico. This is an essential aspect for gaining a comprehensive understanding of how mobile technologies can influence the living conditions of the population. Finally, studying this problem is relevant because it allows us to suggest policy measures aimed at assisting the population to overcome their multidimensional poverty via a mobile Internet adoption process. The goal of these policies should be to close the prevailing digital divide, and consequently, mitigate economic and social inequalities.

The rest of the chapter is organized as follows. Section 2.2 describes the data used in the analysis, 2.3 explains the methods, 2.4 reports the findings, while 2.5 presents the robustness test. The final section contains the discussion and conclusions.

2.2   Data

This research uses three main data sources: information on poverty at the locality level computed with data from the 2020 National Population and Housing Census, novel and non-public spatial information about the mobile Internet coverage in the last quarter of 2020 based on data requested from the Federal Institute of Telecommunications,[19] and data from three rounds of the National Population and Housing Census (2000, 2010, and 2020). By interconnecting this information, we can concurrently assess the extent of poverty, the accessibility of mobile Internet, and various socioeconomic attributes for each locality.

2.2.1 Poverty Data

Every ten years, the federal agency in charge of producing data and official statistics in Mexico (INEGI) conducts a national census to generate information concerning the overall population's size, composition, and geographical distribution. Furthermore, these censuses provide data on important demographic, socioeconomic, and cultural attributes, while also enabling us to collect and assess information related to crucial household features, such as the type of construction materials used, access to essential services (electric power, piped water, health), ownership of assets (furniture, vehicles), and others.

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[19] The Federal Institute of Telecommunications is the body in charge of regulating the telecommunications sector in Mexico. It is also responsible for guaranteeing equitable access to ICT infrastructure, broadcasting, as well as key telecommunications services, such as the mobile Internet.

Our core outcome variable, the locality-level multidimensional poverty index (L-MPI), is constructed with information from the 2020 National Population and Housing Census based on Alkire and Foster's (2011) approach (AF)[20]. Although the AF Multidimensional Poverty Index (MPI) was not proposed to measure poverty at the locality level, we can use a similar methodological approximation to construct our poverty index by considering, as other authors have done (Pasanen, 2017), an aggregate unit of identification. In our case, this unit is the locality. In its original version, the MPI employs three dimensions of poverty (health, education, and living standards) and ten (weighted) indicators (Alkire et al., 2020); however, the number of dimensions and indicators can be modified depending on the particular context. Based on our available data, we define five dimensions:[21] *education*, *health*, *housing quality and spaces*, *access to basic housing services*, and *living standards*, each one contemplating one or more indicators to accurately measure the various deprivations faced by Mexican localities.[22] Like the MPI, our L-MPI allows us to measure multiple deprivations in a locality at the same time, and thus approximate the backward conditions experienced by its inhabitants.

Table 2 indicates how the various criteria are aggregated into one index. Following Alkire et al. (2020), all dimensions have the same weight since we consider them equally important to measure multidimensional poverty. For each indicator presented in column 2, the locality can be either deprived (1) or non-deprived (0), depending on the specific deprivation cutoff / threshold (col. 3). Adding up the thirteen indicators and applying the weights in column 4 gives us a continuous L-MPI ranging from 0 to 1, where a higher score indicates more multidimensional poverty. Formally, our index is defined as follows:

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[20] Amartya Sen's capability approach provides a normative framework for conceptualizing development as the expansion of individuals' substantive freedoms to pursue lives they have reason to value. Building upon this foundation, the Alkire-Foster multidimensional poverty methodology offers an empirical tool to identify and measure poverty through multiple dimensions—such as education, health, and living standards—rather than relying solely on income-based indicators. While Sen emphasizes the importance of enhancing individual capabilities, the Alkire-Foster approach translates this conceptual framework into a systematic and policy-relevant methodology for assessing deprivations in key aspects of human well-being, thereby enabling a more comprehensive understanding of poverty and informing more effective development interventions.

[21] We do not include income as an additional dimension due to lack of information; however, we do include specific indicators in the *living standards* dimension directly associated with the assets owned by the households to proxy their economic status.

[22] All the indicators are directly related to a particular Sustainable Development Goal (see the last column of Table 2).

$$\text{L-MPI}_k = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} I_{ijk}\omega_{ij} \right)$$

where n indicates the number of dimensions, I_{ijk} is the binary deprivation variable of indicator j in dimension i of locality k, m represents the number of indicators in each dimension, and ω_{ij} indicates the weight of indicator j in dimension i.

Table 2. Dimensions and Indicators to Identify Multidimensionally Poor Localities

Dimension (1)	Indicator (2)	Deprivation cutoff / threshold[/a] (3)	Weight (4)	SDG (5)
Education (1/5)	% population without completed primary, secondary education	>= 25%	6.66%	SDG 4: Quality Education
	% population with no formal education	>= 15%	6.66%	SDG 4: Quality Education
	Average level of education	< 7 years of schooling	6.66%	SDG 4: Quality Education
Health (1/5)	% population without access to health services	>= 30%	20%	SDG 3: Health and Well-being
Housing quality and spaces (1/5)	Average overcrowding (number of household members per room) in the locality	> 2 household members per room	10%	SDG 11: Sustainable Cities and Communities
	% of households with packed earth without covering floors	>= 15%	10%	SDG 11: Sustainable Cities and Communities
Basic housing services (1/5)	% of households without electric power	>= 8%	6.66%	SDG 7: Affordable and Clean Energy
	% of households without piped	>= 60%	6.66%	SDG 6: Clean

	water supply			Water and Sanitation
	% of households without drainage service	>= 25%	6.66%	SDG 6: Clean Water and Sanitation
Living standards (1/5)	% of households without a toilet	>= 30%	5%	SDG 1: No Poverty
	% of households without a refrigerator	>= 35%	5%	SDG 1: No Poverty
	% of households without a washing machine	>= 50%	5%	SDG 1: No Poverty
	% of households without a TV	>= 30%	5%	SDG 1: No Poverty

Source: By author inspired by Alkire and Foster (2011) and Alkire et al. (2020).

a/ According to Alkire et al. (2015, p. 25-27), "deprivation cutoffs may be justified with reference to international or national standards. They may be set to reflect *basic minima* that have arisen in participatory, consultative, or deliberative exercises. They might reflect *targets* of national development plans or some international agreement or normative guidelines…".[23] Since this study represents the first attempt in Mexico to measure multidimensional poverty at the locality level using the AF approach, coupled with the fact that there are no normative guidelines in this regard, we defined all deprivation cutoffs (thresholds) based on a simple metric of performance: the mean value of the data distribution of each indicator.

Considering that we are interested in analyzing the (potential) effects of the mobile Internet on multidimensional poverty, once we have estimated the L-MPI$_k$ for each locality, the next step consists of defining a poverty threshold or poverty categories that help us classify the localities into poor/non-poor or into different poverty levels.[24] To fully take advantage of the nature of our data (continuous index) and estimate the effect of the mobile Internet on different degrees of poverty instead of on a dichotomous indicator (poor/non-

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[23] For example, in Mexico, the deprivation cutoffs used by CONEVAL to measure multidimensional poverty at the individual level are defined based on normative guidelines (CONEVAL, 2019).

[24] According to Sen (1976), one fundamental problem that needs to be solved when measuring poverty is the clear identification of poor/non-poor units of analysis (individuals, households, localities).

poor), we follow a similar approach to the one used by the National Population Council[25] (CONAPO) to formulate the marginalization index.[26] Therefore, we employed the Dalenius-Hodges stratification procedure (minimum variance stratification)[27] to divide our L-MPI into five predetermined strata: *very low*, *low*, *medium*, *high*, and *very high*. We use five strata to be consistent with the categories employed by CONAPO to compute the marginalization index, but also, Cochran (1977) concluded that only a small reduction in variance is to be expected from having six or more strata. One crucial advantage of the Dalenius-Hodges technique over other stratification methods is that it allows us to determine the strata boundaries while guaranteeing higher homogeneity within each stratum, and, at the same time, higher heterogeneity between them.

Based on our available data, we computed the L-MPI for 108,165 localities, which represent 125.6 million inhabitants, or 99.6% of Mexico's total population in 2020. Employing the Dalenius-Hodges stratification, 23,334 (21.6%) localities were classified in the very low multidimensional poverty category, 31,309 (28.9%) as localities facing low multidimensional poverty, 21,199 (19.6%) were classified in the medium multidimensional poverty category, 20,335 (18.8%) as localities confronting high multidimensional poverty level, and 11,998 (11.1%) were categorized in the very high multidimensional poverty category. Map 1 shows the geographical distribution of multidimensional poverty in Mexico at the locality level. As can be noted, poverty levels are highly heterogeneous not only across the country but also between regions.

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[25] CONAPO is the federal agency in charge of designing, operating, and evaluating public policies aimed at regulating population growth and distribution, as well as demographic movements in Mexico.
[26] For additional information about the methodology used to compute the marginalization index, see CONAPO (2021)
[27] The Dalenius-Hodges stratification technique was proposed by Tore Dalenius and Joseph L. Hodges in 1959. Since then, it has been widely used by international literature in multiple disciplines (Skoufias et al., 2001; Oh and Lucas Jr., 2006; García-González et al., 2009; Hoffmann et al., 2017).

Map 1. Multidimensional Poverty in Mexico at the Locality Level
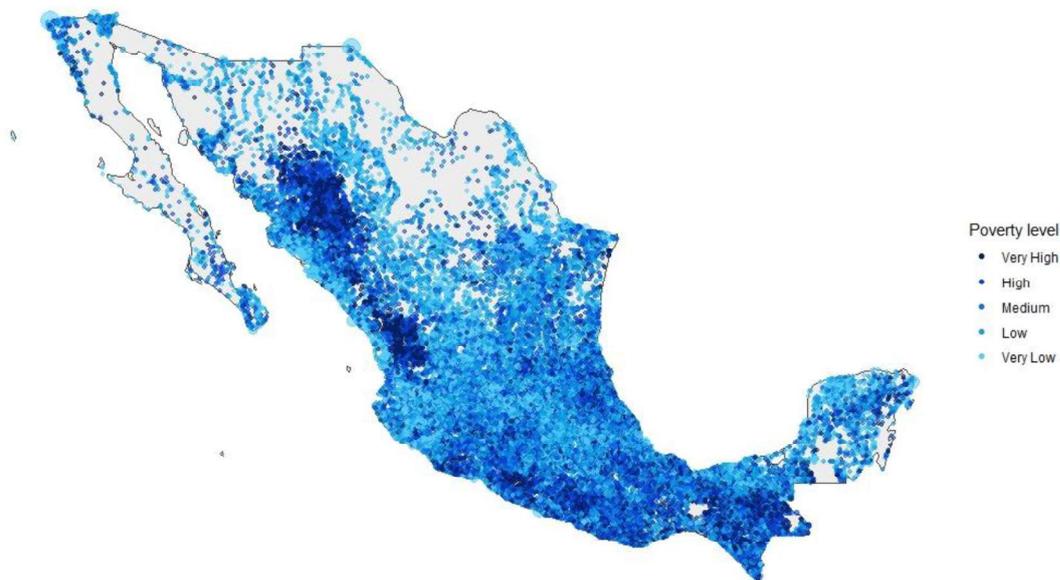
Source: By author based on the locality-level multidimensional poverty index (L-MPI) calculations.

2.2.2 Mobile Internet Coverage Data

This research employs novel and non-public spatial data about mobile network coverage in Mexico. Unlike usage or access, which is determined by decisions at the individual or household level, coverage considers a broader perspective. This enables us not only to measure the direct impact of the mobile Internet on multidimensional poverty but also to account for spillover effects. Such externalities encompass various aspects like sharing information with non-Internet users, enhancing educational processes, expanding job creation and increasing productivity as a result of greater technology adoption and access to domestic and global markets, simplifying job training, improving job quality, and boosting financial inclusion. As a result of the 2013 constitutional reforms and the agreement published in the Federal Official Gazette in 2018 (DOF, 2018), Mobile Network Operators (MNOs) are required to submit detailed mobile Internet coverage maps to the Federal Institute of Telecommunications (IFT),[28] every quarter. These maps include both

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[28] Due to the non-public nature of the mobile Internet coverage maps, we requested them from the IFT.

guaranteed and differentiated (guaranteed and non-guaranteed) coverage information.[29] It is worth noting that since federal regulations were initiated in 2018 and the most recent data at the locality level was collected in 2020 (as further addressed below), we were unable to conduct a panel data analysis.

The maps include coverage data of the MNOs in Mexico (Telcel, AT&T, Telefónica, and Altán) that held a valid concession in the fourth quarter of 2020. While there are additional MNOs known as Virtual Mobile Operators (VMOs) in the country, they are obliged to use wholesale mobile services supplied by concession-holding operators to offer their service. In simpler terms, the coverage provided by VMOs does not extend beyond that already contemplated by the main MNOs. Since we aim to assess how the mobile Internet affects multidimensional poverty across all covered localities, our attention is directed toward guaranteed coverage. This is because non-guaranteed coverage does not entirely ensure that localities reap the benefits of mobile network services, suggesting that the inhabitants of these localities might not fully capitalize on the connectivity. Additionally, our analysis is restricted to 3G and 4G mobile technologies, mainly because 2G technology lags significantly behind in terms of transmission capacity and speed when compared to more advanced technologies.[30] Furthermore, MNOs are discontinuing 2G mobile services both in Mexico and on a global scale.[31]

Using the information on 3G and 4G mobile Internet coverage, we project each of the 108,165 localities for which we computed the L-MPI into the coverage zones using their geographical coordinates (available in the 2020 national census). Therefore, a locality was considered covered if it falls within the coverage zone of any of the MNOs–Telcel, AT&T, Telefónica, or Altán. This methodological approach (joining two or more spatial datasets) has been widely used among scholars when examining the link between mobile

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[29] *Guaranteed coverage* refers to the geographical area reported by each MNO in which the quality conditions of its service are guaranteed, following the current official guidelines (DOF, 2020).

[30] 2G mobile network was introduced in 1993; at that time, it represented an important advantage over its predecessor (1G), mainly because it introduced the Short Message Service (SMS). However, regarding Internet service, the 2G technology had a very low transmission speed (14.4 − 64 kbps) compared to 3G (2 Mbps) and 4G (2000 Mbps − 1 Gbps). As for the 5G mobile Internet, this technology was launched in Mexico in February 2022, initially contemplating 18 cities; in 2024 it is available in 104 cities. Therefore, we were unable to incorporate this technology as part of our analysis.

[31] Worldwide, 2G mobile network represents 3% of total coverage. In Mexico, Telcel is the only MNO that continues to offer 2G mobile Internet, covering 39.2% of the country's total population. In 2020, 2G mobile Internet data traffic represented just 0.1% of total mobile Internet data traffic (IFT, 2021).

networks and phenomena such as violence (Pierskalla and Hollenbach, 2013; Ackerman, et al., 2021), political mobilization (Manacorda and Tesei, 2020), poverty (Bahia, et al., 2023), and welfare outcomes (Bahia, et al., 2024; Masaki et al., 2020). Our data show that, in the last quarter of 2020, 50,980 localities (47.1% of the total) have 3G mobile Internet coverage, 41,868 (38.7% of the total) are covered by 4G mobile network, and 56,473 localities have coverage of either technology. Map 2, panels A, B, and C, shows the spatial distribution of mobile Internet coverage by type of technology.

Map 2. Mobile Internet Coverage in Mexico at the Locality Level

Panel A. 3G Mobile Network
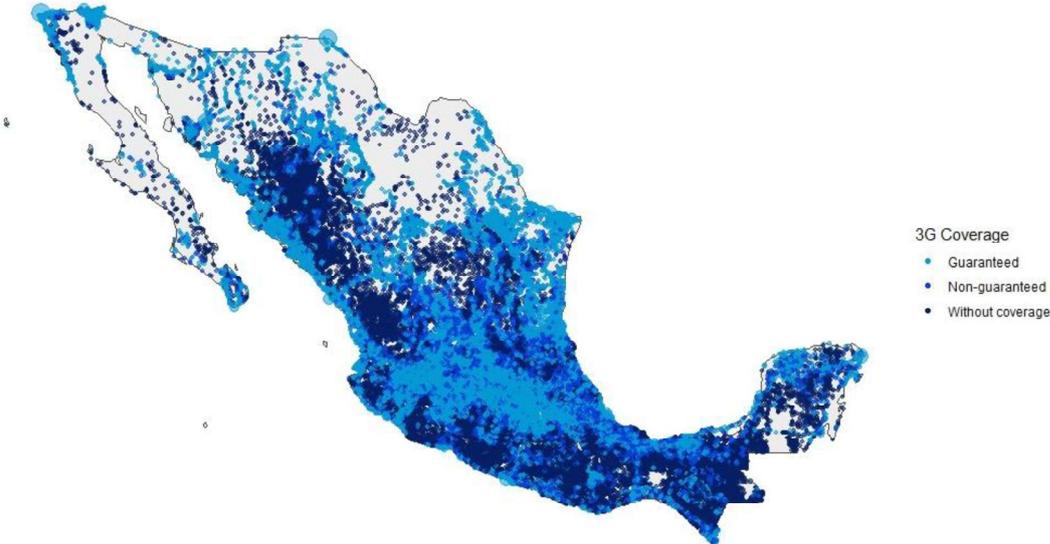
Panel B. 4G Mobile Network
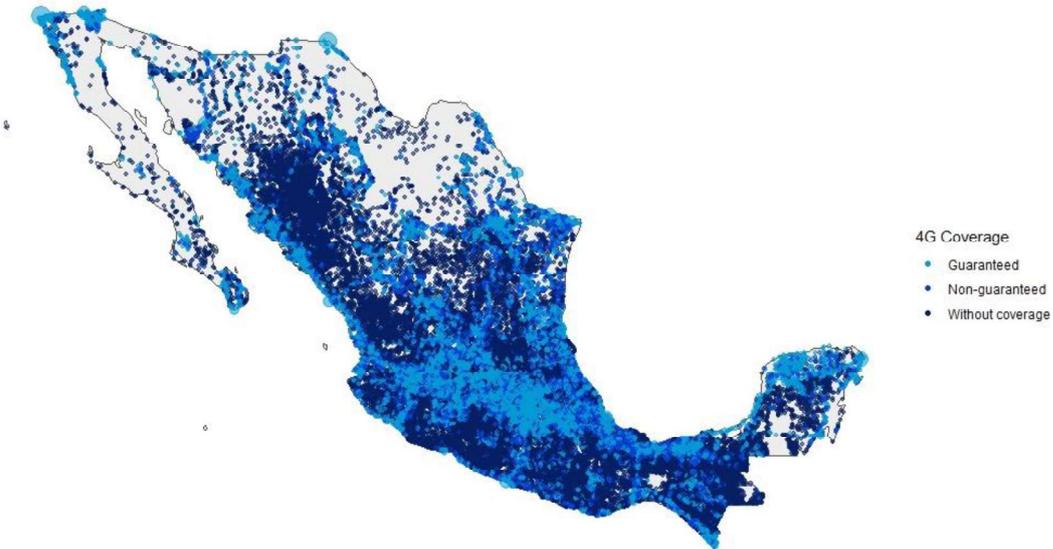
Panel C. 3G+4G Mobile Network
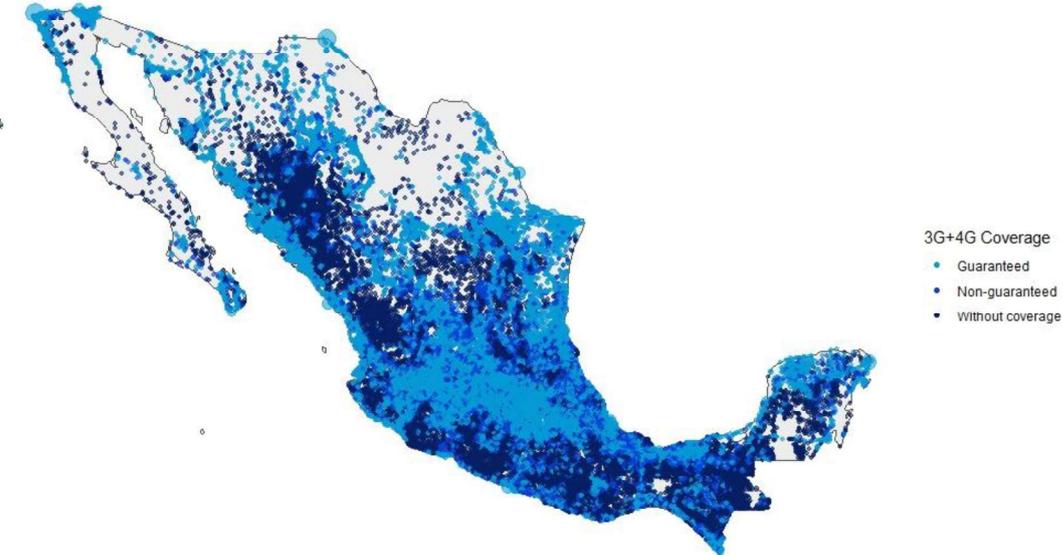
Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico.

Note: Gray areas primarily correspond to deserts, mountainous regions, or tropical forests. There are also some localities, yet they account for only 0.4% of Mexico's population.

2.2.3 Control Variables

The information from the 2020 census allows us to account for confounding factors that help to explain the localities' multidimensional poverty level, by including variables of the characteristics of their population, households, the localities themselves, and the municipalities that geographically enclose them.[32] At the population level, we control for the youth population (aged 15-29, 23% on average), the elderly population (65 years old and more,11% on average), the illiterate population (about 14% of inhabitants), and the population that speaks an indigenous language (around 16% of the population). We also control for labor market conditions using a weighted measure of the employment rate.[33] The prevailing economic circumstances faced by the households are also an important determinant of multidimensional poverty; therefore, we include indicators of the share of households with three or more rooms—67% on average—and households without a car, truck, or motorcycle—57% on average. At the locality level, we account for socioeconomic features such as whether the locality has a medical clinic (31%), a drugstore (6% on average), a DICONSA store[34] (one in five localities), and public street lighting system (75% on average). To take into consideration external factors such as international migration that could affect poverty status, we control for the percentage of households that receive international remittances at the municipality level. Concerning geographical conditions, we account for the altitude of the locality (in meters above sea level), and its location in one of the six poverty regions into which the country is divided.[35]

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[32] Mexico's territory is divided into 32 states, each one encompassing five or more municipalities, which in turn enclose two or more localities.

[33] To account for the variation in sizes of localities (and thus in labor markets), we weight the employment rate by the locality's population proportion within the overall municipality's population.

[34] In Mexico, the DICONSA stores are minimarkets where the population can buy basic goods (such as milk, rice, beans, oil, soap, toilet paper, and other products) at a subsidized price. According to the federal government, their main aim is to contribute to guaranteeing food security in Mexico, especially in the most marginalized areas.

[35] Following CONEVAL, we divide our sample into six poverty regions. Region 1 comprises two states: Nuevo León and Coahuila; Region 2 includes seven states: Baja California, Baja California Sur, Sonora, Sinaloa, Jalisco, Colima, and Quintana Roo; Region 3 comprises eight states: Chihuahua, Tamaulipas, Nayarit, Aguascalientes, Guanajuato, Querétaro, México, and Morelos; Region 4 includes seven states: Zacatecas, Michoacán, Hidalgo, Tlaxcala, Puebla, Veracruz, and Tabasco; Region 5 encompass four states: Durango, San Luis Potosí, Campeche, and Yucatán; Region 6 comprises three states: Guerrero, Oaxaca, and Chiapas. For additional information about the way these poverty regions were defined see CONEVAL (2021a).

MNOs have an incentive to provide their services in cities where significant economic activities occur. As a result, localities situated near these cities might experience greater benefits from a more dynamic regional economy and, thus, lower poverty incidence. To account for this external factor, we introduced a covariate that measures (in kilometers) the linear distance between localities and the 74 metropolitan zones identified by CONAPO.[36] To compute this variable, we set a centroid for each metropolitan zone and calculated the shortest linear distance between the locality and the centroid, allowing us to control for the locality's proximity to a specific metropolitan area.

Lastly, we also include a geospatial indicator that summarizes the accessibility conditions faced by the localities. The reason for using such an indicator is that geographical conditions could be an additional determinant of multidimensional poverty. This composite indicator is measured by CONEVAL and contemplates six variables: paved road, geographic location, topographical relief, natural barriers (vegetation density, rivers, lakes), public transport availability, and travel time to the nearest urban locality. Once the indicator is computed, the localities are classified into five strata: *very low*, *low*, *medium*, *high*, and *very high* accessibility levels.[37] Table 3 presents the descriptive statistics of the control variables for the 75,905 localities with complete information.[38]

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[36] According to this Council, a metropolitan area is defined as a set of two or more municipalities containing a city with a population of 100,000 inhabitants or more, whose urban area, functions, and activities extend beyond the boundaries of the municipality. Metropolitan areas also include municipalities (i) with a city of more than 500,000 inhabitants, (ii) with cities of 200,000 citizens on the northern, and southern borders, and in the coastal regions, and (iii) in which the state capitals are located.

[37] For additional details about the methodology used to compute this indicator, see CONEVAL (2021b).

[38] The number of observations decreases due to the lack of information to compute the instrumental variables as well as some control variables; however, we continue considering 95 million inhabitants (75.8% of the Mexican population). It is worth noting that we do not detect a pattern within the lost observations (localities); therefore, we are confident that we face a missing-at-random situation (Little and Rubin, 2002).

Table 3. Descriptive Statistics of Control Variables

	mean	st. dev.
Control Covariates		
pop: % youth population (15 - 29 years old)	0.230	0.071
pop: % elderly population (65 years old and more)	0.112	0.086
pop: % of illiterate population	0.141	0.120
pop: % indigenous language speakers	0.164	0.319
pop: weighted employment rate	0.008	0.033
hhs: % households with 3 or more rooms	0.670	0.211
hhs: % households without a car/motorcycle	0.570	0.274
loc: medical clinic	0.313	0.464
loc: drugstore	0.058	0.235
loc: DICONSA store	0.223	0.416
loc: public street lighting system	0.745	0.436
mun: % households receiving international remittances	0.002	0.006
acc: level of accessibility via paved road	3.384	1.359
acc: distance btw. locality - closest metropolitan area	70.624	45.985
geo: altitude	1160.733	872.440
geo: Region_1	0.031	0.173
geo: Region_2	0.116	0.320
geo: Region_3	0.208	0.406
geo: Region_4	0.335	0.472
geo: Region_5	0.088	0.284
geo: Region_6	0.222	0.416
Observations	75,905	

Source: By author based on information from the 2020 census and the data repository of CONEVAL.

2.3   Methods

2.3.1 Identification Strategy

The endogenous relationship between the mobile Internet and different development indicators such as welfare, poverty, employment, and trust in government institutions has been recognized by Bahia et al. (2023), Chiplunkar and Goldberg (2022), Mensah (2021), Guriev et al. (2021), and Masaki et al. (2020). The main idea behind the non-random rollout of mobile Internet coverage lies in the fact that MNOs tend to focus on more prosperous regions initially, as such areas are anticipated to exhibit higher economic engagement and potentially high demand for this particular service. Therefore, multidimensional poverty trends could be (strongly) linked to the presence of 3G/4G mobile Internet coverage. Our task involves addressing the issue of endogeneity (reverse causality) and disentangling causal impacts.

We use an instrumental variable approach (Angrist et al., 1996) to account for the endogeneity of mobile Internet expansion with respect to development variables (Chiplunkar and Goldberg, 2022; Mensah, 2021). The key requirement of this methodology is to define exogenous variables that are correlated with the endogenous covariate (mobile Internet coverage) and simultaneously do not lead to changes in the locality's multidimensional poverty level (aside from the indirect route via mobile network coverage). We propose to employ lagged information on the ICT development in the locality ten and twenty years before 2020, a similar (but not identical) approach to that used by Barnichon and Mesters (2020), Boler et al. (2015), and Minoiu and Reddy (2010). Specifically, we argue that the former penetration of traditional technologies, such as landline telephone, TV, or fixed Internet, helps to explain (recent) mobile Internet coverage (Sultanov et al., 2016; Gupta and Jain, 2012; Chu et al., 2009; Hwang et al., 2009), while, at the same time, we assume that this specific characteristic of the locality with a ten- and twenty-year lag does not directly affect its (current) multidimensional poverty level. The first part of the previous statement, known as the relevance condition of the instruments,

can be empirically tested by employing an underidentification test.[39] The second condition, known as the exclusion restriction (Wooldridge, 2010; Angrist and Pischke, 2009), is more challenging to validate empirically and rests on theoretical and contextual justifications.

To support the plausibility of the exclusion restriction in our setting, we contend that the influence of historical ICT infrastructure on current poverty operates primarily through its impact on the development and expansion of modern technologies, particularly mobile Internet networks. In other words, while past ICT adoption may shape the technological trajectory of a locality and its readiness to adopt mobile technologies, it is unlikely to have an independent, direct effect on today's multidimensional poverty, which is constructed using indicators that are not inherently tied to past ICT features. Moreover, the dimensions used to calculate the poverty measure, such as education, health, and housing conditions, have likely evolved due to broader socioeconomic and political dynamics at the national level, rather than as a direct continuation of local ICT trends from one or two decades ago. To further assess the validity of this assumption, we conducted an overidentification test to evaluate whether the instruments are uncorrelated with the error term, thereby lending support to the exclusion restriction.

Data on the availability of landline telephone, TV, and fixed Internet at the household level were obtained from the 2000 and 2010 national censuses, respectively. Particularly, the censuses ask whether the household owns a landline telephone, a TV, or a fixed Internet subscription, which allows us to create four indicators that measure the percentage of households with a landline telephone in 2000 and 2010, the percentage of households with a TV in 2000, and the percentage of households with fixed Internet service in 2010. Finally, we create two additional variables by interacting the percentage of households with a landline telephone in 2010 with the percentage of households with fixed Internet service in 2010, and the percentage of households with a landline telephone in 2000 with the percentage of households with TV in 2000.

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[39] Additionally, in Appendix 2.1 we show some basic statistics that strengthen the relevance of our instruments to explain recent mobile Internet coverage.

2.3.2 Empirical Framework

Our outcome variable, the L-MPI$_k$, is measured on a five-point scale (see subsection 2.2.1) rather than as a continuous variable. Additionally, since the distances between each multidimensional poverty level are determined by a specific stratification approach (Dalenius and Hodges, 1959), we need to consider an ordinal outcome model. As for our endogenous variable, it has a dichotomous nature (1 if the locality has mobile Internet coverage and 0 if not); however, the standard IV/2SLS model was purposely designed for a continuous endogenous covariate. Consequently, we also have to account for the binary nature of the endogenous variable in the specification of the first stage equation.

We formulate the probability distribution function of a model that takes into consideration the ordered and dichotomous nature of the outcome and endogenous variables. Following Regmi and Paudel (2017) and Mora-Rivera and van Gameren (2021), we set a framework consisting of two equations. The first explains the primary connection between the observed multidimensional poverty level (L-MPI$_k$) to the binary indicator of mobile Internet coverage (MI$_k$) and a vector of variables determining the multidimensional poverty status (X_k) of the locality k through the use of a latent continuous variable L-MPI$_k^*$ which can be understood as the locality's propensity to face multidimensional poverty:

$$\text{L-MPI}_k^* = \delta \text{MI}_k + \alpha' X_k + \varepsilon_k, \tag{5}$$

with

$$\text{L-MPI}_k = p \text{ if } m_{p-1} \leq \text{L-MPI}_k^* \leq m_p \text{ for } p = 1, 2, 3, 4, 5$$

where the values of the cut-off points m_p ($p = 1, 2, 3, 4$) must be estimated along with the parameter of interest δ and the vector of parameters α, while $m_0 = -\infty$ and $m_5 = \infty$.

The second equation associates the binary mobile Internet coverage to the same set of determinants that influence multidimensional poverty (X_k) and a set of instrumental variables (Z_k), using a latent continuous variable MI$_k^*$:

$$\text{MI}_k^* = \beta' X_k + \gamma' Z_k + \eta_k, \tag{6}$$

with

$\text{MI}_k = 0$ if $\text{MI}_k^* \leq 0$ (the locality does not have mobile Internet coverage)

$\quad = 1$ if $\text{MI}_k^* > 0$ (the locality has mobile Internet coverage)

where the cut-off point is normalized to 0. This gives rise to the following loglikelihood function:

$$\log L = \sum_{k=1}^{N} \sum_{p=1}^{5} \sum_{r=0}^{1} D_{k,pr} \log Pr[\text{L-MPI}_k = p, \text{MI}_k = r], \tag{7}$$

where $D_{k,pr} = 1$ if $\text{L-MPI}_k = p$ and $\text{MI}_k = r$, and $D_{k,pr} = 0$ otherwise, while $Pr[\text{L-MPI}_k = p, \text{MI}_k = r]$ is the probability that locality k faces a multidimensional poverty level p (with $p = 1, 2, 3, 4, 5$) and mobile Internet coverage r (with $r = 0$ or 1). Assuming that the error terms ε_k and η_k follow a standard bivariate normal distribution, we can estimate our model using the *eoprobit* command (StataCorp, 2017).

Moreover, using the potential-outcomes framework (Rubin, 1974, 2005), we can compute treatment effects of mobile network coverage on multidimensional poverty. To do so, we consider our binary indicator for mobile Internet coverage (MI_k) as if it were an endogenous "treatment" t_k, with two levels ($t_k = 0$ and $t_k = 1$),[40] which allows us to index potential outcomes of our dependent variable L-MPI_k: L-MPI_{k0} and L-MPI_{k1}, of which only one is observed. Also, we assume that the treatment assignment process is modeled with a probit regression like equation (6). Therefore, our ordered probit model of L-MPI_k on treatment t_k with levels $t_k = 0$ and $t_k = 1$ has the form:

$$\text{L-MPI}_k = \sum_{j=0}^{1} 1(t_k = j)\text{L-MPI}_{kj} \tag{8}$$

where for $j = 0, 1$ and exogenous covariates $\boldsymbol{X_k}$

$\text{L-MPI}_{kj} = p$ if $m_{(p-1)j} \leq \boldsymbol{\alpha_j'X_k} + \varepsilon_{kj} \leq m_{pj}$ for $p = 1, 2, 3, 4, 5$

while $m_{0j} = -\infty$ and $m_{5j} = \infty$.

Since $t_k = 0$ is the control treatment level, the treatment effect on a given category (p) of multidimensional poverty is the difference between L-MPI_{k1} and the control L-MPI_{k0}, $1(\text{L-MPI}_{k1} = p) - 1(\text{L-MPI}_{k0} = p)$; that is to say, the difference in the outcome

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[40] $t_k = 0$ means that the locality does not have mobile internet coverage, while $t_k = 1$ indicates that the locality has mobile network coverage.

for locality k on being in category p if the locality receives the treatment $t_k = 1$ instead of the control $t_k = 0$ (not receiving the treatment). Evaluating this treatment effect allows us to see how the treatment affects the probability of being in outcome category p.

Now, the average treatment effect (ATE) for outcome category p is:

$$ATE_p = E\{1(\text{L-MPI}_{k1} = p) - 1(\text{L-MPI}_{k0} = p)\} = E\{TE_p(X_k)\} \tag{9}$$

where $TE_p(X_k) = E\{1(\text{L-MPI}_{k1} = p) - 1(\text{L-MPI}_{k0} = p)|X_k\}$ is the treatment effect on category p conditioned on X_k.

Additionally, the average treatment effect on the treated ($ATET$) for outcome category p is:

$$ATET_p = E\{1(\text{L-MPI}_{k1} = p) - 1(\text{L-MPI}_{k0} = p)|t_k = 1\} = E\{TET_p(X_k, Z_{kt}, t_k = 1)|t_k = 1\} \tag{10}$$

where $TET_p(X_k, Z_{kt}, t_k = 1) = E\{1(\text{L-MPI}_{k1} = p) - 1(\text{L-MPI}_{k0} = p)|X_k, t_k = 1\}$ is the treatment effect on the treated on category p conditioned on X_k and Z_{kt}. We use the *estat teffects* option of the *eoprobit* command (StataCorp, 2017) to compute treatment effects on each outcome category p.

2.3.3 Validity and Reliability of the IV Model

Having presented the intuitive justification for the use of lagged information on the ICT development in the locality to construct valid instruments, and before discussing results in detail, we will review some tests for the validity of our instrumental variables (IVs). Specifically, we use three instruments: (i) the percentage of households with a landline telephone in 2000, (ii) the interaction between the percentage of households with a landline telephone in 2000 and the percentage of households with a TV in 2000, and (iii) the interaction between the percentage of households with a landline telephone in 2010 and the percentage of households with fixed Internet service in 2010.

Given that calculating the proper tests in an IV ordered probit model is not straightforward, we discuss indicative tests obtained from a standard IV/2SLS model. The key assumption is that if these tests suggest the (in)validity of the IV, then we can expect the same (in)validity in the correctly specified model. The results of the tests are shown in

Table 4. Since the underidentification tests are clearly passed, our IVs are significant in the explanation of mobile Internet coverage. The null hypothesis of exogeneity is rejected; therefore, mobile Internet coverage should be considered as an endogenous phenomenon. The robust weak instrument tests are also passed; thus, our IVs are not weak. Finally, the overidentification tests (under the null of valid exclusion restrictions) show that our IVs are valid instruments. Taken as a whole, the information in Table 4 gives us confidence in the validity of our instruments.

Table 4. Indicative Instrumental Variable Tests

	3G	4G	3G+4G
Instrumental variables			
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	598.76	488.1	481.42
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	2.18	1.23	1.17
H_0: exclusion restrictions of instruments are valid	0.1402	0.2677	0.2797
Underidentification test (Kleibergen-Paap rk LM Statistic)	1217.68	891.51	1042.08
H_0: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Montiel-Pflueger robust weak instrument test	719.045	482.087	604.047
H_0: weak instruments	a	b	c
Endogeneity test of endogenous regressor	29.67	27.53	56.23
H_0: regressor can be considered as exogenous	0.0000	0.0000	0.0000

(a) 2SLS critical values: 5% 17.35, 10% 11.34, 20% 7.87.

(b) 2SLS critical values: 5% 8.75, 10% 6.28, 20% 4.83.

(c) 2SLS critical values: 5% 17.19, 10% 11.24, 20% 7.82.

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, and the data repository of CONEVAL.

2.4 Findings

2.4.1 Econometric Findings

Our results from the IV ordered probit models show that mobile Internet coverage positively contributes to poverty reduction at the locality level (see Table 5),[41] however, as we expected, the impact is far from being homogeneous among technologies. Despite being a less advanced technology, 3G mobile Internet has a larger positive effect on poverty alleviation compared to 4G mobile Internet. We associate this finding with a longer exposure time (adaptation period) to the technology, enabling the population of these localities to better appropriate the benefits that come with the mobile Internet, and therefore use it more efficiently, thereby generating larger positive spillovers. While 4G mobile Internet also contributes significantly to reducing multidimensional poverty, its impact may be somewhat diminished as it is relatively new in localities that previously did not have mobile network coverage and have recently been incorporated into the areas of influence of MNOs. Consequently, this leads to less efficient adoption by the population and therefore smaller beneficial spillovers. As for the combined effect (3G+4G), we found that broadening the mobile Internet also has a positive impact on multidimensional poverty reduction; in other words, enlarging mobile network coverage leads to positive spillovers on the population's living conditions. Nevertheless, our intuition suggests that those localities where both technologies are available (which are included in the combined effect) are the primary drivers of this result. This is mainly because they have had 3G mobile Internet coverage for a more extended period (longer adaptation time), allowing their population to better embrace this technology. Furthermore, they have benefited from a technological evolution by transitioning to 4G mobile coverage, which enhances the technology's impact, and therefore the positive spillovers. Overall, our findings show evidence that mobile network coverage is a key driver in reducing multidimensional poverty, and thus improving people's well-being.

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[41] In Appendix 2.2 we show the impact of the mobile Internet on multidimensional poverty using two binary thresholds of poverty.

The remaining covariates explain multidimensional poverty behavior in line with what we expected. Regarding the demographic composition of the locality, we found that the percentage of the youth population as well as the percentage of the elderly population raises multidimensional poverty. Also, as the percentage of native language speakers increases, poverty incidence increases. Concerning human capital conditions, we found that localities with a higher percentage of illiterate population are more likely to face moderate or severe poverty levels. On the other hand, the variables linked to the economic conditions of the households revealed that a higher percentage of households with three or more rooms decreases the locality's propensity to face a higher level of multidimensional poverty; however, if the percentage of households without durable assets (like a car or motorcycle) in the locality increases, the poverty level also increases. The four variables used to account for the infrastructure situation prevailing in the locality show that better infrastructure is associated with lower multidimensional poverty. As for migratory patterns, we found that a higher percentage of remittance-receiving households is associated with lower multidimensional poverty. Regarding accessibility, our results show that as the distance between the locality and the nearest metropolitan zone increases, poverty status worsens; however, if the transportation conditions improve, the locality's propensity to face a higher level of poverty decreases. Geographical factors show evidence that higher altitude associates with a higher multidimensional poverty level. Lastly, regional variables unveiled that those localities situated in Regions 1, 2, 3, and 5 are less likely to have a higher level of poverty compared to those located in Region 6 (reference region), while those located in Region 4 have a higher propensity to face worse poverty conditions.

Table 5. IV Models for Multidimensional Poverty

	3G	4G	3G+4G
	Multidimensional Poverty		
3G mobile Internet	-0.633 ***		
	(0.032)		
4G mobile Internet		-0.496 ***	
		(0.044)	
3G+4G mobile Internet			-0.635 ***

60

					(0.034)	
pop: % youth population (15 - 29 years old)	0.242	***	0.258	***	0.267	***
	(0.071)		(0.071)		(0.071)	
pop: % elderly population (65 years old and more)	0.387	***	0.345	***	0.402	***
	(0.062)		(0.064)		(0.062)	
pop: % of illiterate population	2.734	***	2.808	***	2.747	***
	(0.054)		(0.056)		(0.054)	
pop: % indigenous language speakers	0.247	***	0.264	***	0.250	***
	(0.016)		(0.016)		(0.016)	
pop: weighted employment rate	-1.480	***	-1.476	***	-1.527	***
	(0.169)		(0.177)		(0.168)	
dwe: % households with 3 or more rooms	-1.344	***	-1.371	***	-1.362	***
	(0.024)		(0.024)		(0.024)	
dwe: % households without a car/motorcycle	0.584	***	0.674	***	0.586	***
	(0.022)		(0.021)		(0.022)	
loc: medical clinic	-0.226	***	-0.219	***	-0.223	***
	(0.009)		(0.009)		(0.009)	
loc: drugstore	-0.076	***	-0.083	***	-0.089	***
	(0.018)		(0.019)		(0.018)	
loc: DICONSA store	-0.240	***	-0.228	***	-0.239	***
	(0.010)		(0.010)		(0.010)	
loc: public street lighting system	-0.352	***	-0.374	***	-0.347	***
	(0.010)		(0.010)		(0.010)	
mun: % households receiving international remittances	-9.912	***	-9.603	***	-10.418	***
	(0.844)		(0.859)		(0.854)	
acc: level of accessibility via paved road	-0.151	***	-0.171	***	-0.146	***
	(0.005)		(0.006)		(0.006)	
acc: distance btw. locality - closest metropolitan area	0.001	***	0.001	***	0.001	***
	(0.000)		(0.000)		(0.000)	
geo: altitude	0.0002	***	0.0002	***	0.0002	***
	(0.000)		(0.000)		(0.000)	
geo: Region_1	-0.045		-0.186	***	-0.060	**
	(0.028)		(0.027)		(0.028)	
geo: Region_2	-0.019		-0.126	***	-0.024	
	(0.020)		(0.019)		(0.020)	

	Model 1		Model 2		Model 3	
geo: Region_3	-0.253	***	-0.341	***	-0.241	***
	(0.017)		(0.017)		(0.018)	
geo: Region_4	0.070	***	0.047	***	0.096	***
	(0.012)		(0.013)		(0.013)	
geo: Region_5	-0.039	**	-0.056	***	-0.016	
	(0.017)		(0.017)		(0.017)	
Cut-off point 1 (m_1)	-2.136		-2.130		-2.169	
	(0.036)		(0.036)		(0.036)	
Cut-off point 2 (m_2)	-1.018		-0.999		-1.048	
	(0.036)		(0.036)		(0.036)	
Cut-off point 3 (m_3)	-0.197		-0.170		-0.226	
	(0.036)		(0.036)		(0.036)	
Cut-off point 4 (m_4)	0.930		0.969		0.904	
	(0.037)		(0.037)		(0.037)	
Correlation between mult. poverty and mobile internet	0.289	***	0.201	***	0.278	***
	(0.019)		(0.026)		(0.020)	
Number of observations	75905		75905		75905	
Log pseudolikelihood	-130403.76		-130067.36		-130152.67	
χ^2	44722.25		43469.64		44487.44	
Model test p-value	0.00		0.00		0.00	

Robust standard errors are in parentheses. *** p<.01, ** p<.05, * p<.1

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, and the data repository of CONEVAL.

Table 6 shows the average treatment effects (ATE) and the average treatment effects on the treated (ATET) as derived from the IV ordered probit models. Focusing on the ATE, we found that 3G mobile Internet coverage increases the locality's probability of remaining in the lowest level of poverty by 12.3 percentage points (pp). The intuition of this result is that in more developed localities (which have lower levels of poverty), a mobile network contributes to enhancing their degree of development and, thus, preserving their current conditions. This positive effect decreases importantly within the localities with low poverty levels (4.2 pp). In contrast, the expansion of 3G mobile Internet reduces by 4.1 pp the

probability of a locality remaining in the medium poverty category, and by 8.9 pp that of remaining in the high poverty level. Interestingly, the beneficial effect of the mobile network on poverty decreases to 3.5 pp in the category of greater poverty (very high); nevertheless, this is not an unexpected result, since these are the localities facing worse backwardness. Therefore, providing them with mobile Internet is necessary to help them overcome their marginalized conditions but is far from sufficient to eradicate poverty.

Regarding 4G mobile Internet, we observed the same patterns as in the 3G case but with small differences in magnitude. This technology increases the probability of remaining in the lowest level of poverty by 11.4 pp and by 4.2 pp that of prevailing in the low poverty category. Interestingly, 4G mobile network has a larger effect on the probability of a locality remaining in the medium poverty category compared to 3G mobile Internet (4.4 vs 4.1, respectively). More important to highlight is the case of the combined mobile technologies (3G+4G). In such a situation, the beneficial effect of the mobile Internet as a tool for reducing poverty intensifies in four out of five poverty categories compared to the 4G mobile network, thus reinforcing our argument regarding the time of exposure to technology. Moreover, in the very low and very high poverty levels, results are stronger in comparison to 3G mobile Internet; the latter is especially important since it comprises localities facing the most marginalized conditions. In the remaining three categories (low, medium, and high) the impact is marginally lower than that of 3G technology. Taken together, the ATE demonstrates that the expansion of the mobile network could significantly contribute to poverty reduction. However, it is important to note that in extremely impoverished localities, the mobile Internet should not be understood as a definitive solution to all the challenges they encounter. Additional efforts in terms of public policy need to be made to ensure that the population living in these localities can effectively harness all the advantages that this technology offers.

As for the ATET, we found that (3G, 4G, and 3G+4G) the mobile Internet positive effect on poverty reduction increases in the very low and medium categories of poverty among treated localities (those that currently have mobile network coverage), which could indicate that the mobile network provision is well targeted in these localities. The same happens in the high category of poverty but only in the 3G+4G case. These findings could

be attributed to providers expanding their services where it was more profitable; however, additional information on the commercial decisions of MNOs is necessary to reach better conclusions. On the other hand, the ATET show that, while the mobile Internet indeed has a positive effect as a tool for alleviating poverty, the selection bias that most MNOs implement is negatively affecting the mobile network's potential to increase people's well-being in localities with critical poverty conditions (very high poverty level).

Table 6. Treatment Effects

	Average treatment effect (ATE)			Average treatment effect on the treated (ATET)		
	Difference (treat. vs cont.)	Std. Error	z-value	Difference (treat. vs cont.)	Std. Error	z-value
3G mobile Internet						
Very low	12.3396	0.0080	15.34	14.2769	0.0080	17.78
Low	4.1824	0.0041	10.19	2.8456	0.0048	5.89
Medium	-4.0982	0.0039	-10.56	-6.1438	0.0041	-15.14
High	-8.8824	0.0051	-17.30	-8.7195	0.0057	-15.23
Very high	-3.5414	0.0037	-9.70	-2.2592	0.0027	-8.22
4G mobile Internet						
Very low	11.4209	0.0104	11.02	11.7530	0.0099	11.87
Low	4.1575	0.0039	10.78	2.9586	0.0047	6.35
Medium	-4.3781	0.0045	-9.74	-5.7977	0.0047	-12.34
High	-7.7801	0.0056	-13.93	-7.0566	0.0061	-11.48
Very high	-3.4201	0.0040	-8.62	-1.8574	0.0030	-6.25
3G+4G mobile Internet						
Very low	12.5043	0.0077	16.16	14.5365	0.0078	18.53
Low	4.1625	0.0043	9.60	2.9928	0.0051	5.84
Medium	-4.0891	0.0038	-10.82	-6.0887	0.0040	-15.31
High	-8.8537	0.0053	-16.70	-8.9420	0.0059	-15.04
Very high	-3.7239	0.0037	-10.11	-2.4986	0.0030	-8.39

The difference between treatment and control localities is expressed in percentage points.

Source: By author based on the IV ordered probit models results shown in Table 4.

2.4.2 The Role of Labor Markets as a Transmission Channel

Once we have presented empirical findings regarding how the mobile Internet can positively affect poverty reduction, we shift our focus to explore the transmission mechanism that allows this to happen. We hypothesize that the impact of the mobile Internet on multidimensional poverty could be influenced by the state of development of labor markets. Consequently, we would expect that in those localities where labor markets are better developed, the effect of the mobile Internet will be amplified. To approximate said development we use the informal employment rate since informal jobs are often characterized by small or undefined workplaces, unsafe and unhealthy working conditions, low levels of skills and productivity, low or irregular incomes, long working hours, and lack of access to information, markets, finance, training, and technology (ILO, 2020). It is important to emphasize that this analysis does not rule out that the mobile Internet has a beneficial impact on poverty alleviation in localities with an important presence of informal employment. The introduction of mobile Internet technology can also be advantageous for this segment of the workforce by enhancing information access, simplifying job training, and improving financial inclusion. Nevertheless, our intuition leans towards expecting a greater impact of technology in localities where formal employment predominates.

Given that we do not have data to examine the labor markets at the locality level, we use information on the informality rates at the municipality level. The data source used to obtain the informality rates is the National Employment and Occupation Survey (ENOE). INEGI computes the informality rates representative at the municipality level employing a small area estimation technique.[42] Once we have the information on the informality rates for each municipality, we divide them into terciles where lower terciles represent less informality.[43] Next, we estimate the impact of 3G, 4G, and 3G+4G mobile Internet on multidimensional poverty at each tercile. In this way, we can explore the role that labor markets have as a transmission channel of the effect of the mobile Internet on multidimensional poverty. To guarantee statistically reliable estimates, we used the following two IVs across the three terciles: the interaction between the percentage of households with PC in 2010 and the percentage of households with fixed Internet service in

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[42] For additional details about the methodology see INEGI (2022).
[43] The mean informality rate for each tercile is 1st 0.568, 2nd 0.746, 3rd 0.905.

2010, and the interaction between the percentage of households with landline telephone service in 2010 and the percentage of households with fixed Internet service in 2010. Validity tests for each tercile and mobile Internet technology are shown in Appendix 2.3.

Table 7. Impact of the Mobile Internet on Multidimensional Poverty at each Tercile of Municipality Informal Employment Rate

Panel A	(-)		Informality rate		(+)	
	1st tercile		2nd tercile		3rd tercile	
3G mobile Internet	-1.389	***	-1.467	***	-1.059	***
	(0.343)		(0.191)		(0.319)	
Controls	Yes		Yes		Yes	
Number of observations	23299		26561		26045	
Log pseudolikelihood	-38584.63		-48355.15		-43776.23	
χ^2	13009.14		22389.39		15288.94	
Model test p-value	0.00		0.00		0.00	

Panel B						
	1st tercile		2nd tercile		3rd tercile	
4G mobile Internet	-0.657	***	-1.267	***	-1.008	***
	(0.207)		(0.183)		(0.314)	
Controls	Yes		Yes		Yes	
Number of observations	23299		26561		26045	
Log pseudolikelihood	-40503.43		-47410.16		-42082.37	
χ^2	9227.75		18156.39		14827.17	
Model test p-value	0.00		0.00		0.00	

Panel C						
	1st tercile		2nd tercile		3rd tercile	
3G+4G mobile Internet	-1.927	***	-1.754	***	-1.192	***
	(0.328)		(0.171)		(0.340)	
Controls	Yes		Yes		Yes	
Number of observations	23299		26561		26045	
Log pseudolikelihood	-37129.94		-48218.08		-45025.79	
χ^2	18136.61		31713.66		16427.69	
Model test p-value	0.00		0.00		0.00	

Robust standard errors are in parentheses. *** p<.01, ** p<.05, * p<.1

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, the data repository of CONEVAL, and data from the 2020 National Employment and Occupation Survey.

The first observation drawn from the results in Table 7 is that irrespective of the tercile, the impact of the combined technologies (3G+4G) on multidimensional poverty surpasses that of each technology individually. In addition, the effect of 3G mobile Internet is more pronounced compared to that of 4G mobile network. This is the same pattern as that presented in Table 5. Regarding the core of this analysis, the findings from Table 7 show, in a general context, that the impact of the mobile Internet on multidimensional poverty is stronger in localities with lower informality rates, or what is the same, the effect is more pronounced in the first and second terciles compared to the third one. However, it is worth highlighting that in panels A and B (3G and 4G mobile Internet, respectively), the stronger impact is observed in the second tercile. Specifically, in the case of 4G mobile Internet, the effect in the first tercile is the lowest. This outcome could be explained by the fact that we are capturing the impact of those localities where the mobile Internet has recently been introduced, and thus the role of labor markets in transmitting the effect has not yet gained sufficient relevance.

Conversely, in the case of 3G mobile Internet (Panel A), which considers the impact in localities with more extended exposure to the technology, the developmental state of municipal-level labor markets plays a more prominent role. This is evident in a larger difference in the effect's magnitude between the first two terciles and the last one. Finally, when both technologies are combined (Panel C), our findings reveal an even greater difference in the impact of the mobile Internet on multidimensional poverty between localities in the first two terciles and those in the last tercile. As discussed in subsection 2.4.1, it is plausible that this outcome is driven by those localities where both technologies are available. In such localities, the population has had more time to adapt and embrace the mobile Internet, leading to the full development of key elements associated with labor markets, such as expanding job creation, increasing productivity, simplifying job training, and improving job quality.

Altogether, these findings support our hypothesis concerning the role of the development level of labor markets in driving the benefits linked to the mobile Internet. Nevertheless, it is important to note that our results are not definitive; they represent an initial effort to understand the mechanisms through which the mobile Internet may impact

multidimensional poverty. Thus, further endeavors are necessary to disentangle the relationship between the mobile Internet and multidimensional poverty.

2.5 Robustness Tests

To check the validity of the results presented in the preceding section, we conducted six additional econometric analyses. The initial three are geared towards examining whether the findings presented in Table 5 are robust when employing alternative instrumental variables.[44] Table 8 (Panel A) shows the impact of mobile network on multidimensional poverty using the percentage of households with PC in 2010 instead of the percentage of households with landline telephone service in 2010 to calculate the third instrument (row 4). Despite the straightforward nature of this adjustment, the intention is to minimize the correlation between IVs, and thus any (potential) bias in our findings. Our results reveal that even employing less correlated instrumental variables, the effect of the mobile Internet on multidimensional poverty maintains a consistent pattern, similar to that reported in Table 5.

In Panel B of Table 8 we propose using IVs derived from the 2010 census covariates only; in other words, with a ten-year temporary lag. In addition to confirming the robustness of our results when using alternative IVs, we validate our intuition about the role of the exposure time (adaptation process) on the overall impact of the mobile Internet on multidimensional poverty. Our findings demonstrate that the stronger effect on multidimensional poverty is linked to 3G mobile Internet, whereas the combined technologies (3G+4G) exhibit an effect that falls between that of 4G and 3G mobile networks. We can attribute this outcome to the fact that in those localities where both technologies are available, we may not be fully capturing the technological appropriation impact. To test this statement, in Panel C, we employ IVs derived from covariates of the 2000 census only, that is to say, a timeframe with a twenty-year lag. Specifically, two instruments are used: the percentage of households with a TV in 2000 and the number of households in the locality in 2000 as a proxy for population density. The idea behind using an instrument tied to population density stems from the consideration that MNOs view locality size as a factor influencing the diffusion of the mobile Internet (Sultanov et al.,

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[44] IV tests are shown in Appendix 2.4.

2016; Yamakawa et al., 2013). Consequently, localities with higher population density in 2000 are more likely to have mobile network coverage in 2020 than those with lower population density. Consistent with our primary intuition, our results revealed a stronger impact in the 3G+4G mobile Internet case, suggesting that we are better capturing the technology's appropriation effect. Furthermore, it should be noted that for all technologies, the magnitude of the impact increases in absolute terms. Additionally, the difference in the magnitude of the effect between 4G mobile Internet and 3G or 3G+4G mobile Internet narrows. Nonetheless, this result could once again be attributed to the adaptation effect, which we capture more effectively using IVs derived from the 2000 census. This added to the technological evolution process (going from 3G to 4G mobile Internet), amplifies the global impact of the mobile Internet on multidimensional poverty. The findings from Panels B and C collectively strengthen our assertion regarding the pivotal role of the technological adoption process in enhancing the positive spillovers of the mobile Internet.

Table 8. Robustness Exercises Considering Different IVs

Panel A

Instrumental Variables	3G	4G	3G+4G
	Multidimensional Poverty		
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
	-0.624 ***	-0.489 ***	-0.626 ***
	(0.032)	(0.045)	(0.034)
Controls	Yes	Yes	Yes
Number of observations	75,905	75,905	75,905
Log pseudolikelihood	-130428.18	-130094.18	-130173.00
χ^2	44611.08	43400.33	44385.37

	3G		4G		3G+4G	
Model test p-value	0.00		0.00		0.00	
Panel B						
Instrumental Variables	3G		4G		3G+4G	
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes		Yes		Yes	
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes		Yes		Yes	
	-0.642	***	-0.492	***	-0.578	***
	(0.034)		(0.048)		(0.040)	
Controls	Yes		Yes		Yes	
Number of observations	75,905		75,905		75,905	
Log pseudolikelihood	-130783.03		-130264.23		-130550.42	
χ²	44759.72		43377.08		43819.21	
Model test p-value	0.00		0.00		0.00	
Panel C						
Instrumental Variables	3G		4G		3G+4G	
% households with TV in 2000	Yes		Yes		Yes	
number of households in 2000	Yes		Yes		Yes	
	-1.088	***	-1.064	***	-1.098	***
	(0.016)		(0.017)		(0.016)	
Controls	Yes		Yes		Yes	
Number of observations	75,905		75,905		75,905	
Log pseudolikelihood	-129156.90		-129048.89		-128836.46	
χ²	53732.03		52498.19		53506.48	
Model test p-value	0.00		0.00		0.00	

Robust standard errors are in parentheses. *** p<.01, ** p<.05, * p<.1

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, and the data repository of CONEVAL.

To conclude the robustness tests, we conducted three additional exercises to assess the sensitivity of our IV ordered probit models under different specifications. In Table 9, Panel A, we omitted two control variables—the percentage of households with three or more rooms and the percentage of households without a car/motorcycle. The idea of excluding these two covariates is that they may be correlated with some indicators of the dimensions constituting the LMPI. To minimize this (potential) bias, our IV models did not include them. The results align with those reported in Table 5, showing a similar pattern with slightly stronger impacts. In Panel B of Table 9, we examine the robustness of our main results by employing an alternative poverty regionalization. This is done under the assumption that our current analysis might inaccurately account for the heterogeneous poverty conditions that prevail across the country. To address this potential issue, we use a different poverty regionalization, based on Pérez (2021); nevertheless, the findings align closely with the outcomes presented in Table 5. Lastly, in Panel C, we excluded four control variables—medical clinic, drugstore, DICONSA store, and public street lighting system—to increase the number of observations (localities) with complete information in the final sample up to 81,340, which represents 94.7% of the Mexican population. Nevertheless, the impact of the mobile Internet on multidimensional poverty exhibits a consistent pattern compared to that reported in Table 5, albeit with a slightly reduced magnitude.

Table 9. Robustness Exercises Considering Different Specifications

Panel A			
Instrumental Variables	3G	4G	3G+4G
	Multidimensional Poverty		
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes

	-0.827 ***	-0.659 ***	-0.822 ***
	(0.025)	(0.036)	(0.026)
Additional controls	Yes	Yes	Yes
Number of observations	75,905	75,905	75,905
Log pseudolikelihood	-133412.97	-133155.54	-133208.59
χ^2	41738.20	39203.46	41313.81
Model test p-value	0.00	0.00	0.00
Panel B			
Instrumental Variables	3G	4G	3G+4G
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
	-0.730 ***	-0.574 ***	-0.743 ***
	(0.028)	(0.036)	(0.030)
Additional controls	Yes	Yes	Yes
Number of observations	75,905	75,905	75,905
Log pseudolikelihood	-131005.84	-130758.50	-130916.17
χ^2	44453.46	43028.51	44336.64
Model test p-value	0.00	0.00	0.00
Panel C			
Instrumental Variables	3G	4G	3G+4G
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
	-0.543 ***	-0.419 ***	-0.556 ***
	(0.030)	(0.040)	(0.031)
Additional controls	Yes	Yes	Yes

Number of observations	81,340	81,340	81,340
Log pseudolikelihood	-140092.00	-139900.76	-139556.51
χ^2	46341.91	45410.43	46148.49
Model test p-value	0.00	0.00	0.00

Robust standard errors are in parentheses. *** p<.01, ** p<.05, * p<.1

2.6   Discussion and Conclusions

Our study offers valuable insights into the relationship between the mobile Internet and multidimensional poverty in Mexico. Given the prevailing high levels of poverty in the nation as well as the digital divide experienced by the population facing the worst marginalization, the findings of this research provide crucial evidence to enhance our understanding of the impact of the most influential ICT worldwide, the mobile Internet, on well-being levels in developing countries.

We employed an instrumental variable approach to isolate the causal impact of mobile Internet coverage on different levels of multidimensional poverty in Mexican localities. We propose to use historical data on the ICT development in the locality before 2020 to identify exogenous variables that are correlated with mobile network coverage but do not directly cause changes in our outcome variable. Because of the multidimensional nature of our poverty measure, our results align with studies asserting that the Internet is an important tool to reduce educational inequality (Korkmaz et al., 2022), improve public health (Wang and Xu, 2023), or increase consumption (Melaine and Nonvide, 2023; Miyajima, 2022; Bahia et al., 2024; Masaki et al., 2020). However, they differ from the findings reported by Njangang (2022), who argues that ICT (including the Internet) increases wealth inequality, or Wang et al. (2021), who report that ICT has not contributed to the urbanization process in less-developed cities of China. Although our study does not allow for an independent examination of the impact of the mobile Internet on each variable, integrating our multidimensional poverty measure, we can conclude that mobile network contributes to enhancing the overall well-being of the population.

Similar to the findings of Bahia et al. (2023) in Tanzania and Yang et al. (2021) in China, our results reveal that the mobile Internet positively contributes to poverty

alleviation in Mexico. However, our study goes beyond examining the differentiated impacts of the mobile network by technology type. The effect of 3G mobile Internet is stronger than that of the 4G mobile network, which we attribute to a more extended adaptation period to the technology among the population, thereby amplifying the positive spillovers associated with mobile Internet access. Interestingly, the impact of combined technologies (3G+4G), which links to broader coverage, equals that of the 3G mobile network alone. Once again, our interpretation is that in localities where both technologies are available, the population benefits from a more extended period to appropriate the technology's advantages as well as from the evolution of the mobile Internet from 3G to 4G.

Our research also adds to the previous literature in two aspects. First, according to our findings, the impact of the mobile Internet is far from being homogeneous across Mexican localities. Treatment effects reveal that regardless of the technology, broadening mobile Internet coverage to the entire population helps to alleviate multidimensional poverty. However, the impact varies importantly across localities. In those characterized by (very) low levels of multidimensional poverty, the mobile network contributes to preserving the current conditions, while in the localities facing (very) high levels of multidimensional poverty, the mobile Internet contributes to overcoming their adverse situation. These results parallel those reported by Qiu et al. (2021), who find that mobile network access has heterogeneous effects on the inter-city income gap within China, and highlight the positive effect in lower-income strata of the population.

Second, we explore the role of labor markets as a transmission mechanism of the impact of the mobile Internet on multidimensional poverty in Mexico. Along the same vein as Bahia et al. (2023), who argue that the impact of the mobile Internet on poverty is mainly driven by positive effects on labor market outcomes, such as an increase in labor force participation, wage employment, and non-farm self-employment, we found that the impact of the mobile Internet on multidimensional poverty is stronger in localities with lower informality rates, the indicator we use to approximate the development of labor markets. This finding becomes more evident when both technologies are combined (3G+4G). In such a scenario, the difference in the impact's magnitude between localities

with lower informality rates and those with higher informality rates is more conspicuous. We attribute this outcome to an extended period of adaptation and appropriation, which allows labor markets to play a relevant role in transmitting the effect. Likewise, our findings are consistent with the conclusions of Qiu et al. (2021), who emphasize that the mechanism underlying broadband Internet affecting inter-city income inequality is the expansion of market potential and the enhancement of manufacturing agglomerations. Kuhn and Mansour (2014), and Bhuller et al. (2020) have also pointed out that the Internet can reduce unemployment by speeding up the job search process and improving firm-worker matching. Similarly, Kusumawardhani et al. (2023) found that internet availability increases the likelihood of young or low-educated women having a full-time job.

Our research underscores the urgent need for public policies that promote the expansion of mobile Internet access across Mexico, as this could significantly enhance the economic and social wellbeing of the population. While increasing mobile coverage and improving access to advanced mobile technologies can contribute to reducing social inequality, current spectrum pricing policies hinder this objective. Specifically, the high cost of radio spectrum, particularly the payment entitlement, which accounts for over 90% of the total cost, undermines the feasibility of widespread coverage and limits the rollout of next-generation services. Elevated spectrum prices hinder competition by discouraging participation in auctions, particularly among smaller mobile network operators (MNOs), who bear a disproportionately higher financial burden. This has resulted in reduced market diversity. Moreover, the high cost of spectrum limits investment in infrastructure deployment in underserved areas and delays the modernization of existing networks.

To address these challenges, we recommend policy reforms aimed at reducing the financial burden associated with spectrum, especially by revising the payment entitlement structure. Additionally, we advocate for strengthened coverage obligations in future tenders, and for continued support of public-private partnerships such as Mexico's Red Compartida. This initiative—developed, operated, and marketed by Altán Redes under a wholesale model—aims to provide coverage to at least 92.2% of the population by 2028. Complementary technologies, including satellite, fixed wireless access (FWA), and the

expansion of wireless internet service providers (WISPs), should also be leveraged to extend connectivity in hard-to-reach areas.

Nevertheless, expanding mobile Internet infrastructure alone is insufficient to significantly improve indicators of poverty. Digital inclusion must be supported by public policies that promote the development of digital literacy across broad segments of the population, with particular emphasis on rural areas. Enhancing digital literacy will facilitate and accelerate the process of technological adoption, which is essential for enabling individuals to fully realize the benefits associated with mobile Internet access. The expected outcomes include more effective and meaningful use of digital technologies, along with positive spillover effects—especially for populations residing in rural and underserved regions.

Despite the contributions of our study, it has limitations associated with the type of data employed in the analysis. It would be desirable to have panel data or repeated cross-sectional data enabling the examination of the dynamics of development variables, such as poverty and inequality, based on the gradual expansion of mobile Internet penetration. Unfortunately, the available databases in Mexico do not allow us to accomplish this task at the moment. Finally, more detailed information at the household level, or ideally at the individual level, would enable a better understanding of the transmission mechanisms underlying the positive impact of the mobile Internet on poverty.

Chapter 3

Digital Influence: The Internet's Effect on Migration Networks and Female Labor Force Participation in Rural Mexico

3.1 Introduction

Global migration represents one of the most significant development challenges worldwide (World Bank, 2023). According to figures from the World Bank, while total international migration increased from 2.3% of the global population in 1980 to 3.5% in 2020, migration from developing/emerging economies to advanced economies grew substantially. It accounted for approximately 10% of the receiving countries' population in 2020, up from 4% in 1990 (World Bank, 2023).[45] One of the most important migrant corridors is the Mexico-USA corridor, ranked first worldwide (BBVA-CONAPO, 2023). Between 2018 and 2023, 1.06 million Mexicans migrated to the USA, representing a 58% increase compared to the 2013–2018 period (ENADID, 2023, 2018). An important part of this movement of Mexicans to the USA originates from rural areas, primarily because these households face the most severe conditions of marginalization and, therefore, are forced to find additional sources of income to help smooth their income flow.

Persistent global migration, including that from Mexico to the USA, has sparked the interest of international academia in analyzing which factors currently affect migratory networks worldwide (Baccini, et al., 2024; Soto-Nishimura and Czaika, 2024; Zanoni and Díaz, 2024). Within this body of literature, recent studies have highlighted the potential role that Information and Communication Technologies (ICT), particularly the Internet, may play as a catalyst of the migratory networks (Ali et al., 2024; Czaika and Parsons, 2017; Dekker et al., 2016, 2018; Hidayat et al., 2023; Thulin and Vilhelmson, 2016). The central

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[45] Migration is a powerful sustainable development driver, benefiting migrants and their home communities. It can help reduce poverty for migrants and their families while also significantly contributing to development initiatives in origin and destination countries (IOM, 2018).

argument supporting this idea, whether it involves regular or irregular migration, is that the Internet enhances the quality of information available to migrants and to potential migrants. For regular migration, the Internet facilitates access to more and better information about migration opportunities, particularly in education and employment, helping migrants identify suitable programs or job openings. It also provides deeper insights into the associated requirements and the application process. In the case of irregular migration, the Internet enables migrants to communicate with their families during their journey from their communities of origin to the destination country and after they have settled. This readily available communication helps reduce feelings of loneliness, thereby diminishing their incentive to return. Additionally, the Internet allows (potential) irregular migrants to learn about migration routes, border crossings, and transit points, helping them plan their journey more effectively while also sharing knowledge about risks, such as areas with increased law enforcement activity. It may also assist migrants in contacting emergency services, NGOs, or humanitarian organizations if they encounter threats during their journey. Furthermore, the Internet may enable relatives and other village members to learn about migrants' experiences abroad, fostering interest in migration.

Once migration takes place, various adjustments occur within households (Ratha et al., 2011; McGregor et al., 2014). Among these adjustments, one particularly notable, driven by the household's loss of labor force (mainly male but also female), is the shift in female labor force participation rates. Different studies have pointed out that one consequence of international migration is an increase in women's participation in the local labor markets, as they must compensate for the loss of the workforce in the migrants' villages of origin (Adhikari and Hobley, 2015; Urama et al., 2017; Maharjan et al., 2013). In rural areas of Mexico, social phenomena like migration, which structurally affect households, can alter the role of women in the workforce, either by increasing their participation in salaried jobs or by promoting women's self-employment. In any case, the prevailing conditions in the localities—both socioeconomic and geographic—play a significant role in influencing women's decisions to engage in agricultural or non-agricultural activities.

Despite the relevance of migration in rural Mexico, no studies have examined the potential link between the penetration of ICT (particularly the Internet), changes in migratory networks, and shifts in women's participation in labor markets within the rural sector. To address this gap in the literature, this research aims to explore the role of the Internet on Mexican rural migration and how this (potential) increase in migratory flows, driven by the introduction of Internet technologies, affects female labor force participation in the migrants' home villages. To achieve this goal, we employed data from the 2015 ENCHOR survey, a nationally representative survey of the Mexican rural population, and estimated a trivariate recursive equation model with discrete variables that explain Internet access, the effect of Internet access on the household's migration decisions, and the effects of Internet access and migration decisions on female labor force participation.

The relevance of this research is three-fold. First, the phenomenon of migration remains a significant and widely discussed issue in Mexico, shaped by a multidimensional context. As previously highlighted, Mexican migrants continue to pursue better job opportunities in the USA as a response to unfavorable conditions prevailing in various regions of the country. Simultaneously, return migration is increasing due to deportation policies implemented in recent years in the USA. Second, a significant digital divide persists in the rural sector. Data from 2023 shows that while 86% of the urban population uses the Internet, this percentage drops to 66% in rural areas (INEGI-IFT, 2024). Therefore, it is crucial to analyze whether Internet penetration in these areas influences household decisions, including migration-related ones. Third, female labor force participation has increased significantly since the early 21st century. While in 2001, 40% of women aged 15 to 64 formed part of the labor force, by 2022 this figure had risen to 50%, even surpassing the setbacks caused by the economic crisis triggered by the COVID-19 pandemic (World Bank, 2025). However, prevailing conditions in the rural sector show a significant female labor force participation gap compared to the urban sector. Despite the figures, few studies focus on understanding the mechanisms influencing women's decisions to join the workforce in the rural sector (Elson, 1999; Cameron et al., 2001). Therefore, the present research is particularly relevant because, to the best of our knowledge, it is the first to simultaneously address the role of the Internet in the migration phenomenon and the labor

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participation decisions of women living in rural areas of a developing economy like Mexico.

The rest of the chapter is organized as follows. Section 3.2 reviews the literature. In Section 3.3 we discuss the econometric strategy. The data are introduced in Section 3.4, and the estimation results are presented in Section 3.5. The main conclusions are discussed in Section 3.6.

3.2 Literature Review

The literature review is organized into three main sections. The first examines studies that explore the relationship between ICT and migration, while the second discusses research findings on the impact of migration in rural areas. Section three briefly revisits the theoretical relationship between ICT and development.

3.2.1 ICT and Migration

Over the past fifteen years, and especially in the last decade, numerous studies have investigated the potential effects of ICT on migration. The vast majority of these studies suggest that ICT enhances the quality of information available to migrants and potential migrants, simplifying access to it and thereby fostering the creation and reinforcement of migratory networks (Brown, 2016; Peng, 2016; Baldassar, 2016; Lu et al., 2016; Dekker and Engbersen, 2014; Dekker et al., 2016, 2018; Zijlstra and Van Liempt, 2017; Merisalo and Jauhiainen, 2021; Jauhiainen et al., 2022). On a smaller scale, some researchers argue that ICT expands opportunities for potential migrants, particularly in employment, within their country of origin. As a result, migration may become less necessary while still allowing individuals to maintain family ties. This dynamic could lead to a negative relationship between ICT development and migration intensity (Cooke and Shuttleworth, 2013; Cooke, 2018; Kotyrlo, 2020). This negative nexus may be further reinforced by the formulation or tightening of immigration policies designed to address the challenges posed by the increased availability of migration-related information and to mitigate the risks associated with uncontrolled migration. A recent example is the USA government's stance against illegal migration coming from Mexico.

ICT development has been shown to alleviate the lack of emotional support by enabling affordable communication options, such as low-cost calls and audio or video conferencing, which reduce the impact of family separation (Brown, 2016; Peng, 2016; Madianou, 2016a; Baldassar, 2016). This phenomenon—referred to as the "death of distance" (Cairncross, 1997), the transnational family effect (Madianou, 2016b), "doing family at a distance" (Nedelcu and Wyss, 2016), or e-family formation (Benítez, 2012)—has a dual impact on migration. On the one hand, it mitigates the emotional toll of migration; on the other hand, it facilitates the maintenance of daily emotional connections despite physical separation.

Aker et al. (2011) observed that the distribution of mobile phones among the rural population in Niger significantly influenced seasonal migration. Specifically, they found that access to this technology increased the likelihood of at least one household member migrating by 7 percentage points (p.p.) and raised the total number of household members participating in seasonal migration. Similar findings were reported in China by Lu et al. (2016), who estimated that the diffusion of landline phones increased emigration by 2 p.p. This effect was primarily attributed to improved knowledge of labor market opportunities and the ability to maintain timely contact with family members left behind. Other scholars highlight that the impact of expanding mobile phone coverage on migration depends on personal networks. In particular, expanding mobile phone networks strengthen the influence of existing ethnic networks on migration (Muto and Yamano, 2009, 2011).

International literature has also shown that social media and information gathered from the Internet facilitate the decision to migrate, the selection of a destination, and integration and settlement (Dekker and Engbersen, 2014; Thulin and Vilhelmson, 2016; Dekker et al., 2016, 2018). Drawing on data from migrants in four Western European destination countries (the Netherlands, Norway, Portugal, and the UK) and non-migrants in three origin countries (Brazil, Morocco, and Ukraine), Dekker et al. (2016) show that online media have become fairly important channels of communication in migratory networks. They also found that the use of online media to communicate with migrants in Western Europe is influenced by non-migrants' migration propensity, corroborating their hypothesis that online communication supports migration aspirations and decision-making.

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Czaika and Parsons (2017), in their study of highly skilled migration to 10 OECD countries, highlight a positive correlation between migration and ICT development, particularly mobile phone usage in destination countries. They report that a 10% increase in ICT coverage results in a 9% rise in the inflow of highly skilled workers. Conversely, Hunter (2015) finds that access to mobile communication can hinder the return of older African migrants from France. This effect arises from two factors: the financial pressure on men to support their relatives back home and the "networks of solidarity" among hostel residents, which are strengthened through mobile phone-based social networking.

Recently, due to international conflicts such as the Syrian Civil War, the Israeli-Palestinian conflict, and the Russo-Ukrainian war, academics have gained interest in analyzing how social media, facilitated by the Internet, can influence the decisions of asylum migrants (Emmer et al., 2016; Gillespie et al., 2016; Zijlstra and Van Liempt, 2017; Dekker et al., 2018; Merisalo and Jauhiainen, 2021; Jauhiainen et al., 2022). These studies indicate that smartphones and social media have become essential for 21st-century asylum migrants. Social media and other smartphone applications for navigation and translation empower asylum migrants by making them less reliant on smugglers. These studies also describe specific obstacles and risks in using social media by asylum migrants. In particular, some information is not considered trustworthy, leading them to adopt various strategies to validate rumors that appear on social media and come from unknown sources.

The influence of ICT on migration has garnered significant attention from social scientists. Existing literature suggests that ICT in destination countries plays a crucial role in migration dynamics. Social networking with earlier migrants often serves as a primary driver of migration, offering both official information and insider insights into regular and irregular migration procedures. Simultaneously, ICT enhances border control and the tracking and monitoring of individuals within the destination country, enabling improved management of both regular and irregular migration. Nonetheless, the potential impact of ICT on female labor force participation through the strengthening of migratory networks remains an unexplored area of study.

3.2.2 Welfare impacts of migration on rural households

International literature has acknowledged that migration significantly influences the welfare of rural communities of origin countries in multiple ways (Ratha et al., 2011; McGregor et al., 2014; OECD, 2014). The effects of international migration on the welfare of rural households can be assessed through various socio-economic indicators, such as labor, livelihood activities (both agricultural and non-agricultural), income, food security, and land use. These factors are key drivers of emigration among rural workers (FAO, 2016) and play a central role in shaping migration decisions for rural households in developing economies. Additionally, the potential impacts of migration can be categorized into those that occur immediately after migrants depart and those that emerge during a mid-term period following their departure (Obi et al., 2020).

3.2.2.1 Migration and Labor

The immediate impact of migration on the welfare of rural households is primarily associated with the loss of labor. Under the assumption that family labor decreases as migration occurs, this may result in an increased reliance on hired labor. Remittances are expected to alleviate the constraints caused by the loss of family labor by providing financial resources to hire external labor or invest in mechanized agriculture (Adhikari and Hobley, 2015). Several studies have emphasized that the migration of male household members, commonly referred to as "missing men", can raise the agricultural workload for women (feminization of agriculture) and children (Alcaraz et al., 2012; Maharjan et al., 2013; Adhikari and Hobley, 2015; Karki Nepal, 2016; Urama et al., 2017). However, despite receiving remittances, many rural households still face the negative impacts of labor shortages, resulting in reduced farming activities. In a series of studies conducted in Nepal, Adhikari and Hobley (2015), Maharjan et al. (2013), and Karki Nepal (2016) found that due to the increasingly important role of women within the household, the migration of men led to reduced household participation in agricultural activities, and remittances are seldom used to hire additional farm labor. Along the same vein, Alcaraz et al. (2012) studied the effects of remittances from the United States on child labor and school attendance in recipient Mexican households. They found that the negative shock to remittance receipts caused by the 2008 crisis led to a significant increase in child labor and

a substantial decrease in school attendance. The authors argue that remittance-receiving households are credit-constrained, as they appear to cope with the shock by sending their children to work. In contrast to these findings, Piras et al. (2018) and Thomas-Hope (2017) identified a positive impact on agricultural labor, as remittances were used to hire external workers. In both cases, the researchers noted that this positive effect was linked to migrants' interest in resuming farm work upon their return. Thus, the effects of international migration on family agricultural labor are mixed, though most studies highlight the loss of family labor in agriculture.

3.2.2.2 Migration, Livelihood Activities, Household Income, and Food Security

When households experience a reduction in their labor force alongside receiving remittances, there is also a mid-term impact on livelihood activities, household income and expenditure, and food security. Regarding livelihood activities, households must decide whether to shift toward commercial farming activities (Hernández-Solabac et al., 2011; Thomas-Hope, 2017) or diversify into non-farming activities (Thomas-Hope, 2017; Piras et al., 2018; Sunam and McCarthy, 2016). Within the first group, some studies show that migrant households intensify cash crop production while reducing their engagement in subsistence farming (Böhme, 2015; Zhunusova and Herrmann, 2018; Aguilar-Støen et al., 2016). Böhme (2015) observed that migrant households in Mexico tend to accumulate more agricultural assets for cash crop production than for less profitable livestock production. Similar findings were reported in Guatemala by Aguilar-Støen et al. (2016), who emphasized that migration intensifies cash crop production. As for the second group, Thomas-Hope (2017), Piras et al. (2018), Sunam and McCarthy (2016), Sauer et al. (2015), Arouri and Nguyen (2018), and Thomas and Inkpen (2013) demonstrated that remittances enable migrant households to diversify into non-farming activities. In Kosovo, Sauer et al. (2015) provided further evidence of a shift away from agriculture. Similarly, Arouri and Nguyen (2018) found that international migration in Egypt increased the likelihood of transitioning to self-employment in non-farming activities. Thomas and Inkpen (2013) also reported that in Malawi, migrants returning from other African countries were less inclined to engage in agriculture but participated more actively in self-employment.

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The departure of a family member often results in a reduction of family labor, which can influence household income and expenditure patterns. Studies examining the link between migration and household income consistently highlight that remittances act as an additional source of income. These funds often enhance household expenditure on food, education, healthcare, housing, and intra-household monetary transfers (Ajaero et al., 2017; Atamanov and Van den Berg, 2012; Cuong and Linh, 2018; Ducanes, 2015; Hassan and Jebin, 2018; Karki Nepal, 2016; Mergo, 2016; Sharma, 2013). In countries like Egypt, Senegal, Bangladesh, Vietnam, and Pakistan, evidence suggests that families tend to prioritize investments in real estate over agricultural assets (Arouri and Nguyen, 2018; Hossain et al., 2017; Javed et al., 2017; Mezger and Beauchemin, 2015; Viet Cuong and Mont, 2012).

Regarding food security, international research has largely concentrated on how migration enhances household access to food in general, and to nutritious food in particular (Jayatissa and Wickramage, 2016). Scholars suggest that remittances tend to increase household liquidity, which can result in dietary changes, often observed through improvements in child growth patterns. Evidence from Nicaragua and Mexico highlights that seasonal migration by mothers allows them to acquire knowledge of various cuisines which, upon return, are translated into improved dietary changes that benefit their children's development (Macours and Vakis, 2010; Rosales et al., 2018). Also in Mexico, Mora-Rivera and van Gameren (2021) estimated ordered probit regressions with instrumental variables to assess the heterogeneous impacts of international and internal remittances (resulting from migration) on the food insecurity of rural households. The authors find suggestive evidence that remittances serve as an important coping strategy but are insufficient to eradicate the persistent food insecurity of poor households in rural Mexico. Using anthropometric measures, Carletto et al. (2011), Azzarri and Zezza (2011), and De Brauw (2011) analyzed the link between migration and child development. In Guatemala, Carletto et al. (2011) observed that the height-for-age (HAZ) measure was 0.45 SD higher for children living in migrant households. In another Latin American country, De Brauw (2011) studied the effects of remittances during El Salvador's food crisis and found that, while the crisis caused an overall decline in child growth, children from remittance-receiving households had a lower decline in their HAZ scores.

3.2.2.3 Migration, Land Use, and Rural Development

Beyond the immediate and mid-term effects of migration on the welfare of rural households, literature has explored its influence on two "ultimate" outcomes: land use and rural development. Regarding the former, most studies draw on data from ethnographic research and remote sensing. Based on the assumption that migration leads to forest transitions through the abandonment of agricultural land and the regrowth of native vegetation in rural areas (Lambin and Meyfroidt, 2011), these studies examine how migration impacts land use, land tenure, and forest cover (Gray and Bilsborrow, 2014; Jaquet et al., 2016; Oldekop et al., 2018; Garni, 2013; Aguilar-Støen et al., 2016; Sunam and McCarthy, 2016). Additionally, external factors, such as government policies, may shape the ways migration influences land use (Nava-Tablada and Martínez-Camarillo, 2012; Taylor et al., 2016; Walters, 2016; Manning and Taylor, 2014; Moran-Taylor and Taylor, 2010). Nava-Tablada and Martínez-Camarillo (2012) found that in Mexico, migration alone may not drive changes in land use; however, reductions in public agricultural funding make farming less appealing for migrant households. Similarly, Taylor et al. (2016) demonstrated that in Guatemala, migrant households are more likely to purchase land and leave it fallow to take advantage of national forestry policies that incentivize rural residents to maintain forested land.

Concerning rural development, two investigations provide evidence of how international migration and remittances lead to rural social and infrastructure development (Bada, 2016; Hübler, 2016). Bada (2016) analyzes the impact of the Three-for-One federal program on rural migrant-origin communities in Mexico. Through this program, the federal government effectively incentivized the sending of remittances to finance infrastructure projects in rural areas. Furthermore, the collective remittance initiative that emerged from the program enhanced social interaction between migrant and non-migrant households, particularly by fostering a sense among migrants that they were contributing to the development of their communities. However, one of the main challenges associated with this program was the decision-making process for selecting projects to implement, as these projects did not always represent the most productive investments. Additionally, the

perspectives of households without migrants were often excluded from the decision-making process.

As observed, international research has empirically examined, on the one hand, the effects of ICT (including the Internet) on migration and, on the other, the impacts of migration on various welfare indicators. However, to the best of our knowledge, no study has reconciled these two lines of research, particularly by analyzing how migration influences migratory networks and how this potential effect on migration could translate into an impact on a specific labor indicator—female labor force participation.

3.2.3 ICT and development

In international literature, two main lines of research have contributed to constructing a theoretical framework that underpins the relationship between ICT and various development outcomes. The first, known as Information and Communication Technologies for Development (ICT4D), argues that the use of digital technologies, such as the Internet, smartphones, and computers, drives economic and social development, particularly in low- and middle-income countries (Heeks, 2018). This perspective positions ICT as a central tool for enhancing the economic opportunities and livelihoods of the population, especially among those facing the most significant disadvantages (Heeks, 2008).

The second line of research centers on the digital divide approach and provides key insights into the effects of ICT penetration across various dimensions of society, including economic, cultural, political, and social spheres (Van Dijk, 2013). This perspective contends that closing the digital divide strengthens multiple facets of a country's development and enhances access to opportunities for its population. The digital divide framework identifies three levels: (i) physical access; (ii) digital skills, usage patterns, and the interaction between access and technology adoption (Hargittai, 2002; van Dijk and Hacker, 2003); and (iii) the tangible offline benefits of internet access and use (Castells and Himanen, 2014; van Deursen and Helsper, 2015).

While literature acknowledges that both theoretical approaches are complementary, primarily because one of ICT4D's core objectives is to bridge the digital divide and ensure that marginalized populations benefit from technological advancements, there have been

few efforts to reconcile them within a unified theoretical framework. In this context, chapter one presents a specific framework that clarifies the relationship between Internet access and development and offers an initial exploration of the transmission channels through which this technology can positively impact development outcomes.

3.3   Econometric Strategy

Our dependent variables are dichotomous. For Internet access, we consider whether the household is located in a village where Internet access is available. Regarding migration decisions, we distinguish whether any household member is currently working (has worked during the previous year) in the USA. The final variable in our model is labor force participation, specifically whether any female member of the household is a salaried or self-employed worker. Thus, we have a system of endogenous dummy variables. We propose using a trivariate recursive probit, an extension of the bivariate recursive probit introduced by Maddala and Lee (1976) and Maddala (1983), also referred to as a triangular endogenous system (Wooldridge, 2010).

Our model is recursive because the dependent variable in the first equation (Internet access) appears as an explanatory variable in both the second and third equations (thus we account for both a direct and an indirect effect), while the dependent variable in the second equation (migration) is present as a covariate in the third equation. However, the migration variable does not appear in the first (Internet access) equation, and the labor variable from the third equation is not included as a covariate in the first and second equations. Therefore, there is no simultaneity, and assuming compliance with coherence and logical conditions (Maddala, 1983; Lewbel, 2007), we establish causal relationships. The identification in the recursive model does not necessarily require exclusion restrictions but can rely on the nonlinearity of the model (Heckman, 1978; Lewbel, 2007; Maddala, 1983; Wilde, 2000), although the existence of at least one varying exogenous regressor is recommended (Wilde, 2000). Our model resembles the bivariate recursive probit framework proposed by Mancino et al. (2016) to examine the impact of education on crime, as well as the analysis by Fleming and Kler (2014) investigating the relationship between overeducation and workplace satisfaction. Also, Stabridis and van Gameren (2018) utilized a trivariate probit model to, first, examine the factors influencing fuel choice in Mexican households, second,

assess whether exposure to indoor air pollution from firewood contributes to respiratory problems, and third, determine if these health issues affect labor force participation probabilities.

In the third equation, let W^* be a latent variable of female labor force participation which is determined by the migration decisions M of the household, Internet access I, and other covariates X'_W,

$$W^* = X'_W \beta_W + \zeta_M M + \zeta_I I + \varepsilon_W \tag{10}$$

However, W^* is unobserved; we observe $W = 1$ if $W^* > 0$ and $W = 0$ otherwise, where a value of 1 stands for a household in which at least one woman participates in the labor market. In this equation, the migration status M of the household is assumed to be endogenously determined by exogenous covariates X'_M and a dummy variable for Internet access, I:

$$M^* = X'_M \beta_M + \theta_I I + \varepsilon_M \tag{11}$$

M^* is also unobserved; what we observe is $M = 1$ if $M^* > 0$, representing that a household has at least one member working in the USA, and $M = 0$ if the household has never had migrant members ($M^* \leq 0$).

Both the migration decisions M and the female labor force participation W depend endogenously on Internet access, which in turn depends on exogenous covariates X'_I:

$$I^* = X'_I \beta_I + \varepsilon_I \tag{12}$$

What we observe is Internet access I, where a value of 1 ($I = 1$ if $I^* > 0$) indicates that the household is located in a village where Internet access is available and a value of 0 that the household is located in a village without Internet access ($I^* \leq 0$). It is important to note that while each set of exogenous variables (X_W, X_M, X_I) included in equations (10) to (12) serves to identify the dependent variable associated with its respective equation, some variables appear in multiple equations, whereas others are included exclusively in a single equation. This structure strengthens the proposed identification strategy by employing exclusion restrictions, mitigating collinearity issues, and facilitating the identification of causal effects. A more detailed discussion of this point is provided in the following section.

The three equations are also interrelated through the error terms (Greene, 2008). We assume that the error terms are independent and identically distributed across all observations, following a trivariate normal distribution, $N(0, \Sigma)$, with variances set to one due to the dichotomous dependent variables. Therefore, the covariance matrix is:

$$\Sigma = \begin{pmatrix} 1 & \rho_{WM} & \rho_{WI} \\ \rho_{WM} & 1 & \rho_{MI} \\ \rho_{WI} & \rho_{MI} & 1 \end{pmatrix}$$

To construct the log-likelihood, let $q_k = 2k - 1$ for $k = W, M, I$. Thus $q_k = 1$ if W, M or I are equal to 1 and -1 if $q_k = 0$. Now let

$$z_k = X'_k \beta_k \quad \text{for} \quad k = W, M, I$$

Thus, the probabilities related to the three variables of interest are given by:

$$\text{Prob}(W = w, M = m, I = i) = \mathbf{\Phi}_3(q_W(z_W + \zeta_M M + \zeta_I I), q_M(z_M + \theta_I I), q_I(z_I), \Sigma)$$

which accounts for all the necessary sign changes needed to compute probabilities (Greene, 2008). This gives rise to the log-likelihood of the model:

$$\ln L = \sum_{j=1}^{N} \ln \mathbf{\Phi}_3 \left(q_{jW}(z_{jW} + \zeta_M M_j + \zeta_I I_j), q_{jM}(z_{jM} + \theta_I I_j), q_{jI}(z_{jI}), \Sigma \right) \tag{13}$$

The issue with this log-likelihood function is that trivariate normal densities must be evaluated, but no closed-form solution is available. Thus, we use a Maximum Simulated Likelihood (MSL) method that applies the GHK simulator to mimic the multivariate normal distribution function (Train, 2009; Cameron and Trivedi, 2005; Cappellari and Jenkins, 2003).

We can derive predicted probabilities and "treatment effects" using the trivariate probit model estimates (Zhang et al., 2009). For instance, we can estimate the probability of having a migrant as a result of Internet access or the likelihood of a woman being employed (whether salaried or self-employed) given migration. These "treatment effects" are obtained by subtracting two conditional probabilities that lead to the same outcome but originate from different initial conditions. Accordingly, the effect of Internet access on the likelihood of having a migrant household member is calculated as the probability of migration given Internet access, minus the probability of migration in the absence of Internet access.

Following Zhang et al. (2009), the effect of Internet access on migration, in terms of probabilities is:

$$Treat.effect_{Internet-on-migration} = \hat{P}(M = 1|I = 1; X) - \hat{P}(M = 1|I = 0; X)$$

where

$$\hat{P}(M = 1|I = 1; X) = \frac{\sum_{w=0,1} \hat{P}(W = w, M = 1, I = 1; X)}{\sum_{w,m=0,1} \hat{P}(W = w, M = m, I = 1; X)}$$

$$\hat{P}(M = 1|I = 0; X) = \frac{\sum_{w=0,1} \hat{P}(W = w, M = 1, I = 0; X)}{\sum_{w,m=0,1} \hat{P}(W = w, M = m, I = 0; X)}$$

Moreover, the joint or simultaneous effect of two "treatments", could be defined as:

$$Treat.effect_{Internet\&migration-on-female\ work}$$
$$= \hat{P}(W = 1|I = M = 1; X) - \hat{P}(W = 1|I = M = 0; X)$$

3.4   Data

Our data comes from the 2015 ENCHOR survey, which aimed to evaluate the performance of the National Crusade Against Hunger.[46] The survey covers villages with populations between 500 and 2,499 inhabitants. In 2015, a total of 2,400 households from 120 villages were surveyed. The sample design and selection, equally divided between Crusade and non-Crusade municipalities, allows for nationally representative results for the 400 Crusade municipalities and the non-Crusade rural municipalities in the country.[47] The final estimation sample consists of 2,228 households, for which we have information on all the variables used in the analysis.

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[46] The National Crusade Against Hunger was a strategy coordinated by a previous federal administration, aimed at the population simultaneously experiencing food deprivation and extreme poverty. In 2010, this represented 7.4 million people distributed across the country (CONEVAL, 2018).

[47] The microdata and the questionnaires of the 2015 ENCHOR are available via http://www.coneval.org.mx/Paginas/Busqueda.aspx?k=enchor.

The ENCHOR is a survey that enables the study of the effect of Internet access on household members' migration decisions and female labor force participation within the rural sector of Mexico. The survey provides village-level information on Internet access and also collects detailed data on household members' migration history to the USA. Additionally, it includes data on women's participation in labor markets, both in salaried and self-employed jobs. We also use data from the 2010 National Population and Housing Census to complement the information about village-level characteristics. The census provides aggregate data on important demographic, socioeconomic, and cultural attributes of each village, while also enabling us to collect and assess information related to crucial household features.

The availability of detailed data allows us to draw important distinctions between female labor participation in agricultural versus non-agricultural activities, further differentiated by the nature of employment—whether through salaried work or self-employment. This granularity is especially valuable in the context of rural Mexico, where the socioeconomic and geographic heterogeneity of villages plays a critical role in shaping labor market dynamics.

In many rural areas, women's labor force participation is deeply influenced by factors such as land availability, infrastructure development, educational attainment, and access to credit or markets. For instance, in more remote and agriculturally dependent villages, women may be more likely to engage in informal, unpaid family labor or small-scale farming, often without remuneration or formal labor rights. In contrast, villages with greater infrastructure or stronger linkages to urban centers may offer women access to salaried jobs in sectors such as education, healthcare, or retail, as well as opportunities for self-employment in small enterprises or service provision.

Moreover, the proximity of rural communities to urban centers can significantly expand the spectrum of employment opportunities available to women. Shorter travel distances and better transportation networks facilitate commuting and open access to urban labor markets, where demand for non-agricultural labor is typically higher and employment conditions are more formalized. This spatial advantage can shift the employment profile of women away from subsistence agriculture toward wage labor, entrepreneurship, or

participation in service-oriented industries. With this in mind, we estimate base models for salaried work and self-employment and subsequently, estimate separate models for agricultural and non-agricultural activities, whether through salaried employment or self-employment.

As mentioned earlier, data for the equation concerning Internet access are collected at the village level and not necessarily from the households whose migration and female labor participation status are analyzed in the other two equations. Although Internet access is exogenous from the households' perspective, we argue that in rural villages, many of the characteristics influencing the variation in Internet access at the village level interact with effects at the household level.

Table 10 summarizes the descriptive statistics. Three dichotomous variables represent the dependent variables. The first denotes Internet access in the household; since this information was collected at the village level, the household is assigned a value of 1 if there is Internet access in the village, and 0 if not. About half of households live in a village with Internet access. Migration decisions are assigned a value of 1 if any member within the household is currently working (or has worked during the previous year) in the USA, and 0 if not. In 17% of households, a (male or female) member works in the USA. Regarding female labor force participation, the variable takes a value of 1 if any woman within the household is a salaried (self-employed) worker. The data show that female salaried work (23%) is more prevalent than female self-employment (15%) within the total sample.

Apart from containing data on our three dependent variables, the survey allows us to account for additional factors that could (potentially) explain Internet access, household migration decisions, and female labor force participation. Based on previous international studies (Korkmaz et al., 2022; Birba and Diagne, 2012; Chinn and Fairlie, 2007), we use village-level characteristics to explain the availability of Internet access in the village. We include variables associated with the sociodemographic characteristics of the population: the percentage of the population that is illiterate, and the percentage of the population that speaks an indigenous language and does not speak Spanish. To proxy the average economic conditions in the village, we consider the percentage of households with two or more rooms

and the percentage of households that own a TV. Regarding village infrastructure and access to services, we include whether the village has a medical clinic, a drugstore, a restaurant, a hotel, and a Diconsa store[48]. Since Internet providers are incentivized to supply their services where significant economic activity occurs, we include two additional geographical covariates: the elevation and the minimum distance between the village and the nearest metropolitan area. We acknowledge that other variables, such as the availability of basic public services in the village (e.g., street lighting systems) or the level of accessibility to the village via paved roads, could also explain Internet access. However, the available data does not allow us to include them in our first equation.

Regarding the factors that could explain migration decisions within households, we first consider covariates to account for the characteristics of the household head: gender, age, education level, and whether the household head speaks an indigenous language. Secondly, as McKenzie and Rapoport (2011), Gibson and McKenzie (2011), Adams and Cuecuecha (2010), Taylor and Mora-Rivera (2006), and Adams (2008; 1993) have done, we include a larger set of variables to account for different household features. Concerning demographic composition, we include the number of minors (under 12 years old), the number of elderly individuals (60 years old or above), and the number of children attending school (household members aged 3 to 15 years). For the household's economic conditions, we consider whether the household receives monetary support from a federal program, the number of rooms, whether the household has a separate cooking room, and the availability of a sewerage system. To proxy asset ownership, we include whether the household owns a tractor and whether it owns livestock or work animals.

To explain female labor force participation within the household, we follow international literature (Seneviratne, 2019; Verme et al., 2016; Mujahid, 2014; Ejaz, 2007) by considering various characteristics of the household head related to sociodemographic factors (gender, age, indigenous language, and marital status), human capital (education level), and labor factors (whether the household head is male and engaged in salaried work in non-agricultural activities). Additionally, we include covariates related to the household's sociodemographic conditions: the number of infants (children aged 5 years or younger), the

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[48] The DICONSA stores are minimarkets where the population can buy basic goods at a subsidized price.

number of school-aged children (household members aged 3 to 15 years), and the number of elderly individuals. Furthermore, we consider the household's economic status by accounting for whether the home is owned or rented, the number of male members working in agricultural activities, and whether the household owns real estate assets, such as an apartment, land, or an additional house.

Returning to the point of exclusion restrictions, it is important to note that certain exogenous variables are included in more than one model as they help explain multiple dependent variables. Specifically, we argue that the gender, age, and educational attainment of the household head affect both migration decisions and women's labor force participation in rural households. However, age and educational attainment are included as categorical variables in the labor equation because international literature has provided evidence that female labor participation varies across different age cohorts and educational levels. The indigenous status of the household head also significantly influences both migration and women's labor force participation. Furthermore, the number of children attending school in rural households may impact both migration decisions and women's labor force participation.

Finally, certain variables are included in only one of the two equations (migration or labor) based on theoretical considerations and empirical evidence from international research. The employment status of the household head—particularly when engaged in non-agricultural salaried work—is expected to influence women's labor force participation, but not necessarily the household's migration decisions. This distinction reflects the notion that stable, formal employment reduces the household's economic need for additional earners, thereby shaping intra-household labor dynamics. However, in rural settings where labor markets are segmented and opportunities are limited, migration often remains a necessary strategy for economic advancement, regardless of the household head's employment situation.

Demographic composition is another area in which variables are selectively assigned to reflect distinct underlying processes. The number of minors (children aged 6–17) and elderly individuals (typically aged 60 and above) are included exclusively in the migration equation. These variables serve as proxies for household dependency ratios,

which are frequently associated with migration behavior. High dependency burdens may either encourage migration as a means of securing remittances or constrain it due to caregiving responsibilities—particularly in households with a higher number of elderly members. By contrast, the number of infants (children aged 0–5) is included only in the labor force participation equation. This reflects the disproportionate childcare responsibilities borne by women in rural areas, where public childcare services are scarce and private options are generally unaffordable. Consequently, the presence of very young children often constitutes a significant barrier to female employment, especially in inflexible labor markets.

Housing and infrastructure characteristics—such as the number of rooms in the dwelling, the presence of a separate kitchen, and access to sewerage—are included in the migration equation. These variables not only capture material living conditions but also reflect infrastructure deficits that may prompt households to pursue migration as a pathway to improved well-being. Similarly, ownership of productive assets such as tractors or livestock/work animals is more closely associated with migration. These assets may either be acquired through remittances or signal a household's involvement in agricultural production, where seasonal labor demands and financial constraints shape migration decisions.

Although fully disentangling the causal relationships between these covariates and the outcome variables is inherently challenging—due to potential endogeneity and overlapping influences—our model relies on the assumption that some variables have a more direct and substantial association with one decision-making process over the other. This assumption underpins our identification strategy: by including variables that are theoretically and empirically justified to affect only one equation, we enhance the model's internal validity and mitigate the risk of violating exclusion restrictions. These differential associations clarify the pathways through which household characteristics influence either migration or female labor force participation, thereby strengthening the robustness of our joint estimation approach.

Table 10. Summary statistics

	Mean	Std. Dev.
Dependent variables		
Internet access	0.483	0.500
Migration decisions	0.173	0.378
Female labor force participation		
Salaried job	0.233	0.423
Self-employment	0.154	0.361
Explanatory variables		
Information about the household head		
Male HH head[1]	0.812	0.391
Age of HH head	48.798	15.534
Age squared of HH head	2622.482	1608.923
Age of HH head btw 15_29[1]	0.109	0.311
Age of HH head btw 30_55[1]	0.559	0.497
Age of HH head btw 56_or above[1]	0.332	0.471
Years of schooling HH head	5.578	3.681
HH head with no education[1]	0.123	0.328
HH head basic education (primary and secondary)[1]	0.772	0.419
HH head high school education or above[1]	0.105	0.307
HH head speaks indigenous language[1]	0.254	0.435
HH head married or living in free union[1]	0.797	0.403
Male HH head working in a non-agricultural salaried job[1]	0.258	0.438
Information at the household level		
Number of minors (under 12 years old)	0.910	1.102
Number of elderly (60 years old or above)	0.411	0.707
Number of infants (children aged 5 years or younger)	0.389	0.677
Number of children attending school	0.797	1.100
Owned HH[1]	0.866	0.340
Number of male members working in agricultural activities	0.491	0.781

HH owns real estate assets (apartment, land, or additional house)[1]	0.021	0.144
HH receives monetary support from a federal program[1]	0.162	0.369
Number of rooms in the HH	2.748	1.318
HH with a separate cook room[1]	0.843	0.364
HH with sewerage system[1]	0.477	0.500
HH owns a tractor[1]	0.011	0.105
HH owns livestock or work animals[1]	0.219	0.414

Information at the village level		
Percentage of illiterate population	0.017	0.015
Percentage of the population speaks indigenous language and does not speak Spanish	0.054	0.147
Percentage of HHs with two or more rooms	0.287	0.162
Percentage of HHs that owns a TV	0.812	0.202
Medical clinic[1]	0.727	0.446
Drugstore[1]	0.290	0.454
Restaurant[1]	0.408	0.492
Hotel[1]	0.124	0.330
DICONSA store[1]	0.503	0.500
Elevation	1290.092	905.612
Distance between village and closest metropolitan area	56.324	38.249

1/ 1 yes, 0 no

Source: By author based on the 2015 ENCHOR and 2010 National Population and Housing Census data.

3.5   Results

3.5.1 Exploring the nexus between Internet access, migration decision, and female labor force participation

As mentioned earlier, we estimated models for salaried work (Table 11) and self-employment (Table 12). In both cases, we are interested in examining how Internet access

and migration decisions within the household affect female labor force participation, overall, and separately in agricultural and non-agricultural activities.

As for Internet access, which was analyzed based on information at the village level, regardless of the type of female employment examined, it is observed that the demographic composition of the population is a relevant determinant in the provision of this telecommunications service. In particular, a higher percentage of illiterate individuals, as well as a higher percentage of native language speakers who do not speak Spanish, significantly reduces the likelihood of a household having Internet access. In contrast, a higher percentage of households that own a TV in the village increases the likelihood of a household having Internet access. This result may be linked to the prevalence of traditional technologies in the village and, consequently, to existing infrastructure that facilitates the provision of newer telecommunications services, such as the Internet. This finding is similar to those reported by Sultanov et al. (2016) in Kazakhstan and Gupta and Jain (2012) in India.

Additionally, all but one of the variables used to assess infrastructure conditions and access to services in the villages indicate that better infrastructure and greater access to services are associated with a higher probability of a household having Internet access. Geographical factors provide evidence that higher altitude and greater distance between the village and the nearest metropolitan zone are associated with a lower likelihood of Internet access, a result that aligns with the findings of Korkmaz et al. (2022), and Birba and Diagne (2012). Overall, these variables indicate that household-level Internet access is well explained by village-level characteristics, as Internet providers are incentivized to offer services in areas where population demographics and infrastructure development support the demand for telecommunications services.

Migration decisions are positively and statistically significantly related to having Internet access. We argue that Internet access facilitates migratory networks in rural Mexico in the following ways: (i) by enabling communication between migrants and their families both during their journey and after reaching their destination. The Internet helps reduce the isolation migrants may experience abroad and increases the likelihood of their remaining in the host country (Brown, 2016; Peng, 2016; Madianou, 2016a); (ii) by fostering new

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migratory networks, as it allows other family members or other members of their village to connect with migrants abroad (Dekker and Engbersen, 2014; Thulin and Vilhelmson, 2016). This, in turn, helps reduce the information and transportation costs that potential migrants might otherwise incur if they lack the opportunity to communicate with those who have migrated before them.

The gender of the household head is an important determinant of whether a household has migrant members. If the household head is male, the likelihood increases. In addition, as the household head's age increases, the probability of migration within the household also rises; nevertheless, this trend reverses as the household head becomes older. To account for this inverted U-shaped relationship, we include the variable in a continuous rather than a categorical form. Regarding education level, we found an inverse relationship between human capital formation and migration within the household. As the household head's education level increases, the probability of having migrant members decreases. However, coefficients are not statistically significant in any of the models. In contrast, the indigenous status of the household head is statistically significant in determining the household's migration decisions. We found that if the household head speaks an Indigenous language and does not speak Spanish, the likelihood of having migrant members in the household decreases. This result highlights the barriers Indigenous populations face in accessing migration networks, primarily due to their limited ability to communicate effectively, but also because of the discrimination they experience in Mexico—a challenge that is particularly pronounced in rural areas.

Regarding household composition, it was found that a higher number of children (under 12 years old) in the household positively influences migration decisions, whereas a greater number of elderly adults (60 years old or above) has a negative effect. Additionally, an increase in the number of school-aged children increases the likelihood of having migrant members in the household. It should be noted that the direction of the effect of these three variables is as expected; however, their impact is not statistically significant. As for the households' economic conditions, it was found that the likelihood of migration increases if a household receives financial support from a federal program. This result is similar for the variables 'number of rooms', 'whether the household has a separate cooking

room', 'has a sewerage system', 'owns a tractor', and 'owns livestock or work animals'. Overall, the effect of these variables provides suggestive evidence of a direct relationship between financial constraints and access to migration networks. Particularly, rural households with better economic conditions are more likely to access these networks, as they can afford the costs associated with migration.

Table 11. Internet access, migration decisions, and female labor force participation (salaried job)

Variables	Total (I)			Agricultural activities (II)			Non-agricultural activities (III)		
	Internet access	Migration decisions	FLFP	Internet access	Migration decisions	FLFP	Internet access	Migration decisions	FLFP
Internet access		0.355 **	0.468 ***		0.430 ***	-0.214		0.337 **	0.617 ***
		(0.164)	(0.132)		(0.165)	(0.206)		(0.141)	(0.204)
Migration decisions			0.434 **			0.070			0.618 ***
			(0.191)			(0.321)			(0.134)
% of illiterate population	-14.818 ***			-13.987 ***			-14.721 ***		
	(2.803)			(2.801)			(2.779)		
% of the population speaks indigenous language and does not speak Spanish	-0.704 **			-0.830 **			-0.729 **		
	(0.336)			(0.338)			(0.327)		
% of HHs with two or more rooms	0.278			0.252			0.310		
	(0.263)			(0.266)			(0.265)		
% of HHs that owns a TV	1.661 ***			1.554 ***			1.657 ***		
	(0.281)			(0.284)			(0.282)		
Medical clinic	0.954 ***			0.964 ***			0.958 ***		
	(0.073)			(0.073)			(0.073)		
Drugstore	0.562 ***			0.574 ***			0.556 ***		
	(0.072)			(0.072)			(0.072)		
Restaurant	-0.117 *			-0.121 *			-0.116 *		
	(0.070)			(0.070)			(0.068)		
Hotel	0.230 ***			0.225 ***			0.246 ***		
	(0.085)			(0.086)			(0.085)		
DICONSA store	0.398 ***			0.411 ***			0.401 ***		
	(0.064)			(0.064)			(0.064)		
Elevation	-0.0003 ***			-0.0003 ***			-0.0003 ***		
	(0.00003)			(0.00003)			(0.00003)		
Distance btw village and closest metropolitan area	-0.005 ***			-0.005 ***			-0.005 ***		

	(1)	(2)	(3)	(4)	(5)	(6)
Male HH head	-0.825 *** (0.112)	0.198 ** (0.086)	-0.795 *** (0.127)	0.197 ** (0.087)	-0.967 *** (0.106)	0.202 ** (0.087)
Age of HH head		0.058 *** (0.014)		0.052 *** (0.014)		0.054 *** (0.014)
Age squared of HH head		-0.001 *** (0.0001)		-0.0005 *** (0.0001)		-0.0005 *** (0.0001)
Age of HH head btw 15_29 [1]	-0.248 * (0.137)		0.457 *** (0.171)		-0.021 (0.125)	
Age of HH head btw 30_55 [1]	-0.062 (0.081)		0.343 *** (0.107)		0.125 (0.076)	
Years of schooling HH head		-0.002 (0.010)		-0.001 (0.010)		-0.002 (0.010)
HH head basic education (primary and secondary) [2]	0.289 ** (0.117)		0.128 (0.132)		0.261 ** (0.105)	
HH head high school education or above [2]	0.330 ** (0.150)		-0.327 (0.213)		0.149 (0.140)	
HH head speaks indigenous language	-0.344 *** (0.093)	-0.306 *** (0.086)	-0.174 (0.114)	-0.292 *** (0.087)	-0.356 *** (0.0827)	-0.302 *** (0.087)
HH head married or living in free union	-0.102 (0.111)		-0.028 (0.125)		-0.021 (0.104)	
Male HH head working in a non-agricultural salaried job	0.508 *** (0.080)		-0.247 ** (0.117)		0.301 *** (0.075)	
Number of minors (under 12 years old)		0.023 (0.042)		0.004 (0.043)		0.019 (0.043)
Number of elderly (60 years old or above)		-0.108 (0.078)		-0.102 (0.079)		-0.108 (0.079)
Number of infants (children aged 5 years or younger)	-0.014 (0.051)		-0.081 (0.065)		-0.034 (0.047)	

(0.001)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Number of children attending school		0.030 (0.029)	0.060 (0.043)		0.044 (0.039)	0.072 * (0.043)		0.031 (0.031)	0.057 (0.042)
Owned HH		0.035 (0.090)			-0.100 (0.117)			0.127 (0.099)	
Number of male members working in agricultural activities		0.121 *** (0.039)			0.457 *** (0.050)			-0.050 (0.051)	
HH owns real estate assets (apartment, land, or additional house)		-0.308 (0.241)			0.212 (0.318)			-0.467 * (0.267)	
HH receives monetary support from a federal program			0.259 ** (0.131)			0.269 ** (0.130)			0.271 ** (0.130)
Number of rooms in the HH			0.101 *** (0.025)			0.092 *** (0.026)			0.101 *** (0.025)
HH with a separate cook room			0.330 *** (0.104)			0.311 *** (0.105)			0.325 *** (0.100)
HH with sewerage system			0.225 *** (0.070)			0.219 *** (0.072)			0.228 *** (0.069)
HH owns a tractor			0.666 *** (0.253)			0.677 *** (0.258)			0.653 *** (0.249)
HH owns livestock or work animals			0.153 ** (0.077)			0.147 ** (0.078)			0.160 ** (0.077)
Constant	-1.755 *** (0.321)	-0.663 *** (0.153)	-3.368 *** (0.379)	-1.660 *** (0.326)	-1.153 *** (0.211)	-3.344 *** (0.377)	-1.753 *** (0.322)	-1.034 *** (0.168)	-3.460 *** (0.381)
Correlations (rho) between...									
Internet access, Migration decisions	-0.0812 (0.112)			-0.1372 (0.113)			-0.07634 (0.093)		
Internet access, FLFP	-0.20517 ** (0.087)			0.0875 (0.150)			-0.22163 *** (0.086)		
Migration decisions, FLFP	-0.15218 (0.102)			-0.01218 (0.172)			-0.25268 ** (0.105)		

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p-value of all rho's zero	0.0200	0.5788	0.0028
Observations	2,228	2,228	2,228

Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.10.

1/ The reference category is "Age of HH head btw 56 or above".

2/ The reference category is "HH head with no education".

Source: By author based on trivariate recursive probit regressions and data from the 2015 ENCHOR survey.

For the female labor force participation equation, we found interesting results. Table 11 shows that the overall effect of Internet access on female salaried work is positive and statistically significant; however, the impact is not uniform when we distinguish between agricultural and non-agricultural activities. For agricultural activities, the effect of Internet access on female salaried work is negative and not statistically significant, whereas for non-agricultural activities, it is positive and highly significant. This finding may be linked to the Internet's role as an additional tool that enables women in rural households to access new employment opportunities in non-agricultural activities, as these are more closely associated with technology access and usage. In other words, there are more job opportunities in non-agricultural activities that women can take advantage of once they have Internet access.

Having a household member working in the USA increases the likelihood of a woman in the household working in non-agricultural activities. This finding holds in the full sample model. In contrast, when focusing on agricultural activities, we found that migration is not a statistically significant factor in explaining female labor force participation within the household. Therefore, our findings suggest that migration encourages female labor participation in non-agricultural salaried jobs within Mexican rural households but does not impact agricultural salaried jobs. Since we account for the potential endogeneity of migration decisions and Internet access, we can distinguish between a direct Internet effect and an indirect effect through its influence on migration decisions within households.

The results of Table 11 (salaried work) encourage us to examine whether Internet access and migration also impact women's self-employment. Specifically, it is important to examine whether Internet access and migration in rural households influence women's integration into both agricultural and non-agricultural self-employment activities. We find that the overall effect of Internet access on women's self-employment decisions is negative and statistically significant. However, this effect is not stable when we break down the analysis into agricultural and non-agricultural self-employment activities. On one hand, Internet access negatively affects agricultural self-employment, likely because in these activities (such as land preparation, planting, fertilizing, and harvesting), the Internet does

not serve as a tool that supports women's participation. Furthermore, the Internet appears to have a detrimental (statistically significant) effect on agricultural self-employment. On the other hand, for non-agricultural self-employment, the Internet has a positive impact on women's participation in these types of jobs. This result aligns with our expectations, as the Internet can function as a valuable resource, offering women access to information on entrepreneurship, self-training, financing opportunities, and other relevant tools. Also, it is consistent with our earlier results on salaried jobs, reinforcing the conclusion that Internet access plays a positive and statistically significant role in promoting both self-employment and salaried employment.

Regarding migration decisions and their impact on women's participation in agricultural and non-agricultural self-employment, we find that, from one angle, migration in rural households discourages women's participation in agricultural self-employment activities; however, this result is not statistically significant. From another angle, migration facilitates women's engagement in non-agricultural self-employment, which is likely driven by remittances as a key mechanism.

When analyzing the results for both salaried work and self-employment together, we can argue that there is suggestive evidence that migration does not contribute to the integration of women into agricultural activities. Therefore, there is no evidence of a feminization process in agriculture due to migration within rural Mexican households. In contrast, migration does contribute to women's participation in non-agricultural activities, both in self-employment and salaried work. As a natural extension of this line of research, it would be valuable to incorporate an analysis of women's income dynamics. Specifically, it is important to investigate whether the increase in income associated with women's integration into non-agricultural employment offsets the loss of income resulting from their exit from agricultural activities. This would allow for a clearer understanding of the substitution effect—that is, whether non-agricultural work serves as an effective economic replacement for traditional agricultural livelihoods among women living in the rural sector.

Concerning the rest of the covariates, we found that having a male household head negatively affects the likelihood of a woman in the household working in both agricultural and non-agricultural activities. Regarding the household head's age, our results show that

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when the household head is between 15 and 29 or between 30 and 55 years old, the probability of a woman in the household working in an agricultural salaried job increases compared to when the household head is over 55 years old. However, this result is reversed for non-agricultural salaried work, though it is only statistically significant when the household head is between 15 and 29 years old. As for self-employment, our results provide evidence that the probability of a woman in the household engaging in non-agricultural self-employment decreases when the household head is between 15 and 29 years old, compared to when the household head is over 55 years old.

As for the education of the household head, we find noteworthy results. When analyzing salaried work (Table 11, model III), we observe that if the household head has completed basic education or higher, the likelihood of a woman in the household working in a non-agricultural salaried activity increase. This result also holds for self-employment (Table 12, model III); however, it is only statistically significant when the household head has completed high school education. Notably, as the household head's level of education increases, the likelihood of a woman in the household engaging in agricultural self-employment decreases (Table 12, model II). Overall, these findings suggest that the education of the household head plays a crucial role in both discouraging women's participation in agricultural self-employment and fostering their involvement in non-agricultural self-employment and salaried work. Thus, education has the potential to promote gender equality while contributing to the professional development of women in rural areas.

The models for salaried work consistently show a negative relationship between the indigenous status of the household head and female labor force participation. In contrast, the results for self-employment indicate that the indigenous status of the household head contributes to an increased likelihood of a woman in the household engaging in agricultural self-employment activities. This outcome is expected, as agricultural activities are a crucial element of subsistence for rural indigenous populations. However, the same does not hold for non-agricultural self-employment activities, where indigenous status is associated with a lower probability of a woman in the household participating in such work.

An interesting result is related to the impact of having a male household head working in a non-agricultural salaried job. While in the case of agricultural activities (Table 11, model II) it has a negative effect—reducing the likelihood of having a woman within the household working in an agricultural salaried job—it increases the likelihood of having a woman within the household working in a non-agricultural job (Table 11, model III). These findings are consistent with those of Seneviratne (2019), whose results indicated that the occupational status of the household head plays an essential role in determining the labor opportunities for women within households, particularly those living in rural areas. As expected, a higher number of male household members working in agricultural activities increases the probability of a woman in the household engaging in agricultural self-employment or salaried work (statistically significant only in the latter case), while it decreases the likelihood of a woman in the household participating in non-agricultural self-employment or salaried work (statistically significant only in the former case).

Table 12. Internet access, migration decisions, and female labor force participation (self-employment)

Variables	Total (I)			Agricultural activities (II)			Non-agricultural activities (III)		
	Internet access	Migration decisions	FLFP	Internet access	Migration decisions	FLFP	Internet access	Migration decisions	FLFP
Internet access		0.478 ***	-0.485 ***		0.392 ***	-0.834 ***		0.299 *	0.429 **
		(0.126)	(0.132)		(0.131)	(0.132)		(0.172)	(0.213)
Migration decisions			0.089			-0.152			0.409 *
			(0.173)			(0.165)			(0.230)
% of illiterate population	-12.098 ***			-12.041 ***			-14.175 ***		
	(2.741)			(2.640)			(2.775)		
% of the population speaks indigenous language and does not speak Spanish	-0.764 **			-0.635 **			-0.785 **		
	(0.326)			(0.323)			(0.332)		
% of HHs with two or more rooms	0.055			0.040			0.242		
	(0.257)			(0.248)			(0.268)		
% of HHs that owns a TV	1.630 ***			1.688 ***			1.565 ***		
	(0.274)			(0.272)			(0.283)		
Medical clinic	0.937 ***			0.912 ***			0.968 ***		
	(0.072)			(0.073)			(0.073)		
Drugstore	0.591 ***			0.577 ***			0.576 ***		
	(0.069)			(0.069)			(0.072)		
Restaurant	-0.139 **			-0.118 *			-0.108		
	(0.066)			(0.069)			(0.071)		
Hotel	0.205 **			0.203 **			0.205 **		
	(0.080)			(0.083)			(0.085)		
DICONSA store	0.407 ***			0.422 ***			0.409 ***		
	(0.061)			(0.061)			(0.064)		
Elevation	-0.0003 ***			-0.0003 ***			-0.0003 ***		
	(0.00003)			(0.00003)			(0.00003)		
Distance btw village and closest metropolitan area	-0.004 ***			-0.005 ***			-0.005 ***		

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Male HH head	0.186 ** (0.086)	-0.296 *** (0.103)	0.193 ** (0.087)	-0.170 (0.124)	0.191 ** (0.088)	-0.325 *** (0.120)
Age of HH head	0.046 *** (0.013)		0.045 *** (0.013)		0.050 *** (0.014)	
Age squared of HH head	-0.0004 *** (0.0001)		-0.0004 *** (0.0001)		-0.0005 *** (0.0001)	
Age of HH head btw 15_29[1]		-0.289 * (0.159)		-0.232 (0.174)		-0.719 ** (0.294)
Age of HH head btw 30_55[1]		0.198 * (0.107)		0.086 (0.121)		0.198 (0.145)
HH head basic education (primary and secondary)[2]	0.094 (0.106)	0.092 (0.100)	0.092 (0.108)	-0.023 (0.106)	0.100 (0.108)	0.242 (0.154)
HH head high school education or above[2]	-0.159 (0.156)	0.098 (0.138)	-0.178 (0.159)	-0.011 (0.154)	-0.168 (0.160)	0.414 ** (0.198)
HH head speaks indigenous language	-0.255 *** (0.083)	0.256 *** (0.085)	-0.270 *** (0.085)	0.369 *** (0.098)	-0.308 *** (0.088)	-0.103 (0.116)
HH head married or living in free union		-0.035 (0.105)		-0.045 (0.124)		-0.028 (0.127)
Number of minors (under 12 years old)	0.001 (0.042)		0.0003 (0.043)		0.007 (0.043)	
Number of elderly (60 years old or above)	-0.083 (0.076)	0.095 (0.079)	-0.093 (0.078)	0.023 (0.086)	-0.104 (0.080)	0.171 (0.106)
Number of infants (children aged 5 years or younger)		-0.019 (0.047)		0.010 (0.050)		-0.052 (0.068)
Number of children attending school	0.073 (0.041)	0.026 (0.030)	0.070 (0.042)	0.062 ** (0.031)	0.067 (0.043)	-0.013 (0.044)
Number of male members working in agricultural activities		-0.037 (0.040)		0.019 (0.041)		-0.128 ** (0.067)

Note: isolated standard errors "(0.001)" appear for the constant term in several columns.

	(1) Internet access	(1) Migration decisions	(1) FLFP	(2) Internet access	(2) Migration decisions	(2) FLFP	(3) Internet access	(3) Migration decisions	(3) FLFP
HH owns real estate assets (apartment, land, or additional house)			0.263 (0.196)			0.184 (0.213)			0.208 (0.255)
HH receives monetary support from a federal program		0.238 * (0.126)	-0.099 (0.110)		0.243 * (0.129)	0.055 (0.116)		0.256 ** (0.131)	-0.208 (0.156)
Number of rooms in the HH		0.091 *** (0.025)			0.091 *** (0.025)			0.097 *** (0.026)	
HH with a separate cook room		0.321 *** (0.103)			0.320 *** (0.105)			0.315 *** (0.107)	
HH with sewerage system		0.210 *** (0.069)			0.231 *** (0.070)			0.253 *** (0.071)	
HH owns a tractor		0.687 *** (0.255)			0.675 *** (0.261)			0.679 *** (0.260)	
HH owns livestock or work animals		0.164 ** (0.076)			0.159 ** (0.081)			0.132 * (0.078)	
Constant	-1.654 *** (0.314)	-3.250 *** (0.365)	-0.763 *** (0.167)	-1.665 *** (0.309)	-3.192 *** (0.362)	-0.821 *** (0.194)	-1.668 *** (0.326)	-3.306 *** (0.376)	-1.831 *** (0.215)
Correlations (rho) between...									
Internet access, Migration decisions	-0.18779 ** (0.080)			-0.1119 (0.080)			-0.03161 (0.116)		
Internet access, FLFP	0.5405 *** (0.088)			0.6831 *** (0.084)			-0.05861 (0.140)		
Migration decisions, FLFP	-0.15383 * (0.091)			-0.1204 (0.103)			-0.11522 (0.119)		
p-value of all rho's zero	0.0000			0.0000			0.8025		
Observations	2,228			2,228			2,228		

Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.10.

1/ The reference category is "Age of HH head btw 56 or above".

2/ The reference category is "HH head with no education".

Source: By author based on trivariate recursive probit regressions and data from the 2015 ENCHOR survey.

3.5.2 Treatment effects

In Table 13, Panel A, we report the treatment effects for salaried work; in Panel B, we report the treatment effects for self-employment. In both cases, the first row shows the effect of the Internet on migration. Focusing on key differences, we found that the Internet negatively impacts migration in the case of agricultural self-employed activities, while for non-agricultural salaried and self-employed activities, it has the opposite effect. Regarding the effect of the Internet on female employment, notable differences emerge. While the Internet negatively impacts female agricultural salaried employment (-0.63 percentage points, "p.p.") as well as agricultural self-employment (-12.29 p.p.), it has the reverse effect on female non-agricultural salaried employment (2.28 p.p.) and non-agricultural self-employment (1.19 p.p.). This aligns with the results reported in Table 12, as the Internet plays a significant role in expanding women's non-agricultural employment opportunities. This effect holds regardless of whether they pursue salaried or self-employed non-agricultural work, suggesting that better connectivity facilitates greater labor market participation and access to these types of jobs.

The third row (both panels) presents findings on the effects of migration on female employment. Regardless of the employment type (salaried or self-employment) or the type of activity (agricultural or non-agricultural), migration positively influences female employment, though with notable differences in magnitude. The impact of migration on agricultural activities is stronger for self-employment than for salaried work (6.28 vs. 4.92 p.p.). In contrast, the effect of migration on non-agricultural salaried employment is significantly larger (12.95 p.p.) compared to non-agricultural self-employment (0.21 p.p.). Finally, the last row (panel A and B) shows women's participation in salaried and self-employed jobs, conditional on both Internet access and migration. Once again, our results align with those presented and described in Table 12. Migration and employment together have a negative impact on agricultural self-employment, while they have a positive impact on non-agricultural salaried and self-employed activities, with the former having a stronger impact (16.33 vs. 1.16 p.p.). Thus, we confirm our findings regarding the role of Internet access and migration as important drivers of non-agricultural female labor force

participation, while for agricultural activities, the combined effect does not have a clear direction.

Table 13. Treatment effects of Internet and Migration

Panel A	Salaried job					
	Full model		Agricultural activities		Non-agricultural activities	
Internet on Migration	1.348	***	1.407	***	1.722	***
	(0.002)		(0.002)		(0.002)	
Internet on Employment	2.686	***	-0.634	***	2.285	***
	(0.005)		(0.002)		(0.005)	
Migration on Employment	13.928	***	4.924	***	12.954	***
	(0.003)		(0.001)		(0.004)	
Int. & Mig. on Employment	17.603	***	4.549	***	16.332	***
	(0.006)		(0.002)		(0.006)	
Panel B	**Self-employment**					
	Full model		Agricultural activities		Non-agricultural activities	
Internet on Migration	2.112	***	-0.745	***	1.686	***
	(0.002)		(0.002)		(0.002)	
Internet on Employment	-16.669	***	-12.296	***	1.192	***
	(0.003)		(0.004)		(0.001)	
Migration on Employment	15.080	***	6.287	***	0.217	***
	(0.002)		(0.002)		(0.001)	
Int. & Mig. on Employment	1.434	***	-4.950	***	1.166	***
	(0.003)		(0.004)		(0.001)	

The numbers represent treatment effects measured in percentage points.

Standard errors by bootstrapping (100 replications). ***$p < 0.01$

Source: By author based on predicted probabilities obtained from Tables 11 and 12.

3.6   Conclusions

The literature examining the relationship between ICT (including the Internet) and migration, as well as between migration and female labor, has largely done so without considering their interconnection. This research, however, provides key insights into the role of the Internet in Mexican rural migration and how the resulting increase in migratory flows—driven by the introduction of Internet technologies—affects female labor force participation in migrants' home villages. Studying this three-way relationship is particularly relevant because: (i) Mexico is one of the primary countries of migrant outflows; (ii) the Internet has become a crucial tool for strengthening social networks, including those linked to migration, (iii) the role of women in labor markets as a consequence of migration is increasingly significant and deserves special attention.

Drawing on data from the 2015 ENCHOR survey and applying a trivariate recursive probit model, our main findings provide suggestive evidence that, on the one hand, Internet access is a key driver of migration among rural households. Particularly, we argue that Internet access strengthens migratory networks in rural Mexico by facilitating communication between migrants and their families, both during their journey and after arrival. Additionally, it fosters new networks by enabling connections between migrants and potential migrants, lowering information and transportation costs for those considering migration.

On the other hand, Internet access and migration jointly contribute to the incorporation of women from rural households into both salaried employment and self-employment in non-agricultural activities. The results for both salaried employment and self-employment together allow us to conclude that Internet access and migration do not facilitate women's integration into agricultural work. As Adhikari and Hobley (2015) and Maharjan et al. (2013) found in Nepal, there is no indication of a feminization of agriculture among rural Mexican households due to migration. Instead, Internet access and migration promote women's participation in non-agricultural activities, whether through self-employment or salaried jobs. Thus, the Internet functions as a supplementary tool that helps women in rural households access new employment opportunities in non-agricultural activities, which are more closely tied to technology access and usage. Moreover, migration

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contributes to the integration of women into non-agricultural activities, and particularly in the case of self-employment jobs, we argue that remittances play a central role. This result is in line with the one reported by Thomas-Hope (2017) in three Caribbean countries and Sauer et al. (2015) in Kosovo.

From a public policy perspective, addressing the structural inequalities that limit women's participation in the labor market in rural Mexico requires a multidimensional approach. In the medium term, one of the most strategic investments is in expanding broadband infrastructure in rural and marginalized areas. Reliable Internet access is no longer a luxury; it is an essential component of economic participation, educational advancement, and social inclusion. For rural women—who often face mobility constraints due to caregiving responsibilities, traditional gender norms, or limited access to transportation—the Internet can serve as a gateway to economic autonomy, education, health services, and civic participation.

However, access alone is insufficient. To ensure that digital infrastructure translates into real opportunities, policies must simultaneously promote digital literacy and technical skill development, particularly targeted toward women and girls. This includes offering training programs that are culturally appropriate, flexible in timing, and integrated with other social services like childcare and transportation support. Doing so not only increases women's employability in the digital economy (e.g., remote work, online entrepreneurship, e-commerce) but also strengthens their agency within households and communities. Moreover, the design and implementation of these policies must be gender-sensitive, acknowledging the unequal distribution of unpaid reproductive and care work that disproportionately falls on rural women. Without addressing this, any initiative aimed at increasing women's labor participation—whether digital or otherwise—risks deepening their workload without improving their quality of life. As such, public investments in community-based childcare services, eldercare programs, and education on the redistribution of domestic labor are fundamental complements to digital inclusion policies.

In the long term, this investment in connectivity should be paired with comprehensive labor and social protection programs that recognize the diversity of women's work—both paid and unpaid. Such programs could include incentives for remote

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work, subsidies for female-led digital enterprises, and support for women's cooperatives that utilize digital platforms. This integrated approach can provide viable economic alternatives to migration. For those who do choose to migrate, whether temporarily or permanently, the digital ecosystem can also serve a transformative role. Strengthening existing transnational migration networks through digital platforms can facilitate safer, better-informed migration decisions. Internet-based platforms can help potential migrants access information about legal migration pathways, labor rights in destination countries, and opportunities for skills certification or remittances. Moreover, promoting digital diaspora engagement can enable migrants to maintain ties with their communities, invest in local development, and share knowledge and experiences.

However, for this vision to materialize, the Mexican federal government must prioritize digital and gender equity in its international and domestic policy agendas. In the current international climate—marked by rising anti-immigration sentiment and restrictive migration policies—advocating for bilateral and multilateral agreements that facilitate regular, rights-based migration channels for marginalized populations is both a political and moral imperative. At the same time, national policies must address the structural drivers of forced migration, including gender-based violence, lack of services, and economic exclusion. Thus, integrating a gender perspective into rural development and migration policy is not an add-on—it is a necessary condition for meaningful, inclusive development. This requires sustained intersectoral coordination between ministries of labor, education, communication, social development, and foreign affairs, with strong participation from civil society organizations and women's groups.

Lastly, while acknowledging the contributions of this study, we also recognize an important limitation in the type of data used. Specifically, longitudinal data would be desirable for a more detailed and comprehensive understanding of how migration and female labor decisions evolve in response to increasing Internet penetration over multiple periods. Despite this considerable limitation, our study constitutes a valuable contribution to an underexplored yet relevant topic, highlighting the need to continue this line of research. A deeper understanding of these dynamics will enable the design of effective and

well-targeted public policies to fully leverage the positive effects of Internet access and migration on labor markets.

Conclusions

This thesis advances the understanding of the complex and multifaceted relationship between information and communication technologies (ICT), particularly Internet access, and critical development outcomes in Mexico. Through the integration of a novel theoretical framework and rigorous empirical analyses, the research contributes to bridging existing gaps in the literature by elucidating how ICT influences poverty alleviation, migration dynamics, and female labor force participation. The findings underscore the transformative potential of Internet technologies while emphasizing the contextual factors that shape their impact.

At the theoretical level, this thesis develops a robust conceptual framework that synthesizes the ICT for Development (ICT4D) perspective, the digital divide approach, and Amartya Sen's capability approach to define development as an expansion of individual and collective capabilities. This framework articulates two principal transmission channels, human capital and social capital, through which Internet access promotes development. By providing a mathematical formalization of these mechanisms, the thesis moves beyond descriptive analyses, offering a systematic model to guide future empirical inquiry into the ICT-development nexus.

Building on this foundation, the two empirical chapters employ advanced econometric methods to analyze the causal impact of Internet technologies on multidimensional poverty and socio-economic dynamics at the local level. The results demonstrate that expanded mobile Internet coverage significantly contributes to reducing multidimensional poverty across Mexican localities, with differential effects shaped by initial poverty levels and labor market informality. This highlights the importance of enabling environments that complement technological access to fully realize development benefits. Moreover, the evidence indicates that mobile Internet facilitates improvements in education, health, and consumption, thereby enhancing overall well-being.

Further extending this analysis, the research explores the interconnected roles of Internet access, rural migration, and female labor market participation. The findings reveal that Internet access acts as a key enabler of migration by strengthening migratory networks and reducing barriers to information and movement. Importantly, migration combined with Internet access fosters women's integration into non-agricultural employment, both salaried and self-employed, reflecting the gendered pathways through which ICT influences development. This underscores the critical role of digital infrastructure and skills development in expanding economic opportunities for women in rural areas.

Collectively, the thesis highlights that while Internet access serves as a powerful instrument for promoting development, its effectiveness is highly contingent upon the presence of complementary factors. These include not only digital literacy and adequate labor market conditions but also the existence of enabling institutional and policy frameworks that support equitable access and use. Internet connectivity alone is insufficient to generate meaningful developmental outcomes if individuals lack the skills, resources, or opportunities to use it productively. The findings across the empirical chapters underscore that ICT-related benefits are mediated by structural inequalities and pre-existing socio-economic conditions, which shape individuals' ability to translate connectivity into improved well-being. The heterogeneous impacts observed across regions, income groups, and gender lines clearly caution against the application of one-size-fits-all policies. Instead, the evidence points to the necessity of designing and implementing targeted interventions that are sensitive to the specific needs, capacities, and challenges of different localities and population subgroups. This includes investing in localized digital training initiatives, fostering inclusive labor markets, and ensuring that infrastructure expansion is accompanied by broader strategies aimed at social inclusion and capability enhancement.
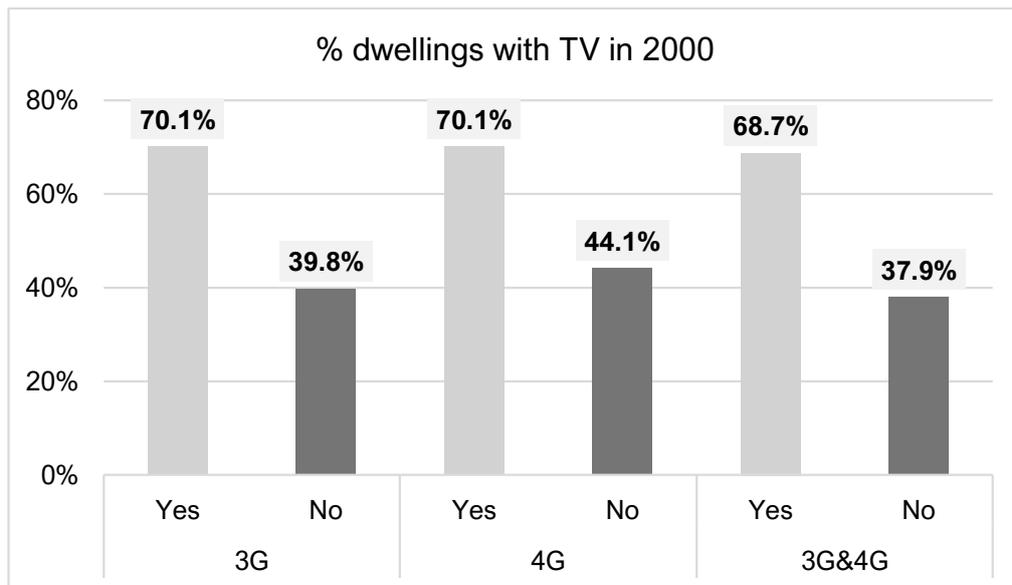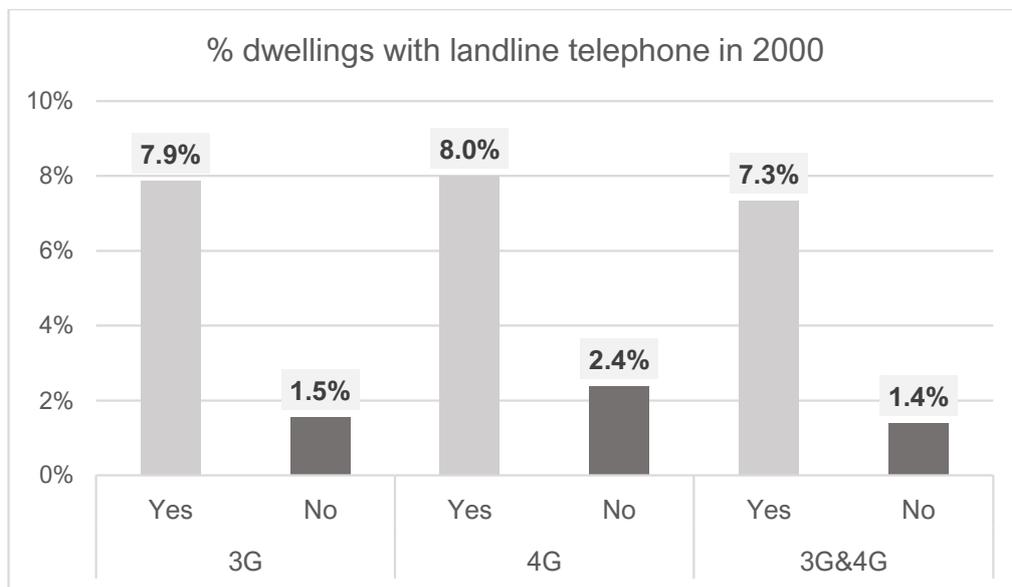
The limitations identified, particularly the lack of panel and individual-level data, point to important avenues for future research to deepen the understanding of dynamic ICT effects over time and across different social strata. Nevertheless, this thesis makes a substantive contribution by integrating theoretical and empirical perspectives, offering actionable insights for policymakers seeking to harness digital technologies to promote inclusive and sustainable development.

In conclusion, this research lays a foundation for more nuanced and effective policies that recognize the interplay of technology, social capital, human capabilities, and institutional factors in shaping development outcomes. By illuminating the pathways through which Internet access can reduce poverty, facilitate migration, and empower women economically, the thesis provides a valuable roadmap for advancing equitable development in the digital age.

Appendixes

Appendixes of Chapter 2

Appendix 2.1. Descriptive Statistics of Lagged Information on ICT Development in the Locality and Mobile Internet Coverage
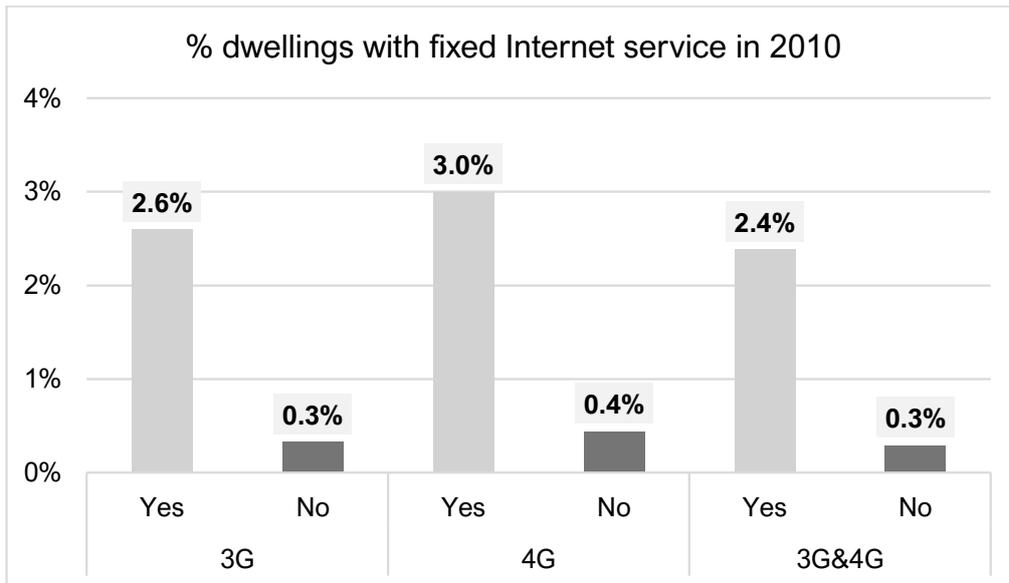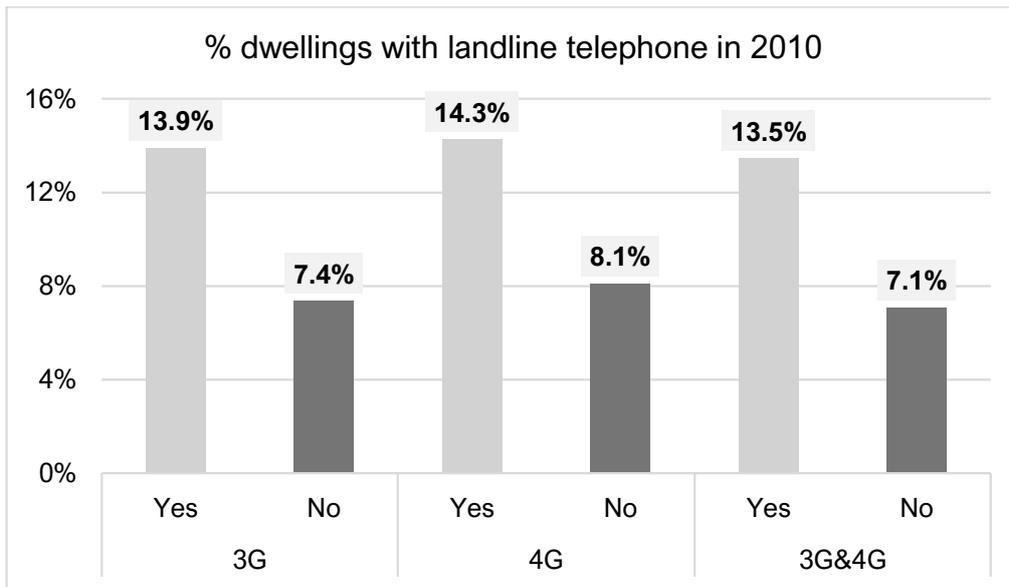
% dwellings with landline telephone in 2000

% dwellings with TV in 2000

% dwellings with landline telephone in 2010

	3G		4G		3G&4G	
	Yes	No	Yes	No	Yes	No
	13.9%	7.4%	14.3%	8.1%	13.5%	7.1%

% dwellings with fixed Internet service in 2010

	3G		4G		3G&4G	
	Yes	No	Yes	No	Yes	No
	2.6%	0.3%	3.0%	0.4%	2.4%	0.3%

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico and data from the 2010, and 2000 censuses.

Appendix 2.2. Impact of the Mobile Internet on Multidimensional Poverty using two Binary Thresholds

We carried out an econometric exercise to estimate the effect of the mobile network on multidimensional poverty when considering two binary poverty thresholds: poverty and extreme poverty. A locality is defined as multidimensionally poor (panel A) if its L-MPI$_k$ is

0.4 or higher, which means at least two complete poverty dimensions. As for extreme multidimensional poverty (panel B), we determine the threshold at 0.6, that is to say, at least three complete poverty dimensions. Using these thresholds, we have 33.1% (25,084) of the localities classified as poor, and 11.5% (8,769) as extremely poor.

To avoid endogeneity, we performed an endogenous treatment-effect model using the *eteffects* Stata command to compute the average treatment effect (ATE) and the average treatment effect on the treated (ATET) for each technology (3G, 4G, and 3G+4G). The sample used is the same as the one employed to estimate the IV ordered probit models (Table 5).

Table A1. ATE and ATET for Multidimensional Poverty and Extreme Multidimensional Poverty Thresholds

Panel A: poor if $L\text{-}MPI_k >= 0.4$						
	3G		4G		3G+4G	
ATE	-14.8	***	-20.5	***	3.29	
	(0.055)		(0.028)		(0.052)	
ATET	-15.5	***	1.14		-8.80	**
	(0.042)		(0.023)		(0.042)	
Panel B: extremely poor if $L\text{-}MPI_k >= 0.6$						
	3G		4G		3G+4G	
ATE	-13.3	***	-9.86	***	-3.83	
	(0.020)		(0.012)		(0.051)	
ATET	-12.1	***	-3.11	*	-11.7	***
	(0.031)		(0.016)		(0.033)	

Robust standard errors in parentheses. *** p<.01, ** p<.05, * p<.1

ATE and ATET are expressed in percentage points.

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020 census, and the data repository of CONEVAL.

In the case of both measures (poverty and extreme poverty), 3G mobile network coverage decreases a locality's likelihood to face multidimensional poverty by more than

12 percentage points (pp), regardless of whether the ATE or the ATET is analyzed. When it comes to 4G mobile network, ATE indicates a 20.5 pp reduction in the probability of a locality facing multidimensional poverty; however, the ATET is not statistically significant. Concerning extreme poverty, ATE exhibit that 4G mobile Internet reduces the probability of a locality being extremely poor by 9.86 pp, while the ATET show a reduction of 3.11 pp. As for the combined technologies (3G+4G), ATET show a reduction of 8.80 pp in a locality's likelihood of being multidimensionally poor, and in 11.7 pp that of being extreme multidimensionally poor. ATE are not statistically significant for both measures. Although the majority of the results point to a positive effect of the mobile Internet on multidimensional poverty mitigation, the 3G technology is the only technology in which a clear pattern is identified. As a whole, these findings strengthen our decision about analyzing the effect of the mobile Internet on several degrees of poverty rather than on a binary indicator, since the latter is overly broad and may hide relevant information for our analysis.

Appendix 2.3. IV Tests for the Impact of the Mobile Internet on Multidimensional Poverty at each Tercile of Municipality Informal Employment Rate

Table A2. Indicative Instrumental Variable Tests for each Tercile and Mobile Internet Technology

Panel A (3G Mobile Internet)	1st tercile	2nd tercile	3rd tercile
Instrumental Variables			
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Interaction between % households with landline telephone service in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	57.08	47.5	18.54
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000

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Overidentification test (Hansen J statistic)	0.93	0.18	1.01
H_0: exclusion restrictions of instruments are valid	0.3352	0.6693	0.3155
Underidentification test (Kleibergen-Paap rk LM Statistic)	98.42	84.67	50.56
H_0: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Endogeneity test of endogenous regressor	2.44	22.38	8.16
H_0: regressor can be considered as exogenous	0.1186	0.0000	0.0043

Panel B

(4G Mobile Internet)	1st tercile	2nd tercile	3rd tercile
Instrumental Variables			
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Interaction between % households with landline telephone service in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	111.60	29.57	19.35
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	1.01	0.56	0.59
H_0: exclusion restrictions of instruments are valid	0.3141	0.4532	0.441
Underidentification test (Kleibergen-Paap rk LM Statistic)	201.16	78.00	40.89
H_0: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Endogeneity test of endogenous regressor	0.40	21.71	8.65
H_0: regressor can be considered as exogenous	0.5288	0.0000	0.0033

Panel C

(3G+4G Mobile Internet)	1st tercile	2nd tercile	3rd tercile
Instrumental Variables			
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Interaction between % households with landline telephone service in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	31.61	38.48	15.97
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	0.70	0.32	0.98
H_0: exclusion restrictions of instruments are valid	0.4016	0.5693	0.3233
Underidentification test (Kleibergen-Paap rk LM Statistic)	57.24	62.41	47.95

H₀: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Endogeneity test of endogenous regressor	2.89	23.35	7.86
H₀: regressor can be considered as exogenous	0.0889	0.0000	0.0050

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, the data repository of CONEVAL, and data from the 2020 National Employment and Occupation Survey.

Appendix 2.4. IV Tests for Robustness Exercises Considering Different IVs

Table A3. Indicative Instrumental Variable Tests of Robustness Exercises Considering Different IVs

Panel A	3G	4G	3G+4G
Instrumental Variables			
% households with landline telephone in 2000	Yes	Yes	No
Interaction between % households with landline telephone in 2000 and % households with TV in 2000	No	No	Yes
Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	587.84	467.48	481.42
H₀: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	1.52	1.16	1.17
H₀: exclusion restrictions of instruments are valid	0.2175	0.2821	0.2797
Underidentification test (Kleibergen-Paap rk LM Statistic)	1197.97	853.16	1042.08
H₀: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Montiel-Pflueger robust weak instrument test	718.215	441.081	604.047
H₀: weak instruments	a	b	c
Endogeneity test of endogenous regressor	28.42	26.66	56.23
H₀: regressor can be considered as exogenous	0.0000	0.0000	0.0000

Panel B	3G	4G	3G+4G
Instrumental Variables			

Interaction between % households with PC in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Interaction between % households with landline telephone in 2010 and % households with fixed Internet service in 2010	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	169.56	197.1	127.55
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	0.06	0.02	0.29
H_0: exclusion restrictions of instruments are valid	0.8055	0.8998	0.5927
Underidentification test (Kleibergen-Paap rk LM Statistic)	307.98	382.96	235.26
H_0: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Montiel-Pflueger robust weak instrument test	131.457	152.47	94.756
H_0: weak instruments	d	e	f
Endogeneity test of endogenous regressor	15.04	9.62	16.30
H_0: regressor can be considered as exogenous	0.0000	0.0019	0.0001

Panel C	3G	4G	3G+4G
Instrumental Variables			
% households with TV in 2000	Yes	Yes	Yes
number of households in 2000	Yes	Yes	Yes
Underidentification test (F test of excluded instruments)	1132.12	868.77	1186.51
H_0: instruments are jointly irrelevant in first stage	0.0000	0.0000	0.0000
Overidentification test (Hansen J statistic)	1.13	0.41	1.12
H_0: exclusion restrictions of instruments are valid	0.2871	0.5207	0.2899
Underidentification test (Kleibergen-Paap rk LM Statistic)	2116.90	1630.75	2214.78
H_0: model is underidentified, instruments are not good	0.0000	0.0000	0.0000
Montiel-Pflueger robust weak instrument test	1783.68	1436.83	1846.55
H_0: weak instruments	g	h	i
Endogeneity test of endogenous regressor	2642.99	2662.67	2605.98
H_0: regressor can be considered as exogenous	0.0000	0.0000	0.0000

(a) 2SLS critical values: 5% 16.63, 10% 10.91, 20% 7.61.

(b) 2SLS critical values: 5% 7.52, 10% 5.55, 20% 4.40.

(c) 2SLS critical values: 5% 17.19, 10% 11.24, 20% 7.82.

(d) 2SLS critical values: 5% 12.24, 10% 8.33, 20% 6.06.

(e) 2SLS critical values: 5% 12.30, 10% 8.37, 20% 6.08.

(f) 2SLS critical values: 5% 13.30, 10% 8.96, 20% 6.44.

(g) 2SLS critical values: 5% 25.49, 10% 16.10, 20% 10.77.

(h) 2SLS critical values: 5% 28.06, 10% 17.61, 20% 11.70.

(i) 2SLS critical values: 5% 24.85, 10% 15.72, 20% 10.54.

Source: By author based on spatial information of mobile Internet coverage from the main MNOs in Mexico, information from the 2020, 2010, and 2000 censuses, and the data repository of CONEVAL.

Table A4. Treatment Effects of Robustness Exercises Considering Different IVs

	Average Treatment Effect (ATE)			Average Treatment Effect on the Treated (ATET)		
	Difference (treat. vs cont.)	Std. Error	z-value	Difference (treat. vs cont.)	Std. Error	z-value
Panel A						
3G Mobile Internet						
Very low	12.0363	0.0081	14.85	13.9924	0.0081	17.13
Low	4.0814	0.0041	9.92	2.7146	0.0047	5.66
Medium	-4.0006	0.0038	-10.26	-6.0380	0.0041	-14.67
High	-8.7047	0.0051	-16.86	-8.5111	0.0057	-14.82
Very high	-3.4124	0.0036	-9.28	-2.1579	0.0027	-7.92
4G Mobile Internet						
Very low	11.1625	0.0105	10.61	11.5201	0.0101	11.36
Low	4.1076	0.0038	10.59	2.8817	0.0046	6.20
Medium	-4.2932	0.0045	-9.45	-5.7077	0.0047	-11.93
High	-7.6509	0.0056	-13.50	-6.9090	0.0062	-11.10
Very high	-3.3260	0.0040	-8.24	-1.7850	0.0029	-5.98
3G+4G Mobile Internet						
Very low	12.2584	0.0077	15.73	14.3015	0.0079	17.95
Low	4.0643	0.0043	9.36	2.8684	0.0050	5.63
Medium	-4.0124	0.0037	-10.57	-6.0048	0.0040	-14.92
High	-8.6975	0.0053	-16.34	-8.7596	0.0059	-14.70
Very high	-3.6128	0.0036	-9.77	-2.4054	0.0029	-8.14
Panel B						
3G Mobile Internet						

Very low	12.0171	0.0085	14.02	14.0121	0.0086	16.19
Low	4.0481	0.0042	9.63	2.6888	0.0049	5.44
Medium	-4.0063	0.0040	-10.00	-6.0629	0.0042	-14.20
High	-8.6849	0.0054	-16.03	-8.5006	0.0060	-13.98
Very high	-3.3739	0.0038	-8.78	-2.1374	0.0028	-7.46
4G Mobile Internet						
Very low	11.2466	0.0112	10.04	11.6030	0.0107	10.78
Low	4.1053	0.0039	10.45	2.8894	0.0047	6.05
Medium	-4.3246	0.0047	-9.16	-5.7460	0.0049	-11.49
High	-7.6843	0.0059	-12.86	-6.9468	0.0066	-10.51
Very high	-3.3430	0.0042	-7.90	-1.7996	0.0031	-5.69
3G+4G Mobile Internet						
Very low	10.5554	0.0090	11.66	12.6165	0.0096	13.06
Low	3.3964	0.0045	7.38	2.0840	0.0051	4.07
Medium	-3.4819	0.0041	-8.49	-5.3857	0.0046	-11.62
High	-7.6287	0.0059	-12.80	-7.5203	0.0066	-11.28
Very high	-2.8412	0.0041	-6.80	-1.7945	0.0030	-5.83
Panel C						
3G Mobile Internet						
Very low	26.2527	0.0050	51.62	24.8408	0.0037	66.16
Low	7.9873	0.0033	23.65	11.1581	0.0047	23.49
Medium	-8.2028	0.0030	-27.22	-8.6844	0.0031	-27.98
High	-16.8416	0.0034	-49.05	-18.5410	0.0040	-45.32
Very high	-9.1955	0.0025	-36.10	-8.7736	0.0033	-25.92
4G Mobile Internet						
Very low	29.2569	0.0061	47.87	24.5081	0.0041	59.42
Low	5.4806	0.0033	16.33	11.1220	0.0048	23.06
Medium	-9.8878	0.0030	-32.24	-9.4168	0.0031	-29.72
High	-15.9113	0.0031	-49.95	-17.4944	0.0040	-42.86
Very high	-8.9383	0.0022	-39.61	-8.7188	0.0033	-25.98
3G+4G Mobile Internet						
Very low	25.1763	0.0046	53.80	24.4645	0.0036	67.93
Low	8.9964	0.0034	25.71	11.7701	0.0048	24.35
Medium	-7.4934	0.0029	-25.11	-8.0356	0.0031	-25.63
High	-16.9735	0.0035	-47.40	-18.7314	0.0041	-44.88

| Very high | -9.7057 | 0.0028 | -34.51 | -9.4676 | 0.0037 | -25.47 |

The difference between treatment and control localities is expressed in percentage points.

Source: By author based on the IV ordered probit models results shown in Table 4.

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