Scale-Biased Technological Change: Evidence from Broadband Adoption in Colombian Firms*

Gaurav Chiplunkar
University of Virginia

July 2025
PRELIMINARY. PLEASE DO NOT CITE OR SHARE.

Abstract

This paper studies how broadband internet adoption reshapes firm production and organization. We leverage rich administrative panel data on Colombian manufacturing firms from 2008–2019, linked to detailed firm-level information on internet use, to estimate the causal effects of broadband adoption using a shift-share instrumental variables strategy. Broadband is a "scale-enabling" technology that increases overall firm output and employment. This is driven by expanding workers in frontline production as opposed to administrative, technical, and managerial ones; and shifting towards hiring workers directly as opposed to from third-party contractors. Detailed ICT usage indicates that broadband adoption: (i) increases external market access through e-commerce, international exports, and customer engagement; (ii) increases internet usage for hiring and training workers, and efficient internal communication. We develop an equilibrium model of heterogeneous firms with *endogenous* organizational productivity, where ICT impacts production choices through multiple, interdependent channels. The model replicates key empirical patterns and provides a framework for quantifying the role of broadband in relaxing internal frictions and enabling firm growth in equilibrium.

Keywords: TBD
JEL Codes: TBD

*Chiplunkar: Darden School of Business, University of Virginia, 100, Darden Blvd., Charlottesville, VA 22905. Email: ChiplunkarG@darden.virginia.edu.

1 Introduction

The diffusion of digital technologies — first broadband internet and now generative artificial intelligence — has transformed how firms operate, organize, produce, and scale. These shifts have revived long-standing questions about the nature of technological change. Are these technologies primarily *skill-biased* i.e., complementing high-skill managerial workers, while displacing lower-skill production ones (Bresnahan and Trajtenberg, 1995; Autor et al., 2003)? Or are they *scale-biased* instead, allowing firms to overcome frictions in coordination, communication, and market access; thereby enabling them to scale output and employment, particularly low-skilled production workers (Hjort and Poulsen, 2019; Cariolle et al., 2018)? Through what channels do these technologies impact firm operations and the production process? How do these firm-level changes aggregate into the broader economy in equilibrium? These questions are particularly salient in low- and middle-income countries (LMICs), where firms digital technologies can often help alleviate informational, logistical, and regulatory constraints, yielding transformational gains and rapid economic growth, with potential implications for labor reallocation and inequality.

In this paper, we provide a detailed empirical and theoretical analysis of how broadband internet adoption reshapes the production structure and performance of manufacturing firms in Colombia. Existing evidence, largely drawn from cross-country studies, or those in high-income ones, suggest that broadband adoption can raise productivity and employment (Cariolle et al., 2018; Bhuller et al., 2023). However, in recent review, Hjort and Tian (2021) point to three essential gaps in the literature: first, most causal studies in LMICs often focus on a narrow set of firm-level outcomes (such as sales, employment, productivity, etc.);[1] second, little is known about how broadband affects the mix of inputs, internal management practices, or the mechanisms through which these efficiency gains are realized; and third, how firm-level responses to broadband adoption shape aggregate outcomes in general equilibrium.

We address these gaps by leveraging rich administrative data on firm production and ICT usage, for a panel of Colombian manufacturing firms spanning over decade between 2008-2019. Our empirical strategy combines this data with supply-side variation on the rollout of broadband services across Colombian regions and an industry-region

[1] See Hjort and Poulsen (2019), Cariolle et al. (2018), and Paunov and Rollo (2015).

intensity of internet usage. This allows us to construct an instrumental variable specification with firm, industry-year, and region-year fixed effects to causally estimate the impact of ICT adoption on a wide range of firm outcomes, including examining detailed channels through which they are realized. We then develop a unified model of heterogeneous firms that maps closely to the reduced-form results. The model incorporates multiple channels through which ICT adoption can (endogenously) change firm productivity, input allocation, and performance in equilibrium. Future drafts would calibrate this model and quantitatively assess the welfare implications of ICT adoption, along with decomposing the importance of the channels through which they operate.

Our primary source of data is the *Encuesta Anual Manufacturera* (or EAM), an annual census of formal manufacturing firms conducted by Colombia's National Statistical Agency — the *Direccion Nacional de Estadística* (DANE).[2] Various aspects of these data make it instrumental for this paper. First, these data track not just key firm outcomes (like sales, costs, inputs, etc.), but also detailed aspects of the production process within the firm, such as: the mix of salaried and contractual labor, production versus administrative workers, capital expenditure in various categories, international trade, transportation expenses on inputs and outputs, communication expenses for production and non-production activities, etc. Second, a novel feature of these data (starting 2008) is a module on ICT usage within the firm. Of special interest is information on internet usage across a wide spectrum of activities: obtaining information, government interactions, communication within firms through VoIP (like Skype), online contracting and customer support, e-commerce, labor hiring and training, etc. The granularity of the data enables us to open the black box of broadband adoption and trace the channels through which it impacts firm production and performance. We use data between 2008-2019, driven by the availability of the ICT module (starting 2008) and the Covid-19 pandemic in 2020.

To address concerns about endogeneity (for e.g., more productive firms may select into broadband adoption), we leverage three empirical strategies. First, we control for firm fixed effects, along with state-year and industry-year fixed effects. Put together, these can account for many common channels that might bias the OLS results, such as average, larger, more productive firms being more likely to adopt broadband; or particular regions experiencing an expansion in broadband infrastructure that increases

[2]Specifically, the EAM surveys all firms employment at least 10 workers, or those who have an output value greater than an inflation-adjusted threshold.

both internet availability and firm productivity; or shocks to sectoral output (such as trade) in ways correlated with adoption. Second, we construct a shift-share instrument that exploits variation in the *supply-side* expansion of broadband availability weighted by the lagged internet usage within a narrow 4-digit industry-region pair. Conditional on the region-year and industry-year fixed effects, this isolates variation arising from the *interaction* of exogenous supply-side expansion in broadband availability with region and sectoral reliance on the internet. Lastly, we incorporate recent econometric advances (Sun and Abraham, 2021; Dube et al., 2023; Malgouyres et al., 2019) and estimate dynamic event study specifications centered around the year of broadband adoption of a firm (see Appendix C). Reassuringly, we find no differential pre-trends in key outcome variables between adopters and non-adopters.

Our empirical results can be summarized in three parts. First, broadband adoption leads to large and sustained gains in firm performance. Real output and sales are around 10-15% higher annually relative to firms who do not adopt broadband. These effects are mirrored in equivalently higher real production costs as well (15%). However, real value added increases by around 10% as well, indicating gains in efficiency beyond those from scale alone.

Second, broadband adoption triggers substantial reorganization of inputs. Firms hire more workers (around 3 workers per year) relative to non-adopters. This is entirely driven by an expansion in production workers, as opposed to either managerial ones, or professionals and technicians. This implies a reallocation of labor away from high-skill administrative roles toward frontline production. Furthermore, firms pivot away from outsourcing hiring through third-party agencies, and to hiring them directly on permanent or temporary contracts. At the same time, capital expenditures, particularly on computers and transportation equipment (like vehicles) increases, reflecting complementary investments in communication and logistics.

Third, firms also expand their market reach. Adopting broadband increases the probability of exports by 11 percentage points (p.p.) and exports as a share of total sales by 10 p.p.. On the other hand, there is no impact on either the probability or share of imports, suggesting broadband primarily reduces barriers to selling rather than sourcing. Lastly, we also find an increase in expenses on transportation (particularly on output), and communication services (especially administrative). These are consistent with broadband allowing for more efficient internal communication as well as access to newer markets.

We further explore mechanisms using the ICT usage module. Firms that adopt broadband report a higher probability of using the internet for gather information from government agencies, designing a website, participating in e-commerce, and sending/receiving orders online. Turning to management practices, firms report a higher incidence of using the internet to hire and train workers, as well as for internal communication through VoIP applications (like Skype for example). Taken together, these results show that broadband adoption induces widespread digitization of firm practices, both externally (through websites, customer engagement, and e-commerce) and internally (through hiring, training, and communication). These behavioral changes complement and help explain compositional changes in the structure of costs and inputs, along with the resulting improvements in firm performance discussed above.

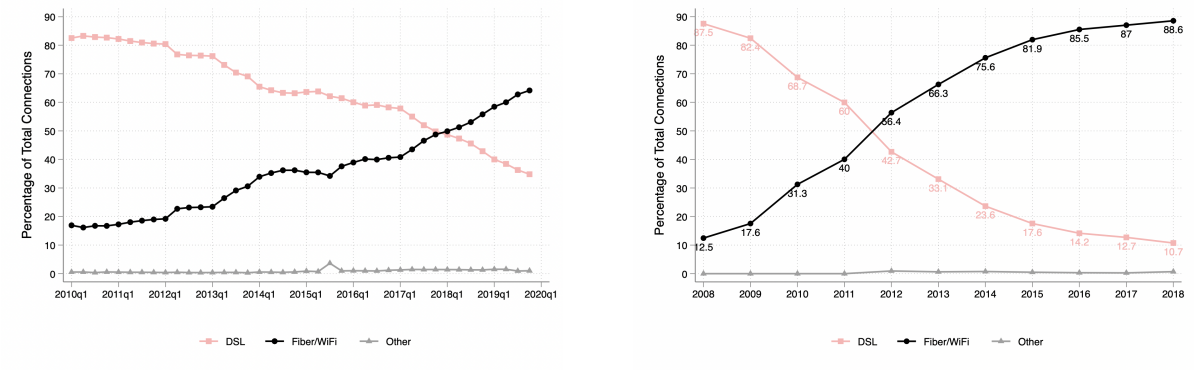
To interpret these findings and assess their broader implications, we develop a structural model of firm production that embeds endogenous productivity and organizational production. Production is organized in two steps. First, firms endogenously determine their organizational productivity ($\widetilde{z}$), which depends on entrepreneurial ability (z) and a composite of administrative labor (managers, technicians, etc.) and ICT capital (like computers). In the second stage, firms use production inputs of capital and labor, along with their organizational efficiency to produce output. Production labor itself is comprised of a composite of salaried and contract workers, reflecting trade-offs in flexibility and monitoring. We embed the model in general equilibrium by including a representative non-manufacturing sector as well as consumer demand to determine market-level prices and wages.

The theory provides four channels through which broadband can impact firm production, namely: (i) enhancing market access; (ii) reducing matching frictions in hiring workers; (iii) reducing monitoring costs of production workers on temporary contracts; and (iv) raising the productivity of ICT capital relative to managerial workers. While many of these channels directly link to the empirical results discussed in previous sections, a key insight from the model is to show that they can reorganize firm production in complex, inter-dependent ways. For example, lower matching frictions pushes firms to hire more workers (including managerial ones), but changes in their relative productivity can mitigate this channel, leaving the overall impact ambiguous. In future drafts, we propose an estimation strategy that uses rich moments from the data to identify key model parameters. This would enable us to decompose the impact of broadband across these channels, as well as provide measures of welfare gains.

Our paper contributes to three strands of the literature. First, we add to the growing empirical literature on broadband and firm performance (Hjort and Poulsen, 2019; Bhuller et al., 2023; DeStefano et al., 2023) by providing causal evidence on a wide range of firm outcomes — beyond the usual measures of firm performance — in a developing country. Importantly, we unpack precise mechanisms through which broadband can reduce frictions along multiple dimensions to enable firms to reorganize production and scale. Importantly, our patterns are consistent with a growing literature on the organizational and behavioral implications of ICT adoption (Akerman et al., 2015; Bloom et al., 2014, 2012; Bartik et al., 2023). For example, Bloom et al. (2014) show that improved information technology facilitates the diffusion of modern management practices, particularly in larger, multi-plant firms. Akerman et al. (2015) emphasize that broadband adoption complements tasks that require information processing and communication, while Bartik et al. (2023) demonstrate that digital tools can shift firm-level decision-making in hiring, contracting, and scaling. Our findings contribute to this literature by providing evidence from a large emerging economy, showing that broadband affects not just the level of firm inputs or outputs, but the structure and boundaries of the firm itself. Broadband alters how firms interact with external agents (via e-commerce and customer service), how they structure internal operations (via hiring and training platforms), and how they adapt to scale through contract and input adjustment. These transformations underscore the role of broadband as a general-purpose technology that operates through a wide range of organizational and behavioral channels. From a theoretical standpoint, we extend canonical models of heterogeneous firm production (Melitz, 2003) by modeling how digital infrastructure alleviates multiple constraints within the firm, how they interact in the production process, and endogenously impact firms' organizational and production decisions.

The remainder of the paper is structured as follows. Section 2 describes the institutional context and the administrative data. Section 3 presents the empirical strategy. Section 4 documents the reduced-form effects of broadband adoption on firm performance, labor structure, and trade. Section 5 explores underlying mechanisms. Section 6 develops the structural model. Section 7 outlines the estimation strategy. Section 8 concludes.

Figure 1: High-Speed Internet Adoption in Colombian Firms



(a) All Firms

(b) EAM Sample

Notes: Figures (a) and (b) plot the fraction of Colombian firms using high-speed broadband internet connection (solid black line) and narrow-band DSL connections (solid red line) between 2008-2020.

2 Data

2.1 Annual Manufacturing Survey (EAM)

Our primary data includes an (unbalanced) panel of 12,313 firms in the manufacturing sector in Colombia over a 12 year period from 2008-2019. These data are collected from the *Encuesta Anual Manufacturera* (or EAM). EAM is a census of manufacturing firms in Colombia that employ at least 10 workers or have an output value that is established annually, which is increased based on the Producer Price Index (PPI). It gathers very detailed information about the production process of a firm such as employment, costs, assets, investment, output, intermediate materials, etc. Moreover, starting 2008, the EAM also collected information on ICT usage in a plant, which reports the type of internet connection (DSL, ADSL, Fiber Optic, etc.), number of workers who use the internet, and most importantly, why the firm uses internet. The ICT module captures detailed information on whether a firm uses internet for email and communication, buying and selling goods online, engaging with government institutions, using apps (like Skype, etc.), online contracting as well as personnel training.

2.2 Supplementary Data

Apart from the EAM, we use other administrative data available from the Ministry of Information and Communication (MinTIC). Importantly, the MinTIC collects data at the municipality level every quarter on the number and type of internet connections (DSL, ADSL, fiber optic, Wifi, etc.), types of users (residential, businesses, government, etc.) and the number of service providers. Since the EAM covers the formal manufacturing sector, we use these data to validate the pattern of supply-side expansion and demand-adoption of high-speed internet across Colombia. We also use these data to construct the instrument (discussed in the next section).

Figure 1 shows the expansions of adoption of high-speed internet by firms in Colombia. Figure 1(a) shows adoption by all Colombian firms, while Figure 1(b) restricts the adoption to firms in the EAM sample. As we can see, there is three-fold increase in the adoption of broadband across Colombian firms between 2010-2020. Adoption within the EAM sample, even faster — from 12% to around 90% over the sample period.

3 Empirical Strategy

We now turn to our main empirical strategy, which aims to identify the causal effect of broadband internet adoption on firm performance, by comparing changes in outcomes before and after adoption across firms, while controlling for rich time-varying heterogeneity at the region and industry level. We construct a binary indicator $\mathbb{1}(\text{Broadband}_{it})$ that takes the value 1 in all years after firm i adopts broadband internet, and 0 otherwise. We then estimate the following regression specification:

$$Y_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \beta \mathbb{1}(\text{Broadband internet})_{it} + \varepsilon_{it} \tag{1}$$

where Y_{it} is an outcome of interest (such as sales, costs, etc.), α_i are firm fixed effects, α_{st} are region-year fixed effects, and α_{jt} are (2-digit) industry-year fixed effects. The combination of these fixed effects control for all time-invariant firm heterogeneity as well as sectoral or geographic changes over time. Put together, these can account for many common channels that might bias the OLS results. For example, if on average, larger, more productive firms are likely to adopt broadband, or if a particular region

experiences an infrastructure expansion that increases both internet availability and firm productivity, or if there are shocks to sectoral output (such as trade) in ways correlated with adoption, these are accounted for by the firm, region-year, or industry-year fixed effects respectively.

That said, endogeneity concerns remain. Even with extensive fixed effects, broadband adoption may still be correlated with time-varying firm-specific unobservables. For example, a firm anticipating growth may be more likely to upgrade its internet connection, which might create a risk of reverse causality. Similarly, measurement error in self-reported broadband usage could further attenuate OLS estimates toward zero. To address these concerns and obtain consistent causal estimates, we turn to an instrumental variables strategy described below.

Instrumental Variable Strategy

We construct an instrument that exploits variation in the interaction between: (i) the (log) number of broadband providers in a region and year — Ln(Providers)$_{rt}$; and (ii) the lagged internet exposure in firms' industry and region — $\overline{\text{Exposure}}_{rjt-1}$. Exposure is calculated as the lagged average internet speed (in Mbps) used by firms in 4-digit industry-region jr in year $t-1$.[3] This measure therefore captures both the extensive margin, and the intensive margin quality of internet usage. For a firm i operating in region r and industry j in year t, our instrument is therefore defined as: $Z_{i(jr)t} = \text{Ln Providers}_{rt} \times \overline{\text{Exposure}}_{jrt-1}$.

This interaction captures two key forces shaping firm adoption of broadband internet. The first component captures supply-side variation: more broadband providers in a region can induce more adoption. One might be concerned about the endogenous expansion of providers across regions based on socio-economic factors in them. Apart from region-year fixed effects, projects were also approved under Colombia's national broadband expansion policy — the Proyecto Nacional de Fibra Óptica, which aimed to increase geographic coverage in broadband internet through public-private partnerships, generating spatial variation in providers across regions (see Figure A1).[4]

[3]For firms that do not use any internet, we set this to zero.

[4]See details on PNFO here. Despite this plausibly exogenous expansion, the presence of more providers in a region would also impact consumers' internet adoption as well, thus generating more demand for firms' goods and services, and hence potentially their decision to adopt broadband. Our region-year fixed effects take into account these channels.

The second component — lagged internet exposure at the region-industry level — reflects latent *firm* demand for adoption. In essence, in regions and industries where firms were already using the internet intensively, broadband availability is more likely to translate into adoption. Crucially, the inclusion of region-year and industry-year fixed effects ensures that identification comes from variation in this interaction, rather than level changes in either dimension i.e., region-year fixed effects (α_{st}) account for all local expansion and adoption in broadband infrastructure, along with its aggregate impact on input and output markets, while industry-year fixed effects (α_{jt}) control for sector-wide changes in demand, technology, or other sector-specific shocks. The interaction of these two channels allows us to separate the effect of broadband adoption from general economic trends in either the region or the sector.

We then estimate the following first-stage regression specification:

$$\mathbb{1}(\text{Broadband Internet})_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \gamma Z_{ijrt} + \varepsilon_{it} \tag{2}$$

Table 1 reports the results from the first-stage. Column (1) reports the specification with only firm and year fixed effects, while Column (2), our preferred specification, includes region-year and industry-year fixed effects as well. As reported in the table, the magnitude and statistical significance of the first stage is robust across both these specifications, with an F-statistic of over 150 in both regressions. In Figure A2, we plot the relationship between residualized broadband adoption and the residualized instrument, conditional on all fixed effects, and find a tight linear relationship across the entire distribution, increasing our confidence in the indentification strategy.

A last potential remaining concern with our identification strategy is that firms may select into broadband adoption based on anticipatory trends in firm performance. For example, firms expecting to grow in the future may adopt broadband in advance. While our fixed effects structure controls for rich time-varying heterogeneity at the region and industry level, along with time-invariant firm characteristics, it does not directly rule out firm-level selection on unobservables that evolve just prior to adoption.

We assess this possibility in in Appendix C. First, we estimate a dynamic event study specifications centered around the year of broadband adoption, incorporating recent econometric advances made in this literature (Sun and Abraham, 2021; Dube et al., 2023; Malgouyres et al., 2019). We regress key measures of firm performance — real

Table 1: First Stage

	1(Broadband Internet)	
	(1)	(2)
Ln(Providers)$_{rt}$ × $\overline{\text{Int. Exposure}}_{rjt-1}$	0.01**	0.07***
	(0.01)	(0.00)
Firm FE	Yes	Yes
Year FE	Yes	No
Ind x Year FE	No	Yes
Region x Year FE	No	Yes
R2	0.71	0.72
N	92828	92828
Firms	11094	11094

Notes: The outcome variable is a binary variable that takes the value 1 for all years after a firm reports first using broadband internet and 0 otherwise. Ln(Providers)$_{rt}$ is the inverse hyperbolic sine number of broadband service providers in a region r in a year t. $\overline{\text{Int. Exposure}}_{rjt-1}$ is the lagged internet exposure in region r and industry j in year $t-1$. Column (1) reports the first-stage regression results with firm and year fixed effects, while Column (2) further adds industry-year and region-year fixed effects. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

output, sales, costs, and value-added — on a series of year indicators relative to the year of adoption (with the year prior to adoption as the reference). The key is to examine whether outcomes trend upward (or downward) in the years before treatment. Across all these outcomes we find that the coefficients are statistically indistinguishable from zero in the pre-treatment period. Put together, these checks strengthen the credibility of our identification strategy by supporting the assumption of conditional exogeneity in adoption timing.

4 Impact on Firm Performance, Inputs, and Trade

We now turn to estimating the impact of broadband internet adoption on firm outcomes based on the empirical strategy described in the previous section. While we focus our interpretation on the IV results in our analysis, we report results for both the OLS and IV specifications for comparison. Our rich data allows us to explore a wide spectrum of firm-level measures, ranging from indicators of firm performance (output, sales, costs, etc.); detailed expenditure on factor inputs such as labor and capital; along with

Table 2: Impact on Firm Performance

	pY		Sales		Costs		Value Added	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	4.26***	36.66**	3.81***	37.25**	0.43***	3.58***	1.32***	14.00**
	(1.02)	(15.43)	(1.00)	(15.56)	(0.10)	(1.33)	(0.44)	(6.29)
Control Mean	54.40	54.40	53.50	53.50	4.37	4.37	21.76	21.76
Annualized $\triangle Y$		0.11		0.12		0.14		0.11
N	88457	88457	88457	88457	88457	88457	88457	88457
No. of firms	10773	10773	10773	10773	10773	10773	10773	10773
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are reported in thousands of real 2010 Colombian pesos and windsorized at the top and bottom 5th percentiles. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

a range of mechanisms that capture changes in digital behavior, market expansion, and firm practices.

4.1 Impact on Firm Performance

We begin by estimating the impact of broadband internet adoption on firm-level performance. Table 2 presents results for four core outcomes: real gross output, real sales, real production costs, and real value added.[5] Odd-numbered columns report the OLS estimates, with the even-numbered columns show the corresponding two-stage least squares (2SLS) results. The OLS estimates suggest modest gains from adoption, ranging from 5-8% of pre-adoption means across these key indicators of firm performance. In comparison, the IV estimates are substantially larger, ranging form 50-70% of the pre-adoption means.

Before we proceed, we would like to provide a few important clarifications to understand the difference in the OLS and IV estimates. Interpreting their magnitudes requires both economic and econometric considerations. First, these differences are

[5]All outcomes are measured in real terms (in thousands of 2010 Colombian pesos) and windsorized at the top and bottom 5th percentile.

neither surprising nor unique to our setting. OLS is likely biased downward due to both attenuation from measurement error as well as hetergoeneous gains from adoption across firms. The IV estimate reflects the local average treatment effect (LATE) for marginal adopters — firms that are induced to adopt broadband due to the instrument. These firms could therefore be better positioned to differentially benefit from adpption as well, when compared to the average firm.

Second, since we pool across pre- and post-adoption periods in our analysis, the estimated coefficients (both OLS and IV) provide a cumulative difference in the average outcome variable across years (around 6 on average in our sample) after adopting broadband internet. Therefore, as a first-order approximation, we can scale the estimated coefficients by $1/N_T$ to get an annualized difference in *levels* of the outcome variable i.e., $\frac{1}{N_T} \cdot \hat{\beta}/\overline{Y}_{Control}$. In that sense, adopting broadband internet causally increases key firm performance indicators annually by around 12-15%. Lastly, in Appendix B.1, we show that the coefficient of interest (β) can be translated more carefully into an approximate difference in annual *growth* rates of the outcome variable instead. In this light, adopting broadband increases the *growth* rate of key firm indicators by around 20-23 p.p.

4.2 Impact on Labor and Capital Inputs

We next examine how firms adjust their input use following broadband adoption. Tables 3 and 4 analyze firm-level employment and occupational structure, changes in contractual arrangements, while Table 5 presents the results for capital investment.

Impact on Labor: Occupational and Contractual Margins

We now examine how broadband adoption affects the composition of firm employment, focusing on both the occupational structure (Table 3) as well as the contractual arrangement of workers (Table 4). These distinctions allow us to assess whether broadband adoption enables firms to scale labor along rigid or flexible organizational margins, and whether the associated employment growth reflects reallocation across tasks or simply an overall change in the size of the workforce.

Table 3: Impact on Type of Workers

	Total		Managers		Prof./Tech.		Workers	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Unconditional								
1(Broadband)	2.01***	18.23***	0.77***	1.70	0.13	-1.35	1.11***	17.88***
	(0.35)	(4.85)	(0.14)	(1.74)	(0.08)	(1.26)	(0.25)	(3.40)
Annualized $\triangle Y$		3.04		0.28		-0.23		2.98
Panel B: Conditional on L								
1(Broadband)			0.26***	-2.88**	-0.09	-3.39***	-0.18	6.27***
			(0.10)	(1.21)	(0.07)	(1.13)	(0.12)	(1.62)
L			0.25***	0.25***	0.11***	0.11***	0.64***	0.64***
			(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)
Control Mean	34.04	34.04	8.91	8.91	2.68	2.68	22.45	22.45
Annualized $\triangle Y$				-0.48		-0.56		1.04
N	87626	87626	87626	87626	87626	87626	87626	87626
No. of firms			10806	10806	10806	10806	10806	10806
Regression	OLS	IV	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are total workers (Columns 1-2), managers (Columns 3-4), professional and technical workers (Columns 5-6), and production workers (Columns 7-8). Panel A reports the unconditional regression, while Panel B controls for the total firm-size (L). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Occupational Composition: We observe workers based on their occupation within the firm hierarchy such as: (i) managers and administrative workers; (ii) technicians and professionals; and (iii) workers involved in production. From Panel A of Table 3, adoption of broadband increases total firm size by around 3 workers per year (Column 2). This increase is driven almost entirely by hiring more production workers (Column 8), as opposed to managerial and professional ones, where the impacts are both quantitatively small and statistically insignificant at conventional levels (Columns 4 and 6). Panel B then examines whether broadband adoption changes the *composition* of employment across occupational categories, by holding firm size fixed. The results indicate a clear reallocation of labor away from non-production roles: a decline in mangerial and professional workers (Columns 4 and 6) with a corresponding increase in production workers (Column 8).

Table 4: Impact on Worker Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	1.27***	6.12*	0.24	8.56***	0.50***	3.36
	(0.29)	(3.63)	(0.23)	(2.36)	(0.18)	(2.11)
Annualized $\triangle Y$		1.02		1.43		0.56
Panel B: Conditional on L						
1(Broadband)	0.18	-3.78	-0.24	4.24**	0.06	-0.66
	(0.22)	(2.34)	(0.21)	(2.14)	(0.16)	(1.83)
L	0.54***	0.54***	0.24***	0.24***	0.22***	0.22***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	20.17	20.17	8.66	8.66	4.77	4.77
Annualized $\triangle Y$		-0.63		0.71		-0.11
N	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806	10806	10806	10806	10806
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are total workers in a firm on permanent, salaried contracts (Columns 1-2), on temporary contracts hired directly by the firm (Columns 3-4), and on temporary contracts hired through third-party intermediaries (Columns 5-6). Panel A reports the unconditional regression, while Panel B controls for the total firm size (L). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Contractual Arrangements: We also observe the nature of the contractual relationship of workers within a firm across three types of contracts: (i) permanent, salaried contracts; (ii) temporary contracts directly within the firm; and (iii) temporary contracts through third-party agencies. From Panel A, we see that an increase in the firm size (discussed previously in Table 3) is reflected in an increase across all types of labor contracts, particularly within the firm. Workers on permanent salaries (Column 2) or directly hired on temporary contracts (Column 4) increase annually by around 1, while those hired through third-parties (Column 6) increase by around 0.5 (though this is statistically insignificant at conventional levels). A compositional analysis conditional on firm-size, reported in Panel B, suggets a substantial reallocation of labor *away* from

salaried work and towards more temporary contracts. [6]

Appendix Tables A4-A6 then show the full breakdown across both occupations and contractual arrangements. These provide further additional insights on how broadband adoption reorganizes workers within the firm. For example, the decline of workers in non-production roles (Panel B, Table 3) is primarily driven by a decline in salaried workers in these roles (Panel B of Tables A4 and A5). In contrast, production workers are more likely to be hired on temporary contracts, with smaller and less precisely estimated increases in salaried or indirect contracts (Panel B, Table A6).

Interpretation of Results: The above results yield a clear and coherent picture of how broadband adoption restructures firm employment. First, broadband *expands* total employment primarily through production roles, consistent with firms increasing output rather than overheads. Second, it also leads to a reallocation of labor within the firm conditional on size — away from salaried managerial and professional workers, and towards production workers on temporary contracts, indicating scale expansion along flexible labor margins.

These patterns are consistent with the interpretation that broadband adoption (in this context) is not *skill*-biased, but *scale*-biased. In the Colombian context, rather than raising the demand for high-skill tasks, broadband appears to enable firms to restructure their activities toward more labor-intensive, flexible, and output-oriented production models. This departs from the standard view of ICT as complementary to non-routine cognitive labor (Autor et al., 2003; Akerman et al., 2015), and instead supports a model of operational expansion—consistent with Bloom et al. (2014) and Bartik et al. (2023), who find that digital tools can enable managerial delayering.

Impact on Capital

Turning to with capital in Table 5, broadband adoption increases real capital stock by around 14% annually (Column 2), driven by an increase in expenditure on machines (Column 4), and transportation equipment (Column 6), but not in land and building

[6] Appendix Tables A7 and A8 show a similar pattern om occupational composition and contractual arrangements with wage-bill instead of firm-size.

Table 5: Impact on Capital

	Total		Machines		Transp.		Land/Bldng	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	1.49***	17.84**	1.08***	9.01*	0.07***	0.62**	0.30	6.37*
	(0.49)	(7.34)	(0.31)	(4.90)	(0.02)	(0.25)	(0.25)	(3.76)
Control Mean	21.96	21.96	12.06	12.06	0.92	0.92	7.76	7.76
Annualized $\triangle Y$		0.14		0.12		0.11		0.14
N	87271	87271	87271	87271	87271	87271	87271	87271
No. of firms	10707	10707	10707	10707	10707	10707	10707	10707
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: pace0.2cm *Notes:* The outcome variables in the above table are total capital expenditure (Columns 1-2), capital expenditure on machines (Columns 3-4), transportation equipment (Columns 5-6), and land and buildings (Columns 7-8). All outcome variables are reported in thousands of real 2010 Colombian pesos and windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

investment (Column 8). These patterns suggest that broadband adoption leads firms to upgrade their productive capacity in mobile, flexible forms of capital, consistent with a shift toward digitally integrated operations and increased logistical reach.

4.3 Impact on International Trade

We now examine whether broadband adoption facilitates firms' participation in international markets. Access to high-speed internet may reduce information frictions, enable faster and more reliable communication with international buyers and suppliers, and allow firms to coordinate production, logistics, and payments across borders. These effects are particularly relevant in settings where infrastructure gaps or high trade costs impede market integration.

Table 6 presents estimates of broadband's impact on international trade, focusing on both the extensive and intensive margins. The extensive margin is captured by binary indicators for whether a firm engages in any international trade, exports, or imports. The intensive margin is measured by the share of exports in total sales and the share of

Table 6: Impact on International Trade

	1(Trader)		1(Exporter)		1(Importer)		X Share		M Share	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1(Broadband)	0.01***	0.09	0.01***	0.12**	0.01	0.03	0.01***	0.10**	0.00	0.00
	(0.00)	(0.05)	(0.00)	(0.05)	(0.00)	(0.05)	(0.00)	(0.05)	(0.00)	(0.02)
Control Mean	0.24	0.24	0.19	0.19	0.14	0.14	0.18	0.18	0.05	0.05
N	92816	92816	92816	92816	92816	92816	92816	92816	92816	92816
No. of firms	11092	11092	11092	11092	11092	11092	11092	11092	11092	11092
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables in Columns (1)-(6) are binary variables that take the value 1 if a firm reports any international trade (Columns 1-2), exports (Columns 3-4), and imports (Columns 5-6). Columns (7)-(8) report the share of exports in total sales, while Columns (9)-(10) report the share of imports in total cost or raw materials. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

imports in total costs.[7] The results imply a significant transformation in the probability and value from international trade. For example, broadband adoption increases the probability of having any international trade by 8 p.p. (Column 2). This is primarily driven by export-behavior: the probability of being an exporter increases by 11 p.p. and exports as a share of sales increase by 10 p.p. (Columns 4 and 8). In contrast, there is little change in import behavior (Columns 6 and 10).

This asymmetric impact is consistent with broadband lowering fixed costs of demand-side market access—for example, enabling firms to identify and reach foreign customers, operate websites, receive online orders, and transact digitally. These mechanisms are supported by the results we will discuss in in Section 5, where we show that broadband adoption increases the likelihood that firms participate in e-commerce, use websites to engage customers, and send or receive online orders.

Taken together, the results indicate that broadband adoption not only enhances productivity and scale, but also enables firms to expand their commercial footprint through international trade. These gains appear concentrated on the export margin, consistent with broadband reducing the fixed costs of foreign market entry and facilitating digital channels of engagement. This complements the interpretation from Section 4.1, where

[7]We set the share of exports and imports to zero for firms that are non-exporters and non-importers respectively.

Table 7: Impact on Firm Expenses

	Materials		Communication		Transportation	
	(1)	(2)	(3)	(4)	(5)	(6)
1(Broadband)	2.04***	28.45***	0.01***	0.06*	0.10***	2.06***
	(0.53)	(8.06)	(0.00)	(0.03)	(0.03)	(0.53)
Control Mean	23.80	23.80	0.20	0.20	1.13	1.13
Annualized $\triangle Y$		0.20		0.05		0.30
N	87356	87356	87356	87356	87356	87356
No. of firms	10690	10690	10690	10690	10690	10690
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are reported in thousands of real 2010 Colombian pesos and windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

broadband functions as a scalable general-purpose input that enables firms to expand not just in size, but also in market scope.

4.4 Material, Communication and Transportation Expenses

On a more aggregate level within the firm, we examine changes in firm expenses along three key dimensions, namely: materials, transportation, and communication services. As reported in Table 7, these increase by 19%, 6%, and 26% respectively each year after the adoption of broadband internet. Put together, these patterns are suggestive of broadband reducing communication costs, thus allowing firms to increase their logistical and supplier networks and operate at larger scale. We will show more evidence on these margins in subsequent sections. Lastly, the fact that real value added increases (in Table 2) alongside input costs suggests that adoption enables more than cost pass-through: it reflects real productivity gains and more operational efficiency, something that we confirm in Appendix Table A1, where we consistently find a 0.1σ increase in firm TFP that is estimated using various methods in the literature (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Wooldridge, 2009).

These results complement earlier findings on expansion in export markets. In particu-

lar, the increase in freight and transportation expenses (Table 7 and Appendix Table A3) are consistent with the growth in export activity: firms that access new markets likely incur higher logistical costs. The increase in export shares, rather than levels alone, also suggests a shift in firm orientation toward outward-facing production. Importantly, the fact that import behavior does not change in comparable magnitude reinforces the interpretation that broadband enables market expansion—rather than merely substituting offline with online sourcing.

5 How Do Firms Use Broadband Internet?

In the following section, we turn to direct evidence on some of these mechanisms, documenting changes in how firms adopt digital tools for market expansion; employee hiring, training, and management; as well as operational efficiency through digital communication. We turn to a range of complementary outcomes that trace how firms integrate digital technologies into operations, customer relationships, and organizational practices. While the preceding sections show that broadband adoption improves firm performance, trade activity, and alters the composition of key inputs, it remains an open question on *how* these gains materialize operationally within the firm. This section addresses that question directly.

Usage of Computers: Table 8 shows that broadband adoption increases the expenditure and usage of computers within a firm. This is perhaps unsurprising, but provides a useful consistency check. From Column (2), we see a 11% annual increase in the computer expenditure of a firm, with a 6-7 p.p. increase in the fraction of workers in a firm that either use computers (Column 4), or the internet (Column 6) for their work-related activities.

Table 9 then examines *how* firms use the internet and reports the effects of broadband adoption on a wide range of digital practices. Each outcome variable in this table is a binary variable that takes the value 1 after a firm first reports using the internet for the activity of interest, and is 0 otherwise.

Table 8: Impact on Computer Usage and Expenditure

	Comp. Exptd.		Comp. Usage		Internet Usage	
	(1)	(2)	(3)	(4)	(5)	(6)
1(Broadband)	0.07***	0.53***	0.02***	0.06**	0.02***	0.05*
	(0.01)	(0.17)	(0.00)	(0.03)	(0.00)	(0.03)
Control Mean	0.63	0.63	0.32	0.32	0.29	0.29
Annualized $\triangle Y$		0.14				
N	90611	90611	85086	85086	85086	85086
No. of firms	10947	10947	10991	10991	10991	10991
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variable in Column (1) is the expenditure on computers in 2010 Colombian pesos. We windsorize it at the 95th percentile. Columns (3)-(4) and (5)-(6) report the fraction of workers in a firm that use computers and the internet for their work respectively. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Online Information and Transactions: Panel A focuses on information acquisition and online transactions. Broadband adoption increases the likelihood that firms report using the internet to gather information from government agencies by 8 p.p. (Column 6). In contrast, adopting broadband has no increase in use of the internet for online government, banking and financial transactions (Columns 2 and 8), as well as searching for information on goods and services (Column 4). This is perhaps unsurprising given the high baseline usage (75-90%) of these activities anyway prior to broadband adoption.

Online Service and Sales: Panel B shifts to external-facing commercial practices. Adopting broadband increases the probability of having a firm website by 14 p.p. (Column 2), sending or receiving online orders by 8 p.p. (Column 6), and participating in e-commerce related activities by 15 p.p. (Column 8). There is no impact on the probability that firms offer online customer support (Column 4). These outcomes suggest that broadband enables firms to adopt digital interfaces for customer engagement and commercial transactions. The increase in having a website as well as e-commerce usage points to a transition to more digitally mediated client relationships. These results

Table 9: Usage of Internet for Information and Online Firm Services

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Online Information (N = 85,619; Firms = 11,005)								
	Banking		Search Info.		Govt. Info.		Govt. Transact.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	0.01**	-0.04	0.00	-0.03	0.05***	0.06	0.03***	0.03
	(0.00)	(0.03)	(0.00)	(0.03)	(0.00)	(0.05)	(0.00)	(0.05)
Control Mean	0.89	0.89	0.93	0.93	0.60	0.60	0.74	0.74
Panel B: Online Service and Sales (N = 85,619; Firms = 11,005)								
	Website		Customer Service		Send/Receive Orders		E-Commerce	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	0.03***	0.12**	0.03***	0.05	0.02***	0.10**	0.02***	0.07
	(0.00)	(0.05)	(0.00)	(0.05)	(0.00)	(0.05)	(0.01)	(0.07)
Control Mean	0.57	0.57	0.77	0.77	0.77	0.77	0.41	0.41
Panel C: Internal Firm Operations (N = 57,946; Firms = 9,746)								
	Hiring		Training		Use Apps		Use VOIP	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	0.06***	0.16**	0.07***	0.13*	0.09***	0.07	0.07***	0.20***
	(0.01)	(0.07)	(0.01)	(0.08)	(0.01)	(0.08)	(0.01)	(0.07)
Control Mean	0.26	0.26	0.39	0.39	0.59	0.59	0.36	0.36
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: All outcome variables in the above table are binary variables that take the value 1 for all years after a firm first reports using the internet for that activity, and 0 otherwise. In Panel A, the outcome variables are whether a firm uses the internet: (i) for electronic banking or online financial services (Columns 1-2); (ii) to search for information on goods and services (Columns 3-4); (iii) to search for information from (Columns 5-6) or transact with government agencies (Columns 7-8). In Panel B, the outcome variables are whether a firm has: (i) a website (Columns 1-2); (ii) online customer support (Columns 3-4); (iii) sends or receives online orders (Columns 5-6); (iv) participates in e-commerce (Columns 7-8). In Panel C, the outcome variables are whether a firm uses the internet for: (i) hiring and training workers (Columns 1-4); (ii) uses applications that need the internet (Columns 5-6); (iii) uses VoIP phone or video facilities (Columns 7-8). The sample size is smaller for e-Commerce and all variables in Panel C since they were only included in surveys from 2012 onwards. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

reinforce the evidence from prior sections on expanded participation in international trade, along with higher expenditure on transport and communication.

Internal Firm Operations: Panel C then examines the impact on internal organizational practices. Broadband adoption increases the likelihood of online hiring by 15 p.p. (Column 2), employee training by 12 p.p. (Column 4), and usage of workflow VoIP tools (like video conferencing facilities, for example) by 23 p.p. (Column 8). These patterns suggest a transition towards more digitally coordinated internal structure, allowing firms to dynamically hire and train larger workforces without proportional increases in professional, managerial, and administrative staff (Section 4.2).

Summary of Results: Taken together, these results show that broadband adoption induces widespread digitization of firm practices, both externally (through websites, customer engagement, and e-commerce) and internally (through hiring, training, and communication). These behavioral changes complement and help explain compositional changes in the structure of costs and inputs, along with the resulting improvements in firm performance documented in earlier sections. Our results suggest that broadband internet can be a *scale-biased* technology, operating through multiple channels that lowers firms' costs of internal and external operations, allowing them to access new markets, workers, and capital, to scale their operations.

6 Theoretical Model

6.1 Consumer Preferences and Demand

Consumers have Cobb-Douglas utility over two sectors manufacturing and non-manufacturing, $j = \{m, n\}$, given by:

$$U = \prod C_j^{\beta_j}, \quad \sum_j \beta_j = 1$$

Within manufacturing, products are imperfect substitutes across firms. Utility is given by a Dixit-Stiglitz CES preferences given by:

$$C_m = \left(\int_{i \in \Omega} q_i^{\frac{\sigma_d}{1+\sigma_d}} di \right)^{\frac{1+\sigma_d}{\sigma_d}}, \quad \sigma_d > 0$$

Given total income I, price indices $\{P_n, P_m\}$, utility maximization implies that:

$$P_j C_j = \beta_j \cdot I \qquad \text{(Exptd. on sector } j\text{)}$$

$$p_i q_i = \left(\frac{p_i}{P_m}\right)^{-\sigma_d} \cdot \underbrace{\beta_m I}_{=P_m C_m} \qquad \text{(Exptd. on product } i\text{)}$$

where P_m is the standard CES price index, given by $P_m = \left(\int_{i\in\Omega} p_i^{-\sigma_d}\, di\right)^{\frac{-1}{\sigma_d}}$

6.2 Firm Production

Firm production consists of inputs used in production (capital and labor) those in managerial productivity of the firm (such as ICT capital and managerial workers). Output is given by the Cobb-Douglas production function: $Y = z_A^{\alpha_Z} M^{\alpha_M}$. z_A is the managerial (or organizational) productivity of the firm (defined below). M is a CES composite of inputs used in production, namely: capital (K_p) and labor (L_p), with an elasticity of substitution σ_m. Furthermore, production workers (L_p) are also a CES composite of payroll (s) and contract (c) workers with an elasticity of substitution σ_l. Organizational productivity of the firm consists of two components: an exogenous productivity (z); and endogenous managerial productivity Z_A, which is a CES composite of managerial workers L_a and ICT capital K_a with an elasticity of substitution given by σ_z and relative productivity of ICT capital θ_{K_a} i.e., $Z_a = z \cdot \left[\theta_{K_a}^{\frac{1}{1+\sigma_m}} K_a^{\frac{\sigma_m}{1+\sigma_m}} + L_a^{\frac{\sigma_m}{1+\sigma_m}}\right]^{\frac{1+\sigma_m}{\sigma_m}}$.

Capital (both for administrative and production purposes) can be rented at a marginal cost r, which is determined endogenously in equilibrium. Workers are paid a wage w, but firms incur an additional marginal cost (λ_l) for hiring them. These could reflect, for example, matching frictions in the labor market. Within production workers, across the type of contract, firms incur relative costs λ_s in hiring salaried workers relative contract ones. Therefore, the marginal cost of hiring managerial, payroll, and contract workers respectively are given by: $\{w_a, w_s, w_c\} = \{\lambda_l w, \lambda_l w, \lambda_c \lambda_l w\}$.

Let $X(z) = \lambda_x p Y$ be the revenues of a firm, where λ_x could capture costs related to market access. Given the above setup, a firm with (exogenous) productivity z chooses

inputs $\{L_s, L_c, L_a, K_a, K_p\}$ to maximize profits, given by:

$$\begin{aligned}
\pi(z) = \max \quad & X(z) - \sum_{o\in\{a,s,c\}} w_o L_o - \sum_{o\in\{a,p\}} r_o K_o \\
\text{s.t.} \quad & Y = Z_A^{\alpha_z} M^{\alpha_M} && \text{(Production Function)} \\
& pY = \left(\frac{p}{P_m}\right)^{-\sigma_d} \cdot P_m C_m && \text{(Demand)}
\end{aligned}$$

where M is a composite of labor and capital inputs in production, and Z_A is a composite of firm productivity z, along with ICT capital and managerial workers.

Proposition 1. *Given the structure of firm production, the optimal choice for an inputs $M_x = \{Z_A, M\}$ for a firm with productivity $\widetilde{z}$ $(= z^{\alpha_Z})$ will be given by:*

$$\begin{aligned}
p_x M_x^*(\widetilde{z}) &= \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_x X(\widetilde{z}) && \textit{(Inputs)} \\
Y(\widetilde{z}) &= \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m}\right]^{1+\sigma_d} \cdot C_m && \textit{(Output)} \\
p(\widetilde{z}) &= \frac{1+\sigma_d}{\lambda_x \sigma_d} \cdot \frac{MC}{\widetilde{z}} && \textit{(Prices)} \\
X(\widetilde{z}) &= \Psi \cdot \widetilde{z}^{\sigma_d} && \textit{(Revenues)} \\
\pi^*(\widetilde{z}) &= \frac{X(\widetilde{z})}{1+\sigma_d} = \frac{\Psi}{1+\sigma_d} \cdot \widetilde{z}^{\sigma_d} && \textit{(Profits)}
\end{aligned} \tag{3}$$

where: (i) $MC = \prod_x (p_x/\alpha_x)^{\alpha_x}$ is the marginal cost index for inputs $x = \{Z_A, M\}$; and (ii) $\Psi = \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{1}{MC/P_m}\right]^{\sigma_d} \cdot \lambda_x P_m C_m$, is the revenue per unit productivity.

See Appendix B.2.1 for the proof.

Corollary 1.1. *Given Proposition 1, the expenditure on: (i) capital and labor used in production; (ii) ICT capital and managerial workers in administrative productivity; and (iii) payroll and contract workers, will be given by:*

$$\begin{aligned}
w_p L_p &= \left(\frac{w_p}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z}) \quad \textit{and} \quad r K_p = \left(\frac{r}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z}) \\
w_a L_a &= \left(\frac{w_a}{p_z}\right)^{-\sigma_z} \cdot p_z Z_A^*(\widetilde{z}) \quad \textit{and} \quad r K_a = \theta_{K_a} \left(\frac{r}{p_z}\right)^{-\sigma_z} \cdot p_z Z_A^*(\widetilde{z}) \\
w_s L_s &= \left(\frac{w_s}{w_p}\right)^{-\sigma_l} \cdot w_p L_p^*(\widetilde{z}) \quad \textit{and} \quad w_c L_c = \left(\frac{w_c}{w_p}\right)^{-\sigma_l} \cdot w_p L_p^*(\widetilde{z})
\end{aligned} \tag{4}$$

where: $p_M = \left(p_z^{-\sigma_m} + p_M^{-\sigma_m}\right)^{\frac{-1}{\sigma_m}}$ *is the composite price index of inputs;* $p_z = (w_a^{-\sigma_z} + \theta_{K_a} k_a^{-\sigma_z})^{\frac{-1}{\sigma_z}}$ *is the composite price index of administrative productivity; and (iii)* $w_p = (w_s^{-\sigma_l} + w_c^{-\sigma_l})^{\frac{-1}{\sigma_l}}$ *is the composite price index of production workers.*

See Appendix B.2.2, B.2.3, and B.2.4 for the mathematical proofs.

6.3 Firm Entry and Broadband Adoption

Impact of Broadband Adoption: Broadband adoption can transform the structure of production within the firm, which includes frictions that the firm faces in hiring workers, or access to markets, etc. Firms that adopt broadband experience reductions in several types of distortions: demand frictions (λ_x), hiring frictions (λ_l), costs for contracting workers (λ_c), and increases in the relative productivity of ICT capital (θ_{K_a}). These changes in turn affect the firm's marginal cost (MC), and therefore firm production.

From Proposition 1, this implies that the profit earned *conditional* on productivity for non-adopters (Ψ_0) and adopters (Ψ_1) respectively are different, such that their ratio is given by: $\left(\lambda_x^{(1)}/\lambda_x^{(0)}\right)^{1+\sigma_d} \cdot \left(MC^{(1)}/MC^{(0)}\right)^{-\sigma_d}$. This expression shows that broadband adoption improves profitability through two channels: changes in frictions related to market access (captured by λ_x), and a reduction in marginal cost MC (captured through λ_l, λ_c, etc). Let F_b be a fixed cost of adopting broadband (denoted in units of the manufacturing good). This implies a threshold productivity z_b, above which a firm adopts broadband, given by:

$$z_b^{\gamma} = \frac{(1+\sigma_d)F_b}{\Psi_1 - \Psi_0} \tag{5}$$

where $\gamma = \alpha_z \sigma_d$. See Appendix B.2.6 for the proof.

Firm Entry: We now examine a firm's entry decision. Assume a potential set of entrants, whose mass is normalized to 1. Similar to Melitz (2003), firms pay an entry cost F_e and draw a productivity $z \sim F(z)$. This defines a threshold productivity z_e above which entry is profitable in expectation i.e., $E(\pi(z)|z > z_e) - F_e \geq 0$. This in

turn implies that firms with $z \in (z_e, z_b)$ enter but do not adopt broadband, while those with $z \geq z_b^*$ adopt. We assume that firm productivity follows a Pareto distribution with shape parameter $\theta > \gamma$, so that $F(z) = 1 - z^{-\theta}$. This allows to generate analytical expressions that characterize entry and adoption, which then helps in aggregating key firm outcomes in equilibrium. The entry threshold (z_e) can be characterized by:

$$z_e^{\gamma} = \frac{(1-\widetilde{\theta})(1+\sigma_d)(F_e + \xi F_b)}{\hat{\Psi}} \tag{6}$$

where: $\widetilde{\theta} = \gamma/\theta < 1$; $\xi = (z_b/z_e)^{-\theta}$; and $\hat{\Psi}$ is weighted average of Ψ_j defined later in Equation (8). See Appendix B.2.6 for the mathematical proof. Equation (6) has an intuitive meaning. First, note that it is directly proportional to the fixed costs of entry and adoption and inversely proportional to the sales per unit productivity. This implies, for example, that the entry thresholds are lower when sales per unit productivity are higher. Also note that since $1 - F(z_x) = z_x^{-\theta}$, ξ denotes the share of *entrants* who adopt broadband (and hence pay the adoption costs F_b).

6.4 Aggregation in Equilibrium

We consider the representative household that supplies one unit of labor inelastically and owns all firms and capital in the economy. The non-manufacturing sector (e.g., agriculture or services) is perfectly competitive, produces a numeraire good with linear technology, and determines the equilibrium factor prices (w and r). We assume that the distortions faced by firms in hiring and monitoring workers, accessing new markets (λ_l, λ_m, λ_x, etc.), etc., are redistributed back to the household and hence, fully accounted for in aggregate income.[8]

Manufacturing Price Index: The aggregate price index in manufacturing, P_m is a weighted average of prices across firms active in the market and can be given by: $P_m = \left[\int_{z_e} p(z)^{-\sigma_d} dG(z)\right]^{\frac{1}{-\sigma_d}}$. Aggregating over both adopters and non-adopters, the

[8]For example, they may be interpreted as payments to intermediaries, managers, or specialized service providers (e.g., recruiters, supervisory staff) that ultimately belong to or are owned by households. In other words, we include all wedge-inclusive payments in aggregate income. No income is lost due to these frictions and therefore cannot mechanically impact aggregate welfare in counterfactual simulations.

aggregate price index in manufacturing can be given by:

$$P_m = \left(\frac{1}{1-\widetilde{\theta}}\right)^{\frac{-1}{\sigma_d}} \cdot \left(\frac{1+\sigma_d}{\sigma_d}\right) \cdot \frac{\widetilde{\nu}}{z_e} \tag{7}$$

where: $\widetilde{\nu} = \left[(1-\xi^{\widetilde{\theta}-1})\nu_0^{1-\sigma_d} + \xi^{\widetilde{\theta}-1}\nu_1^{1-\sigma_d}\right]^{\frac{1}{1-\sigma_d}}$ and $\nu_j = MC_j/\lambda_{xj}$ for adopters ($j=1$) and non-adopters ($j=0$) respectively. See proof in Appendix B.2.7. Intuitively, the price index is a markup over the marginal cost of the average firm ($\widetilde{\nu}$) scaled by the total productivity in the economy.

Aggregate TFP and Sales: For any variable X (sales, labor, etc.), define $\hat{X}$ as the aggregate value in the economy. Define aggregate productivity (TFP) of non-adopting and adopting firms as $\hat{Z} = \int_{z_e} z^\gamma dG(z) = \frac{1}{1-\widetilde{\theta}} z_e^{\gamma-\theta}$. Moreover, since $X_j(z) = \Psi_j \cdot z^\gamma$, aggregate sales are given by:

$$\hat{X} = = \hat{\Psi} \cdot \frac{1}{1-\widetilde{\theta}} z_e^{\gamma-\theta} \quad \text{, where: } \hat{\Psi} = (1-\xi^{\widetilde{\theta}-1})\Psi_0 + \xi^{\widetilde{\theta}-1}\Psi_1 \tag{8}$$

Appendix B.2.8 provides the proof. Intuitively, recall that ξ are the fraction of broadband adopters in the economy. Therefore, aggregate sales are an average of sales per-unit of productivity (Ψ_j), weighted by the proportion of adopters and non-adopters, and scaled up by the mass of firms.

Aggregate Demand for Factor Inputs: Aggregate manufacturing labor demanded ($\hat{L}_m$) is equal to the sum of different types of labor $\hat{L}_a + \hat{L}_s + \hat{L}_c$, with their corresponding optimal expressions given in Corollary 1.1. Similarly, capital demanded ($\hat{K}_m$) is the total of ICT and production capital. Aggregating over all firms, these can be expressed as:

$$\hat{L}_m = \frac{\sigma_d - 1}{\sigma_d} \cdot \Psi_L \cdot \hat{X}, \qquad \hat{K}_m = \frac{\sigma_d - 1}{\sigma_d} \cdot \Psi_K \cdot \hat{X}$$

$$\text{where: } \hat{\Psi}_L = (1-\xi^{\widetilde{\theta}-1})\Psi_{L0} + \xi^{\widetilde{\theta}-1}\Psi_{L1}, \qquad \hat{\Psi}_K = (1-\xi^{\widetilde{\theta}-1})\Psi_{K0} + \xi^{\widetilde{\theta}-1}\Psi_{K1}$$

$$\Psi_{Lj} = \frac{\alpha_M \sum_o w_{oj}^{-(1+\sigma_l)}}{w_{pj}^{-\sigma_l}} \left(\frac{w_{pj}}{p_{Mj}}\right)^{-\sigma_m} + \frac{\alpha_Z w_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}}, \qquad \Psi_{Kj} = \frac{\alpha_M r^{-(1+\sigma_m)}}{p_{Mj}^{-\sigma_m}} + \frac{\alpha_Z \theta_{Ka} r^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}} \tag{9}$$

See Appendix B.2.8 for the proof.

Non-Manufacturing Sector: We assume a representative firm in the non-manufacturing sector, which is the numeraire good. It uses labor L_n and capital K_n to produce output given by: $Y_n = A_n L_n^{\alpha_L} K_n^{\alpha_K}$, where $\alpha_L + \alpha_K = 1$. This implies that the expenditure on labor and capital is given by: $wL_n = \alpha_L(1-\beta_m)\hat{I}$ and $rK_n = \alpha_K(1-\beta_m)\hat{I}$.

Aggregate Factor Prices and Income: The total income generated in the economy is equal to the factor payments in the manufacturing and non-manufacturing sectors i.e., $\hat{I} = I_n + I_m$. From the above, note that $I_n = (1-\beta_m)\hat{I}$. Simplifying, this implies $\hat{I} = I_m/\beta_m$. Within manufacturing, from Proposition (1), factor payments are equal to $\hat{I} = \frac{\sigma_d}{1+\sigma_d} \cdot \frac{\hat{X}}{\beta_m}$. Turning to wages ($w$) and rental rates ($r$), note that in the non-manufacturing sector, $\{w, r\} = \{\frac{\alpha_L}{L_n}, \frac{\alpha_K}{K_n}\} \cdot (1-\beta_m)\hat{I}$, where $L_n = 1 - \hat{L}_m$ and $K_n = 1 - \hat{K}_m$. Putting it together, the equilibrium factor prices will be given by:

$$w = \frac{1-\beta_m}{\beta_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_L \frac{\hat{X}}{1-\hat{L}_m}, \qquad r = \frac{1-\beta_m}{\beta_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_K \frac{\hat{X}}{1-\hat{K}_m} \tag{10}$$

Equilibrium: An equilibrium in this economy consists of productivity thresholds for entry and broadband adoption, a set of factor and goods prices in both sectors (wage, rental rate, etc.), and an allocation of labor and capital across sectors, such that: (i) the productivity thresholds for firm entry and broadband adoption $\{z_e, z_b\}$ are determined by Equations (5) and (6); (ii) firms optimize input choices as in Proposition 1; (iii) the manufacturing price index aggregates firm-level prices over the endogenous distribution of producers, given by Equation (7); and (iv) factor markets clear such that the total labor and capital demand across manufacturing and non-manufacturing sectors equal to their supply as determined by Equation (10).

7 Quantifying the Impact of Broadband Adoption

With the above modeling structure, we can now examine the impact of broadband adoption on firms' entry and production decisions. In particular, assume that firms

incur a fixed cost F_b in broadband adoption, so that the fixed cost of entry is now given by $F_e' = F_e + F_b$. However, broadband also raises the operational efficiency of firms in four ways: (i) it reduces the marginal cost of accessing consumers (λ_x); (ii) reduces matching frictions in hiring workers (λ_l); (iii) reduces monitoring costs for contract workers (λ_m); and (iv) raises the relative productivity of ICT capital in enhancing administrative work. Many of these channels directly link to the empirical results discussed in previous sections, however, a key insight from the model is to show that they can impact firms in complex, inter-dependent ways. For example, Corollary 1.1 indicates that the ratio of ICT capital to administrative workers is directly related to θ_z and inversely related to λ_l. The former increases with broadband adoption, driving firms to adopt more ICT capital, while the latter decreases, incentivizing firms to hire more administrative workers instead.In addition, there could be indirect wage effects through general equilibrium, making the overall impact ambiguous.

References

Akerman, Anders, Ingvil Gaarder, and Magne Mogstad, "The Skill Complementarity of Broadband Internet," *Quarterly Journal of Economics*, 2015, *130* (4), 1781–1824.

Autor, David H., Frank Levy, and Richard J. Murnane, "The Skill Content of Recent Technological Change: An Empirical Exploration," *Quarterly Journal of Economics*, 2003, *118* (4), 1279–1333.

Bartik, Alexander W., Zoë B. Cullen, and Christopher T. Stanton, "Using Machine Learning to Understand Employer Expectations and Hiring Decisions," *Quarterly Journal of Economics*, 2023, *138* (3), 1563–1615.

Bhuller, Manudeep, Domenico Ferraro, Andreas R Kostøl, and Trond C Vigtel, "The internet, search frictions and aggregate unemployment," Technical Report, National Bureau of Economic Research 2023.

Bloom, Nicholas, Christos Genakos, Raffaella Sadun, and John Van Reenen, "Management practices across firms and countries," *Academy of management perspectives*, 2012, *26* (1), 12–33.

_ , Luis Garicano, Raffaella Sadun, and John Van Reenen, "Information Technology and the Diffusion of Management Practices," *American Economic Review*, 2014, *104* (1), 244–278.

Bresnahan, Timothy F and Manuel Trajtenberg, "General purpose technologies 'Engines of growth'?," *Journal of Econometrics*, 1995, *65*, 83–108.

Cariolle, Joel, Maëlan Le Goff, and Olivier Santoni, "Broadband infrastructure deployment, digital vulnerability, and local firm performance in developing and transition countries," *Ferdi Working Paper*, 2018.

DeStefano, Timothy, Richard Kneller, and Jonathan Timmis, "The (fuzzy) digital divide: the effect of universal broadband on firm performance," *Journal of Economic Geography*, 2023, *23* (1), 139–177.

Dube, Arindrajit, Daniele Girardi, Oscar Jorda, and Alan M Taylor, "A local projections approach to difference-in-differences event studies," Technical Report, National Bureau of Economic Research Cambridge, Massachusetts 2023.

Hjort, Jonas and Jonas Poulsen, "The arrival of fast internet and employment in Africa," *American Economic Review*, 2019, *109* (3), 1032–1079.

_ and Lin Tian, "The economic impact of internet connectivity in developing countries," *Annual Review of Economics*, 2021, *17*.

Levinsohn, James and Amil Petrin, "Estimating production functions using inputs to control for unobservables," *The review of economic studies*, 2003, *70* (2), 317–341.

Malgouyres, Clément, Thierry Mayer, and Clément Mazet-Sonilhac, "Technology-induced trade shocks? Evidence from broadband expansion in France," 2019.

Melitz, Marc J, "The impact of trade on intra-industry reallocations and aggregate industry productivity," *econometrica*, 2003, *71* (6), 1695–1725.

Olley, G Steven and Ariel Pakes, "The Dynamics of Productivity in the Telecommunications Equipment Industry," *Econometrica: Journal of the Econometric Society*, 1996, pp. 1263–1297.

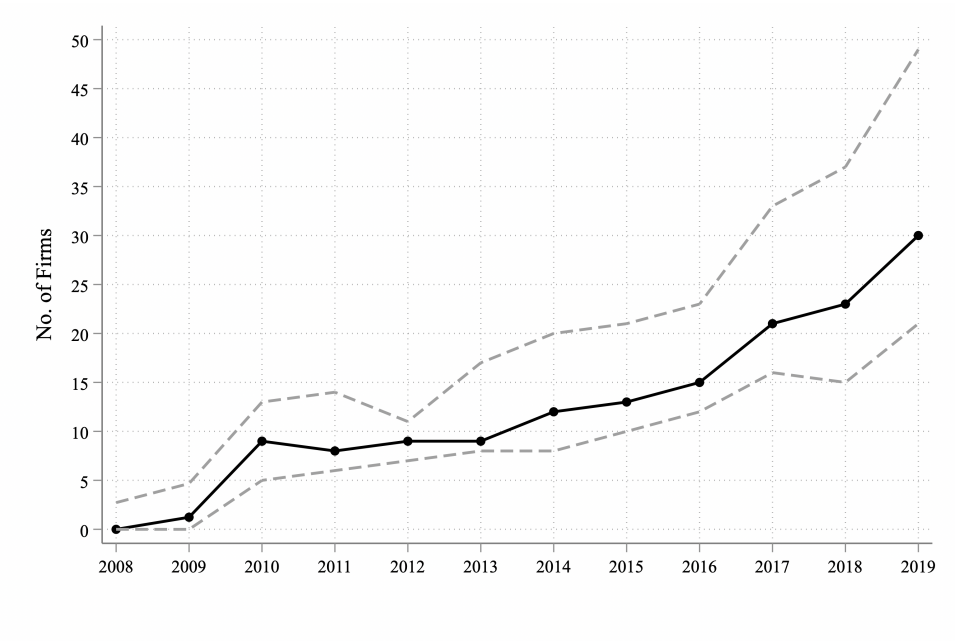
Paunov, Caroline and Valentina Rollo, "Overcoming obstacles: the internet's contribution to firm development," *The World Bank Economic Review*, 2015, *29* (suppl_1), S192–S204.

Sun, Liyang and Sarah Abraham, "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects," *Journal of econometrics*, 2021, *225* (2), 175–199.

Wooldridge, Jeffrey M, "On estimating firm-level production functions using proxy variables to control for unobservables," *Economics letters*, 2009, *104* (3), 112–114.

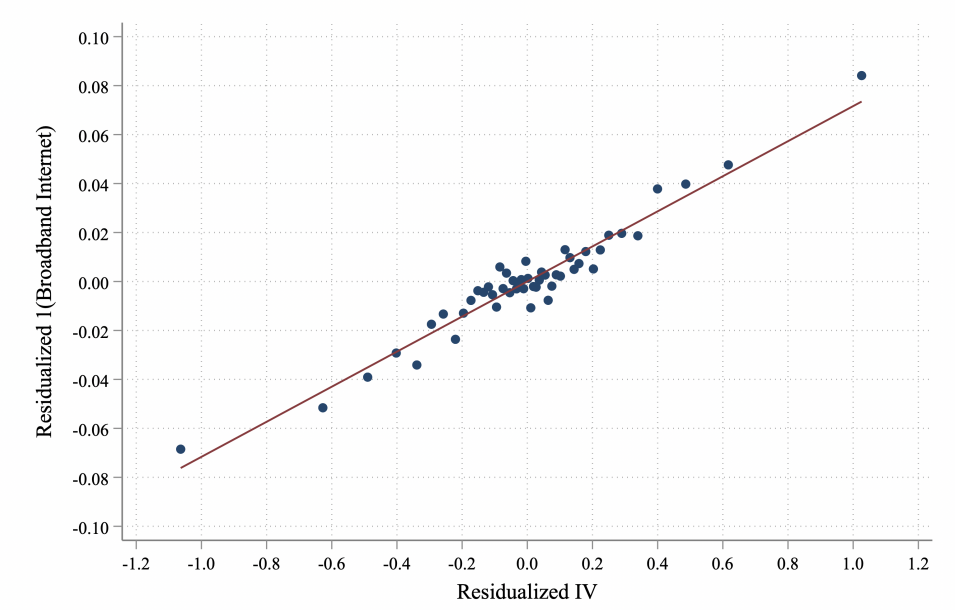
A Tables and Figures

Figure A1: Variation in Broadband Providers Across Departments in Colombia



Notes: The above figure plots the median number of broadband service providers in a Colombian department (region) between 2008-2019. The 90-10 percentile bands are reported in dotted lines.

Figure A2: First Stage Relationship



Notes: The above figure plots the relationship between the residualized instrument (on the horizontal axis) and residualized adoption of broadband variable, $\mathbb{1}(\text{Broadband Internet})_{it}$ after accounting for firm, industry-year, and region-year fixed effects.

Table A1: Impact on TFP

	Levinsohn-Petrin		Olley Pakes		Wooldridge		Average	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	-0.01	0.20***	-0.01	0.20***	-0.01	0.26***	-0.01	0.22***
	(0.01)	(0.07)	(0.01)	(0.07)	(0.01)	(0.09)	(0.01)	(0.07)
Control Mean	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
N	91382	91382	91382	91382	91382	91382	91382	91382
No. of firms	10958	10958	10958	10958	10958	10958	10958	10958
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The above table estimates TFP using a production function estimation approach by Levinsohn and Petrin (2003) (Column 1-2), Olley and Pakes (1996) (Columns 3-4), and Wooldridge (2009) (Columns 5-6). All TFP estimates are normalized to have mean 0 and standard deviation 1. All regressions include firm, region-year and 2-digit industry-year fixed effects. $X_{it} = 1(\text{Broadband})_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A2: Impact on Communication Expenses

	1(Admin.)		1(Production)		Admin.		Production	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	0.00	0.08**	-0.00	0.07	0.01***	0.06**	0.00*	-0.01
	(0.00)	(0.04)	(0.01)	(0.07)	(0.00)	(0.03)	(0.00)	(0.01)
Control Mean	0.92	0.92	0.49	0.49	0.16	0.16	0.03	0.03
Annualized $\triangle Y$						0.06		-0.04
N	87356	87356	87356	87356	87125	87125	86029	86029
No. of firms	10690	10690	10690	10690	10669	10669	10605	10605
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variable in Columns (1)-(4) is a binary variable if a firm reports any communication expenses incurred for managers and administrative work (Columns 1-2) and production activities (Columns 3-4). Columns (5)-(8) report the corresponding expenses in real 2010 Colombian pesos and have been windsorized at the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. $1(\text{Broadband})_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A3: Impact on Transportation Expenses

	1(Inputs)		1(Ouput)		Inputs		Output	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Broadband)	0.01	0.06	0.01**	0.09	0.01**	0.10	0.04	1.37***
	(0.01)	(0.07)	(0.01)	(0.06)	(0.01)	(0.09)	(0.03)	(0.40)
Control Mean	0.40	0.40	0.65	0.65	0.14	0.14	0.83	0.83
Annualized $\triangle Y$						0.11		0.27
N	87356	87356	87356	87356	85561	85561	87077	87077
No. of firms	10690	10690	10690	10690	10590	10590	10675	10675
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variable in Columns (1)-(4) is a binary variable if a firm reports any transportation expenses incurred for inputs and raw materials (Columns 1-2), and output and sales (Columns 3-4). Columns (5)-(8) report the corresponding expenses in real 2010 Colombian pesos and have been windsorized at the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference in the outcome variable relative to the control mean. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A4: Impact on Managerial Worker Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	0.43***	0.38	0.12*	1.36*	0.23***	-0.14
	(0.11)	(1.39)	(0.07)	(0.72)	(0.05)	(0.54)
Annualized $\triangle Y$		0.06		0.23		-0.02
Panel B: Conditional on L						
1(Broadband)	0.10	-2.62**	0.02	0.47	0.15***	-0.83
	(0.10)	(1.09)	(0.06)	(0.69)	(0.05)	(0.52)
L	0.16***	0.16***	0.05***	0.05***	0.04***	0.04***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Control Mean	5.99	5.99	1.81	1.81	0.80	0.80
Annualized $\triangle Y$		-0.44		0.08		-0.14
N	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806	10806	10806	10806	10806
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are total managerial and administrative workers in a firm on permanent, salaried contracts (Columns 1-2), on temporary contracts hired directly by the firm (Columns 3-4), and on temporary contracts hired through third-party intermediaries (Columns 5-6). Panel A reports the unconditional regression, while Panel B controls for the total firm size (L). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A5: Impact on Professional Worker and Technician Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	0.07	-1.90*	0.04	0.54	0.02	-0.11
	(0.07)	(1.11)	(0.03)	(0.38)	(0.02)	(0.25)
Annualized $\triangle Y$		-0.32		0.09		-0.02
Panel B: Conditional on L						
1(Broadband)	-0.08	-3.29***	-0.01	0.12	-0.00	-0.32
	(0.06)	(1.04)	(0.03)	(0.37)	(0.02)	(0.24)
L	0.08***	0.08***	0.02***	0.02***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Control Mean	1.75	1.75	0.61	0.61	0.20	0.20
Annualized $\triangle Y$		-0.55		0.02		-0.05
N	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806	10806	10806	10806	10806
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are total professional workers and technicians in a firm on permanent, salaried contracts (Columns 1-2), on temporary contracts hired directly by the firm (Columns 3-4), and on temporary contracts hired through third-party intermediaries (Columns 5-6). Panel A reports the unconditional regression, while Panel B controls for the total firm size (L). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A6: Impact on Production Worker Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	0.77***	7.64***	0.08	6.65***	0.26*	3.60**
	(0.21)	(2.44)	(0.18)	(1.80)	(0.15)	(1.77)
Annualized $\triangle Y$		1.27		1.11		0.60
Panel B: Conditional on L						
1(Broadband)	0.16	2.13	-0.25	3.66**	-0.09	0.49
	(0.18)	(1.94)	(0.17)	(1.67)	(0.14)	(1.56)
L	0.30***	0.30***	0.17***	0.16***	0.17***	0.17***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	12.42	12.42	6.24	6.24	3.77	3.77
Annualized $\triangle Y$		0.36		0.61		0.08
N	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806	10806	10806	10806	10806
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables are total production workers in a firm on permanent, salaried contracts (Columns 1-2), on temporary contracts hired directly by the firm (Columns 3-4), and on temporary contracts hired through third-party intermediaries (Columns 5-6). Panel A reports the unconditional regression, while Panel B controls for the total firm size (L). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A7: Impact on Wage Bill Across Worker Types

	Total		Managers		Prof./Tech.		Workers	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Unconditional								
1(Broadband)	0.29***	2.80***	0.13***	0.28	0.05***	0.19	0.18***	2.32***
	(0.06)	(0.73)	(0.03)	(0.34)	(0.01)	(0.17)	(0.05)	(0.62)
Annualized $\triangle Y$		0.09		0.03		0.06		0.11
Panel B: Conditional on wL								
1(Broadband)			0.03*	-0.64***	0.03**	-0.01	0.04	0.99**
			(0.02)	(0.24)	(0.01)	(0.16)	(0.04)	(0.48)
Real wL			0.33***	0.33***	0.07***	0.07***	0.48***	0.48***
			(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Control Mean	4.98	4.98	1.72	1.72	0.53	0.53	3.38	3.38
Annualized $\triangle Y$				-0.06		-0.00		0.05
N	87649	87649	87649	87649	87649	87649	87649	87649
No. of firms	10810	10810	10810	10810	10810	10810	10810	10810
Regression	OLS	IV	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variables is the total wage bill for a firm (Columns 1-2), along with the wage bill for managers (Columns 3-4), professional and technical workers (Columns 5-6), and production workers (Columns 7-8). Panel A reports the unconditional regression, while Panel B controls for the total wage bill of the firm (wL). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A8: Impact on Wage Bill Across Contractual Arrangements

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	0.16***	0.88*	0.02	0.74**	0.09***	0.35
	(0.04)	(0.49)	(0.03)	(0.35)	(0.03)	(0.35)
Annualized $\triangle Y$		0.05		0.11		0.07
Panel B: Conditional on wL						
1(Broadband)	0.05	-0.27	-0.03	0.24	0.03	-0.19
	(0.03)	(0.38)	(0.03)	(0.32)	(0.02)	(0.30)
Real wL	0.42***	0.42***	0.18***	0.18***	0.20***	0.20***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	2.81	2.81	1.18	1.18	0.79	0.79
Annualized $\triangle Y$		-0.02		0.03		-0.04
N	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806	10806	10806	10806	10806
Regression	OLS	2SLS	OLS	2SLS	OLS	2SLS

Notes: The outcome variable is the total wage bill for workers on permanent, salaried contracts (Columns 1-2), on temporary contracts hired directly by the firm (Columns 3-4), and on temporary contracts hired through third-party intermediaries (Columns 5-6). Panel A reports the unconditional regression, while Panel B controls for the total wage bill of the firm (wL). All outcome variables are windsorized at the the 95th percentile. All regressions include firm, region-year and 2-digit industry-year fixed effects. 1(Broadband)$_{it}$ that takes the value 1 for all years after which a firm i first reports using broadband internet and 0 otherwise. Control mean is the mean of the outcome variable for firms not using broadband internet. $\triangle Y$ is the annualized difference of the outcome variable relative to the control mean. Standard errors are clustered at the firm level. * is p<0.1 ** is p<0.05 and *** is p<0.01.

B Mathematical Proofs

B.1 Approximate Changes in Growth Rates

We provide a simple approximation to derive the change in the average growth rate for a variable of interest Y (e.g., real sales, costs, etc.) after the adoption of broadband internet. Let Y_t denote the outcome of interest in period t, which is observed over T periods, indexed by $t = \{0, 1, \ldots, T\}$. Suppose the outcome grows at an average annual rate g_0 such that: $Y_t = Y_0(1 + g_0)^t$.

Now consider a firm that adopts broadband internet after k periods. Let $m = T - k$ denote the number of post-adoption periods. Assume that broadband adoption changes the growth rate from g_0 to g_1 starting in period $t = k$. Then for $t \geq k$:

$$Y_t = Y_k(1 + g_1)^{t-k}, \quad \text{where } Y_k = Y_0(1 + g_0)^k$$

Define $\bar{Y_1}$ and $\bar{Y_0}$ as the average values of Y_t in the pre- and post-adoption periods. Furthermore, we assume that for small growth rates, the first-order Taylor expression yields: $(1 + g)^x \approx 1 + xg$. Then:

$$\begin{aligned}
\bar{Y_0} &= \frac{1}{k}\sum_{t=0}^{k-1} Y_0(1 + g_0)^t \\
&= Y_0 \cdot \frac{1}{k}\sum_{t=0}^{k-1}(1 + tg_0) \\
&= Y_0 \cdot \frac{1}{k}\left(k + g_0\frac{k(k-1)}{2}\right) \\
&= Y_0 \cdot \left(1 + \frac{k-1}{2}g_0\right)
\end{aligned}$$

Similarly:

$$\bar{Y_0} = Y_0 \cdot \left(1 + \frac{k-1}{2} g_0\right)$$
$$\bar{Y_1} = Y_0(1+g_0)^k \cdot \left(1 + \frac{m-1}{2} g_1\right)$$

Difference in growth rates: Our linear regression model assumes that $Y_1^T = Y_1^c + T$. Furthermore, to interpret the LATE, assume that $Y_0^c = Y_0^T \equiv Y_0$ i.e., the levels of the outcome variable in the pre-treatment period are identical. Substituting from the above formula, we get:

$$\bar{Y_0}\left(1 + \frac{m-1}{2} g_1\right) = \bar{Y_0}\left(1 + \frac{m-1}{2} g_0\right) + T$$
$$\bar{Y_0} \cdot \frac{m-1}{2} \cdot (g_1 - g_0) = T$$
$$g_1 - g_0 = \frac{2}{(m-1)} \cdot \frac{T}{\bar{Y_0}}$$

B.2 Theoretical Model

Firms choose inputs $\{L_s, L_c, L_a, K_a, K\}$ to minimize total cost for a given level of revenue $X(z)$. Therefore, a firm with productivity z chooses inputs to maximize profits:

$$\pi(z) = \max \quad \lambda_x pY - \sum_{o\in\{a,s,c\}} w_o L_o - \sum_{o\in\{a,p\}} r_o K_o$$

$$\text{s.t.} \quad Y = Z_A^{\alpha_z} M^{1-\alpha_Z} \qquad \text{(Production Function)}$$

$$M = \left[L_p^{\frac{\sigma_m}{1+\sigma_m}} + K_p^{\frac{\sigma_m}{1+\sigma_m}}\right]^{\frac{1+\sigma_m}{\sigma_m}} \qquad \text{(Inputs)}$$

$$L_p = \left[\sum_{o\in\{s,c\}} L_o^{\frac{\sigma_l}{1+\sigma_l}}\right]^{\frac{1+\sigma_l}{\sigma_l}} \qquad \text{(Labor input)}$$

$$M_z = z\left[L_a^{\frac{\sigma_z}{1+\sigma_z}} + K_a^{\frac{\sigma_z}{1+\sigma_z}}\right]^{\frac{1+\sigma_z}{\sigma_z}} \qquad \text{(Administrative input)}$$

$$pY = \left(\frac{p}{P_m}\right)^{-\sigma_d} \cdot P_m C_m \qquad \text{(Demand)}$$

Rearranging the demand system yields:

$$\frac{p}{P_m} = \left(\frac{Y}{C_m}\right)^{-1/(1+\sigma_d)}$$

$$p = \left(\frac{Y}{C_m}\right)^{-1/(1+\sigma_d)} \cdot P_m$$

$$pY = \left(\frac{Y}{C_m}\right)^{\frac{\sigma_d}{1+\sigma_d}} \cdot P_m C_m$$

We solve the optimization problem in three key steps outlined below.

B.2.1 Solve for optimal inputs $M = \{Z_a, K_p, L_p\}$

We re-write the firm's optimization problem as:

$$\begin{aligned}
\pi(z) = \max \quad & \underbrace{\lambda_x pY}_{=X(z)} - rK_p - p_w L_p - p_z Z_a \\
\text{s.t.} \quad Y &= \underbrace{z^{\alpha_Z}}_{=\widetilde{z}} \cdot Z_a^{\alpha_Z} \cdot M^{1-\alpha_Z} && \text{(Production Function)} \\
M &= \left[L_p^{\frac{\sigma_m}{1+\sigma_m}} + K_p^{\frac{\sigma_m}{1+\sigma_m}} \right]^{\frac{1+\sigma_m}{\sigma_m}} && \text{(Inputs)} \\
pY &= \left(\frac{Y}{C_m} \right)^{\frac{\sigma_d}{1+\sigma_d}} \cdot P_m C_m && \text{(Demand)}
\end{aligned}$$

Let $X(z) = \lambda_x pY$ denote the revenue of a firm with productivity z. For an input $M_x = \{Z_A, M\}$ with price p_x and expenditure share $\alpha_x = \{\alpha_Z, 1 - \alpha_Z\}$, the first-order condition implies:

$$\begin{aligned}
p_x &= \frac{\sigma_d}{1+\sigma_d} \cdot \frac{\lambda_x pY}{Y} \cdot \alpha_x \cdot \frac{Y}{M_x} \\
\Rightarrow \quad p_x M_x^*(z) &= \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_x X^*(z) && \text{(Optimal Input Choices)} \\
\Rightarrow \quad \pi^*(z) &= \frac{X^*(z)}{1+\sigma_d} && \text{(Optimal Profit)}
\end{aligned}$$

where we use the fact that $\sum_x \alpha_x = 1$. Substituting the optimal inputs into the production function:

$$\begin{aligned}
Y &= \widetilde{z} \cdot \underbrace{\prod_x \left(\frac{p_x}{\alpha_x} \right)^{-\alpha_x}}_{=1/MC} \cdot \left(\frac{\sigma_d}{1+\sigma_d} \right) X(z) \\
\Rightarrow Y &= \left(\frac{\sigma_d}{1+\sigma_d} \right) \cdot \frac{\widetilde{z}}{MC} \cdot X(\widetilde{z})
\end{aligned}$$

Substitute into the demand equation:

$$Y = \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m} \right]^{1+\sigma_d} \cdot C_m$$

Solving for price:

$$p(\widetilde{z}) = \frac{1+\sigma_d}{\lambda_x \sigma_d} \cdot \frac{MC}{\widetilde{z}}$$

Substitute into revenue:

$$\begin{aligned} X(z) &= \lambda_x p Y \\ &= \lambda_x \cdot \left[\frac{1+\sigma_d}{\lambda_x \sigma_d} \cdot \frac{MC}{\widetilde{z}}\right] \cdot \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m}\right]^{1+\sigma_d} \cdot C_m \\ &= \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m}\right]^{\sigma_d} \cdot \lambda_x P_m C_m \end{aligned}$$

Summary of Results

$$p_x M_x^*(\widetilde{z}) = \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_x X(\widetilde{z}) \qquad \text{(Inputs)}$$

$$Y(\widetilde{z}) = \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m}\right]^{1+\sigma_d} \cdot C_m \qquad \text{(Output)}$$

$$p(\widetilde{z}) = \frac{1+\sigma_d}{\lambda_x \sigma_d} \cdot \frac{MC}{\widetilde{z}} \qquad \text{(Prices)}$$

$$X(\widetilde{z}) = \Psi \cdot \widetilde{z}^{\sigma_d} \qquad \text{(Revenues)}$$

$$\pi^*(\widetilde{z}) = \frac{X(\widetilde{z})}{1+\sigma_d} = \frac{\Psi}{1+\sigma_d} \cdot \widetilde{z}^{\sigma_d} \qquad \text{(Profits)}$$

where:
- $MC = \prod_x (p_x/\alpha_x)^{\alpha_x}$ is the marginal cost index
- $\alpha_x = \{\eta, 1-\eta\}$ for inputs M_Z and M respectively
- $\Psi \equiv \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{1}{MC/P_m}\right]^{\sigma_d} \cdot \lambda_x P_m C_m$ ■

B.2.2 Solve for labor and capital in production — $\{K_p, L_p\}$

Firms choose the optimal combination of capital and labor in production:

$$\min_{L_p, K_p} \quad rK_p + w_p L_p \quad \text{s.t.} \quad M(\widetilde{z})^* = \left[L_p^{\frac{\sigma_m}{1+\sigma_m}} + K_p^{\frac{\sigma_m}{1+\sigma_m}}\right]^{\frac{1+\sigma_m}{\sigma_m}}$$

Define the CES price index of production inputs p_M as:

$$p_M = \left(r^{-\sigma_m} + w_p^{-\sigma_m}\right)^{\frac{-1}{\sigma_m}}$$

From Section B.2.1, we know that:

$$p_M M^*(\widetilde{z}) = \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_I \cdot X(\widetilde{z})$$

Using standard CES cost-minimization results, the optimal expenditure on capital and labor production inputs will be:

$$w_p L_p = \left(\frac{w_p}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z}) \quad \text{and} \quad rK_p = \left(\frac{r}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z})$$

B.2.3 Solve for administrative input — $\{L_a, K_a\}$

Firms choose a mix of administrative labor (L_a) and ICT capital (K_a) to generate organizational efficiency via a CES composite input $M_z^*(\widetilde{z})$. Let $\alpha_Z = \eta$ denote the share of total expenditure allocated to organizational productivity. Let $\sigma_z > 0$ denote the elasticity of substitution between administrative labor and ICT capital. The firm solves:

$$\min_{L_a, K_a} \quad \sum_{o \in \{l,k\}} p_o M_o \quad \text{s.t.} \quad \left[\theta_{Ka}^{\frac{1}{1+\sigma_z}} K_a^{\frac{\sigma_z}{1+\sigma_z}} + L_a^{\frac{\sigma_z}{1+\sigma_z}}\right]^{\frac{1+\sigma_z}{\sigma_z}} = M_z^*(\widetilde{z})$$

where: $w_a = \lambda_l w$. Define the CES price index of the administrative aggregator as:

$$p_z = \left[w_a^{-\sigma_z} + \theta_{K_a} r_a^{-\sigma_z}\right]^{\frac{-1}{\sigma_z}}$$

From the optimal input structure in Section B.2.1, the total expenditure on administrative productivity satisfies:

$$p_z M_z^*(\widetilde{z}) = \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_Z \cdot X(\widetilde{z})$$

Using standard CES cost-minimization, the optimal expenditure on each input is:

$$w_a L_a = \left(\frac{w_a}{p_z}\right)^{-\sigma_z} \cdot p_z M_z^*(\widetilde{z}) \quad \text{and} \quad rK_a = \theta_{K_a}\left(\frac{r}{p_z}\right)^{-\sigma_z} \cdot p_z M_z^*(\widetilde{z})$$

■

B.2.4 Solve for labor in production — $\{L_s, L_c\}$

Let λ_l denote an aggregate matching friction that raises the cost of hiring all workers within the firm, and let λ_s be the additional costs incurred for salaried workers relative ones hired on a contract. This implies that the effective wage payments are given by: $\{w_s, w_c\} = \{1, \lambda_c\} \cdot \lambda_l w$.

Firms choose the optimal combination of salaried (L_s) and contract (L_c) workers to minimize the cost of generating the required composite labor input $L_p^*(\widetilde{z})$: Using standard CES cost-minimization results, the optimal expenditure on each labor type $o \in \{s, c\}$ is:

$$w_o L_o = \left(\frac{w_o}{w_p}\right)^{-\sigma_l} \cdot w_p L_p^*(\widetilde{z})$$

where: $w_p = (\sum_o w_o^{-\sigma_l})^{\frac{-1}{\sigma_l}}$. The ratio of expenditures on contract versus salaried workers is:

$$\frac{w_c L_c}{w_s L_s} = \lambda_c^{-\sigma_l}$$

This implies that the composition of labor shifts toward hiring workers on permanent payroll (as opposed to contract) when the marginal costs for hiring them λ_s are lower.

■

B.2.5 Aggregate TFP and Sales

Aggregate TFP: We assume that $F(z) = 1 - z^{-\theta}$. Define: $\xi(z_e) = (z_e/z_b)^{\theta}$; and $\widetilde{\theta} = \underbrace{\sigma_d \eta}_{=\gamma}/\theta < 1$. Total productivity (TFP) of non-adopting and adopting firms as

follows:

$$\hat{Z}_0 = \int_{z_e}^{z_b} z^\gamma \cdot \theta z^{-\theta-1} dz = \frac{\theta}{\theta-\gamma}\left[z_e^{\gamma-\theta} - z_b^{\gamma-\theta}\right] = \left[1-\xi^{1-\widetilde{\theta}}\right] \cdot \frac{z_e^{\gamma-\theta}}{1-\widetilde{\theta}}$$
$$\hat{Z}_1 = \int_{z_b}^{\infty} z^\gamma \cdot \theta z^{-\theta-1} dz = \frac{\theta}{\theta-\gamma} z_b^{\gamma-\theta} = \xi^{1-\widetilde{\theta}} \cdot \frac{z_e^{\gamma-\theta}}{1-\widetilde{\theta}}$$

Aggregate Sales: Total sales in the economy will be the sum of sales by non-adopting firms (X_0) and adopting firms (X_1) respectively, where $X(z) = \Psi_j \cdot z^\gamma$. Then aggregate sales are given by:

$$\hat{X} = \hat{\Psi} \cdot \frac{z_e^{\gamma-\theta}}{1-\widetilde{\theta}}, \quad \text{where: } \hat{\Psi} = (1-\xi^{1-\widetilde{\theta}})\Psi_0 + \xi^{1-\widetilde{\theta}}\Psi_1 \tag{11}$$

B.2.6 Firm Entry and Broadband Adoption

Let F_b denote a fixed cost of adopting broadband. The above implies a threshold productivity z_b above which a adopts broadband. This threshold can be given by:

$$\pi_1(z) = \frac{\Psi_1}{1+\sigma_d} z^\gamma - F_b \geq \pi^0(z) = \frac{\Psi_0}{1+\sigma_d} z^\gamma$$
$$z_b^\gamma = \frac{(1+\sigma_d)F_b}{\Psi_1 - \Psi_0} \tag{12}$$

Firms enter by paying cost F_e and incur fixed costs F_b to adopt broadband. Aggregating across all firms, total profits ($\hat{\Pi}$) can be given by:

$$\begin{aligned}\hat{\Pi} &= \frac{\hat{X}}{1+\sigma_d} - (1-F(z_b))F_b \\ &= \frac{\hat{X}}{1+\sigma_d} - z_b^{-\theta} F_b \\ &= \frac{\hat{X}}{1+\sigma_d} - \xi F_b \cdot z_e^{-\theta}\end{aligned}$$

Free entry implies that expected (average) profits equal to F_e i.e., : $\hat{\Pi}/(1-F(z_e)) = F_e$, which implies:

$$F_e = \left[\frac{\hat{X}}{1+\sigma_d} - \xi F_b \cdot z_e^{-\theta}\right] \cdot z_e^{\theta}$$
$$F_e + \xi F_b = \hat{\Psi} \cdot \frac{z_e^{\gamma}}{(1+\sigma_d)(1-\widetilde{\theta})}$$
$$z_e^{\gamma} = \frac{(1-\widetilde{\theta})(1+\sigma_d)(F_e+\xi F_b)}{\hat{\Psi}}$$

B.2.7 Aggregate Price Index

Manufacturing Price Index: The aggregate price index for manufacturing is determined by the composition and mass of firms, and by the cutoffs $\{z_e, z_b\}$. Using the fact that the mass of firms is equal to 1, this can be calculated as follows:

$$P_m = \left[\frac{\int_{z_e}^{z_b} p_0(z)^{-\sigma_d} dG(z) + \int_{z_b}^{\infty} p_1(z)^{-\sigma_d} dG(z)}{1-F(z_e)}\right]^{\frac{1}{\sigma_d}}$$

The above implies that P_m is the average price charged across firms. Let us solve each price separately. Define:

$$A_j = \left(\frac{1+\sigma_d}{\lambda_{xj}\sigma_d}\right)^{-\sigma_d} MC_j^{-\sigma_d} \quad = \left(\frac{1+\sigma_d}{\sigma_d} \cdot \underbrace{\frac{MC_j}{\lambda_{xj}}}_{=\nu_j}\right)^{-\sigma_d}$$

Aggregating over the price indices separately:

$$\int_{z_e}^{z_b} p_0(z)^{-\sigma_d} dF(z) = \left[1-\xi^{1-\widetilde{\theta}}\right] \cdot \frac{A_0 z_e^{\gamma-\theta}}{1-\widetilde{\theta}}$$
$$\int_{z_b}^{\infty} p_1(z)^{-\sigma_d} dF(z) = \xi^{1-\widetilde{\theta}} \cdot \frac{A_1 z_e^{\gamma-\theta}}{1-\widetilde{\theta}}$$

Define: $\widetilde{\nu} = \left[(1-\xi^{1-\widetilde{\theta}})\nu_0^{-\sigma_d} + \xi^{1-\widetilde{\theta}}\nu_1^{-\sigma_d}\right]^{\frac{-1}{\sigma_d}}$. Substituting it back, we have:

$$P_m^{-\sigma_d} = \left(\frac{1+\sigma_d}{\sigma_d}\right)^{-\sigma_d} \cdot \widetilde{\nu}^{-\sigma_d} \cdot \frac{1}{1-\widetilde{\theta}} \cdot \frac{z_e^{\gamma-\theta}}{z_e^{-\theta}}$$
$$\Rightarrow P_m = \left(\frac{1}{1-\widetilde{\theta}}\right)^{\frac{-1}{\sigma_d}} \cdot \left(\frac{1+\sigma_d}{\sigma_d}\right) \cdot \frac{\widetilde{\nu}}{\widetilde{z}_e}$$

Putting it all together, we have:

$$P_m = \left(\frac{1}{1-\widetilde{\theta}}\right)^{\frac{-1}{\sigma_d}} \cdot \left(\frac{1+\sigma_d}{\sigma_d}\right) \cdot \frac{\widetilde{\nu}}{z_e} \tag{13}$$
$$\text{where: } \widetilde{\nu} = \left[(1-\xi^{1-\widetilde{\theta}})\nu_0^{-\sigma_d} + \xi^{1-\widetilde{\theta}}\nu_1^{-\sigma_d}\right]^{\frac{-1}{\sigma_d}}$$

■

B.2.8 Aggregate Factor Demand and Income

Aggregate Demand for Factor Inputs: The total expenditure on production labor is equal to $(w_p/p_M)^{-\sigma_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_I X(z)$. Therefore, the demand for contract and salaried workers will be given by:

$$L_o = \left(\frac{w_o}{w_p}\right)^{-\sigma_l} \cdot \left(\frac{w_p}{p_M}\right)^{-\sigma_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_M \frac{X(z)}{w_o}$$
$$\Rightarrow L_p = \sum_o L_o = \sum_o \frac{w_o^{-(1+\sigma_l)}}{w_p^{-\sigma_l}} \cdot \left(\frac{w_p}{p_M}\right)^{-\sigma_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_M X(z)$$

Similarly, the demand for administrative workers is given by:

$$L_a = \left(\frac{w_a}{p_z}\right)^{-\sigma_z} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_z \frac{X(z)}{w_a}$$

Put together, the total labor demand ($L_a + L_p$) is given by:

$$L_j = \left[\frac{\alpha_M \sum_o w_o^{-(1+\sigma_l)}}{w_p^{-\sigma_l}} \left(\frac{w_p}{p_M} \right)^{-\sigma_m} + \frac{\alpha_Z w_a^{-(1+\sigma_z)}}{p_z^{-\sigma_z}} \right] \cdot \frac{\sigma_d}{1+\sigma_d} X(z)$$

Aggregating, the total labor demand in manufacturing can be given by:

$$\begin{aligned} \hat{L}_m = &= \frac{\sigma_d}{1+\sigma_d} \cdot \Psi_L \cdot \hat{X} \\ \text{where: } \hat{\Psi}_L &= (1-\xi^{1-\widetilde{\theta}})\Psi_{L0} + \xi^{1-\widetilde{\theta}}\Psi_{L1} \\ \Psi_{Lj} &= \frac{\alpha_M \sum_o w_{oj}^{-(1+\sigma_l)}}{w_{pj}^{-\sigma_l}} \left(\frac{w_{pj}}{p_{Mj}} \right)^{-\sigma_m} + \frac{\alpha_Z w_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}} \end{aligned} \tag{14}$$

The total demand for capital in manufacturing can be given by:

$$\begin{aligned} \hat{K}_m &= \frac{\sigma_d}{1+\sigma_d} \cdot \Psi_K \cdot \alpha_M \hat{X} \\ \text{where: } \hat{\Psi}_K &= (1-\xi^{1-\widetilde{\theta}})\Psi_{K0} + \xi^{1-\widetilde{\theta}}\Psi_{K1} \\ \Psi_{Kj} &= \frac{\alpha_M r^{-(1+\sigma_m)}}{p_{Mj}^{-\sigma_m}} + \frac{\alpha_Z \theta_{K_a j} r_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}} \end{aligned} \tag{15}$$

Total Income: Note that total factor incomes generated from manufacturing, from Proposition (1), are equal to $\frac{\sigma_d}{1+\sigma_d} X(z)$. Therefore:

$$I = \frac{I^m}{\beta_m} = \frac{\sigma_d}{1+\sigma_d} \cdot \frac{\hat{X}}{\beta_m} \tag{16}$$

C Anticipation of Broadband Adoption: An Event Study

A potential concern with our identification strategy is that firms may select into broadband adoption based on anticipatory trends in firm performance. To test this, we create a variable D_{it}, which is the the number of years relative to the year t in which a firm i first reports adopting broadband internet. For example, $D_{it} = -d$ is d years before a firm i adopts high-speed internet and $D_{it} = +d$ is d years after. We restrict the observations to $d = \{-4, +4\}$ and estimate the following specification:

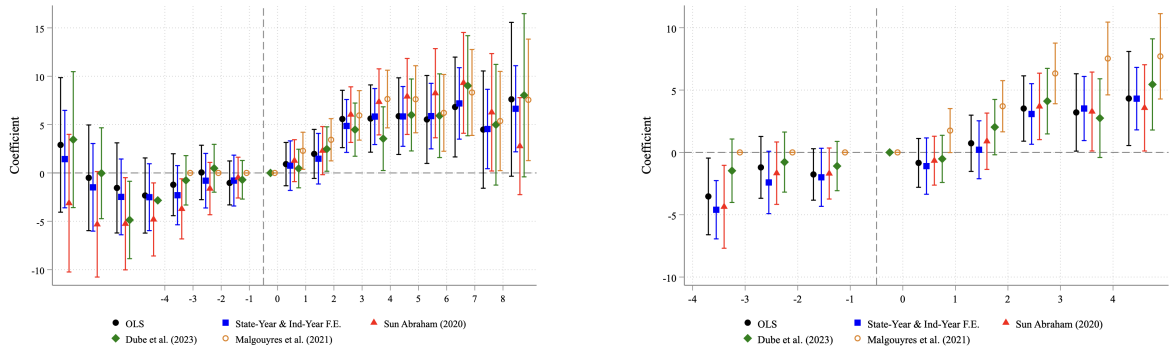
$$Y_{it} = \alpha_i + \alpha_t + \sum_{d=-4}^{d=4} \beta_d 1(D_{it} = d) + \varepsilon_{it} \tag{17}$$

where Y_{it} are a set of firm-level outcomes such as value of production, revenues, costs, value-added, etc., α_i is a firm fixed effect that controls for all observable and unobservable time-invariant characteristics of the firm, α_t is a year fixed effect that controls for all observable and unobservable changes over time that are common to all firms. We cluster standard errors at the firm level.

Figure C1 reports the plots from the above specification for four key outcome variables of firm performance, namely: (i) real value of production (Figure C1(a)); (ii) real revenues (Figure C1(b)); (iii) real costs of production (Figure C1(c)); and (iv) real value-added (Figure C1(d)). We see that for all outcome variables, there are no (or small) statistically significant differences between firms that do and do not adopt broadband internet prior to their adoption. However, significant differences emerge in firm performance after adoption and continue to strengthen over time. For example, after 4 years of adoption, real value of production and sales increase by around 10% each, total real costs of production increase by around 8%, and real value added increases by around 12%. Put together, this suggests substantial and persistent increases in firm performance after adopting broadband internet.

Given the staggered adoption of broadband internet across firms, we redo these figures using more recent advances in this literature to check the robustness of our analysis. First, we show that including region-year and industry-year fixed effects does not alter the results. We also show robustness of these estimates to various other approaches developed in the literature by Sun and Abraham (2021), Dube et al. (2023), and Malgouyres et al. (2019).

Figure C1: Impact of Internet Adoption on Firm Performance



(a) Real Value of Production

(b) Real Revenues

(c) Real Costs of Production

(d) Real Value Added

Notes: The above figures plot the regression coefficients from various specifications for a set of firm-level outcomes. These include OLS (black dots), regressions with region-year and industry-year fixed effects (blue squares), along with approaches developed by Sun and Abraham (2021) (red triangles), Dube et al. (2023) (green diamonds), and Malgouyres et al. (2019) (oranges circles). The horizontal axis shows years relative to the year in which a firm adopts broadband internet ($t = 0$). $t - 1$ is used as the reference year that is omitted from the regression. All outcome variables are windsorized at the top and bottom 5th percentiles. All regressions include firm and year fixed effects. Standard errors are clustered at the firm-level and 90% confidence intervals around the point estimates are reported in the figures.