Broadband as a General-Purpose Technology: Evidence from Colombia*

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Abstract

This paper studies both theoretically and empirically, how the adoption of broadband internet reshapes firm production, internal organization, and management practices. Using detailed data on production and ICT usage for a panel of Colombian manufacturing firms spanning over a decade, we find that broadband acts as a "general-purpose technology" that induces digitalization along multiple dimensions: externally — through websites, online orders, exports, and e-commerce; and internally — through hiring and training frontline production workers, capital investment, improved digital communication, and better transportation logistics. Interpreting these patterns and their aggregate implications through a structural model indicates that broadband simulatneously lowers multiple barriers related to market access, and labor contracting and hiring costs, while increasing the productivity of ICT capital. Counterfactual simulations suggest that last two accounted for most of the observed gains in adoption, employment, and welfare over this time period.

Keywords: Digitalization, Firms, Technology, Internet, Colombia
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1 Introduction

The past two decades have seen a rapid adoption of broadband internet across developing economies, reshaping how firms produce, organize, and interact with markets. In Colombia, the empirical context of this paper, broadband adoption by firms increased fourfold — from around 15% in 2010, to over 60% a decade later (Figure 1).[1] 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; Cusolito et al., 2020; Bhuller et al., 2023). However, key gaps remain, as noted by Hjort and Tian (2021) in a recent review of the literature: first, most causal studies in LMICs often focus on a specific set of firm-level outcomes (such as sales, employment, productivity, etc.);[2] 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 shape aggregate outcomes in general equilibrium.

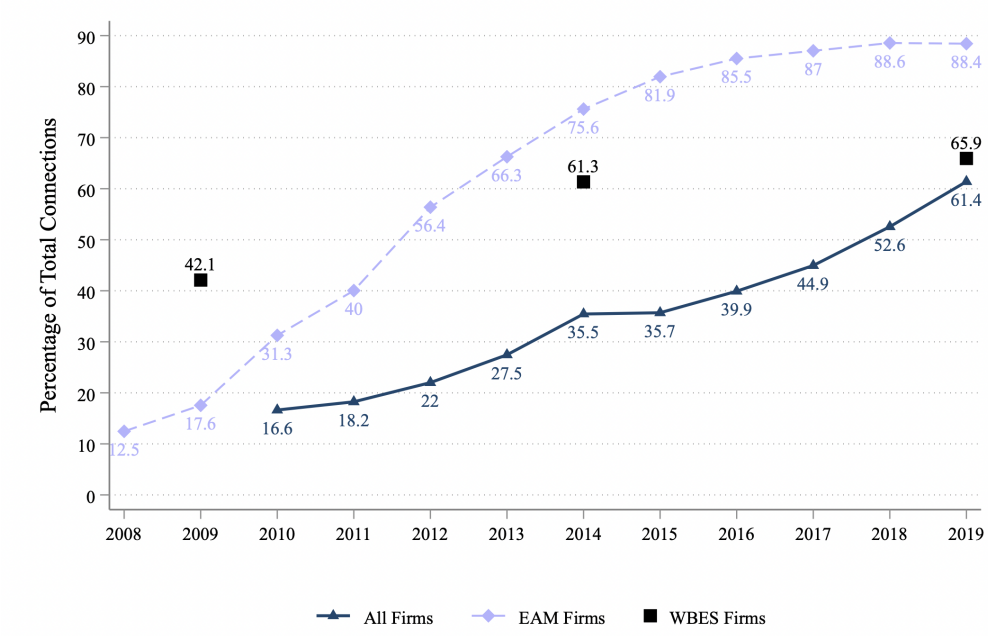
This paper aims to make progress on all these dimensions. We begin by developing a rich theoretical model that embeds broadband into a canonical framework of heterogeneous firms (Melitz, 2003). We show theoretically that broadband adoption can simultaneously change *multiple* frictions faced by a firm (for e.g., access to markets, worker hiring costs, contracting costs, etc.). These interactions imply that its impact on firm production is nuanced and theoretically ambiguous, which lends itself to the need for a detailed empirical analysis. We therefore exploit rich data on Colombian manufacturing firms, coupled with plausibly exogenous supply-side rollout of broadband access, to causally examine its impact on firm growth, market access, and reallocation of labor and capital inputs. A novel module on ICT usage within a firm further enables us to identify precise mechanisms through which firms reorganize production. Lastly, we calibrate the model to estimate these frictions, quantify their relative contributions to explaining the adoption of broadbband over this time period, and their impact on aggregate demand for factor inputs, prices, and aggregate welfare.

Starting with the theory, the motivation to embed broadband in a standard model of heterogeneous firms is twofold. As we will discuss later, the empirical analysis shows that adoption is associated with simultaneous changes along several margins. Adopters expand total employment, primarily through hiring frontline production workers, and on temporary contracts. They also expand market access through e-commerce and increase export intensity (thus increasing sales), and improve internal communication through integrating ICT capital in administrative tasks (like

[1] Adoption rates were even more stark in the manufacturing sector, increasing from 17% to 88%, and consistent with the experience across countries in Latin America more generally (see Figure 1).

[2] See Hjort and Poulsen (2019), Cariolle et al. (2018), Cusolito et al. (2020), and Paunov and Rollo (2015).

Figure 1: Broadband Internet Adoption in Colombia



Notes: The above figures plots the percentage of firms using high-speed broadband internet connection in Colombia between 2008-2019. The sample of firms consists of all firms (triangles) and formal manufacturing firms (diamonds). For comparison, the squares report the percentage of firms using the internet (as measured by whether a firm has a website or not) in Latin America from the World Bank Enterprise Surveys (WBES). Given the sample coverage across countries, we average the WBES data in three time periods: 2005-2009, 2010-2014, 2015-2019.

computers and VoIP applications). A naive interpretation of the data would risk attributing these gains to a single margin (e.g., market expansion) when in reality, they stem from multiple channels related to input frictions and organizational productivity. This implies that broadband acts as a "general-purpose" technology: its economic impact arises precisely because it touches demand, productivity, capital, and labor in interconnected ways. Without a framework that models these interactions, one would risk misappropriating how broadband shapes firm employment and production, and its aggregate implications for productivity and income.

Section 2 therefore develops this framework, which extends a canonical model of heterogeneous firms (Melitz, 2003) to allow for endogenous firm productivity, which in turn depends on the composition of managerial workers and ICT capital. Production inputs consist of capital and labor, with labor consisting of a composite of payroll and contract workers. Broadband adoption can impact firm production through four distinct channels, namely: (i) enhancing market access; (ii) reducing search and matching frictions in hiring workers; (iii) tradeoffs in hiring production workers on temporary contracts as opposed to on payroll; and (iv) raising firm productivity through ICT capital relative to managerial workers. These channels interact in various ways to determine a firm's (endogenous) decision to adopt broadband. In equilibrium, these channels

further determine the entry and adoption cutoffs, reallocate labor and capital both within and across firms, and feed back into wages, rental rates, and aggregate income. A key insight from the model is that the net impact of broadband on firm outcomes is ambiguous in many cases. For example, higher ICT productivity pushes firms to substitute workers for capital, but if broadband lowers hiring costs as well, it may simultaneously increase labor demand. In addition, greater market access scales production and hence, demand for all inputs. These interlocking channels are what Section 2.5 emphasizes as the central conceptual contribution of the theory.

These interdependent channels lend itself to the need for a rich empirical analysis that not only measures these dimensions, but also examines how broadband adoption can causally impact them. Our primary source of data is the *Encuesta Anual Manufacturera* (or EAM) from 2008-2019.[3] The EAM is an annual census of formal manufacturing firms conducted by Colombia's National Statistical Agency, the *Direccion Nacional de Estadística* (DANE).[4] 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 related to obtaining information, government interactions, communication within firms through VoIP apps (like Skype), online contracting and customer support, e-commerce, labor hiring and training, etc. The granularity of the data, coupled with a long panel of firms spanning over a decade, enables us to open the black box of broadband adoption and trace the channels through which it impacts firm production.

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 on average, larger, more productive firms being more likely to adopt broadband; or particular regions experiencing an expansion in broadband infrastructure that increases 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

[3]This is constrained by the availability of the ICT module starting 2008, and the Covid-19 pandemic in 2020.
[4]Specifically, the EAM surveys all firms employment at least 10 workers, or those who have an output value greater than an inflation-adjusted threshold.

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, presented in Section 4, can be summarized in four 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 a 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.

Third, firms 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. Finally, broadband increases complementary investments in communication and logistics. Firms spend more on transportation (particularly of output) and communication services (especially administrative ones). These are consistent with broadband allowing for more efficient internal communication and access to newer markets.

A key empirical contribution of the paper is a novel module on ICT usage that enables us to precisely identify *how* firms use broadband to realize the gains in production. As we discuss in Section 4.5, 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 (e.g., Skype). 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.

While the empirical patterns shed light on the theoretical channels that impact firm production, they do not reveal, however, *which* channels are quantitatively dominant driving adoption between 2009-19 as well as their aggregate implications for productivity and welfare. Section 5 therefore connects these empirical patterns to the theory. We jointly estimate key parameters in 2009 and 2019. They are identified using the structure of the model and various expenditure ratios of sales, and spending on types of workers and capital between firms that do and do not adopt broadband. The estimates show, most notably, a substantial increase in the productivity of ICT capital between 2009-19 (by 30%), coupled with a decline in the marginal costs of hiring workers (7%). Firms that adopt broadband (relative to those that do not) face substantially lower barriers to accessing markets (30%), and this gap slightly widens over time as well. Lastly, our estimates show a closing of the gap in costs of hiring payroll workers relative to contractual ones, which is reflected by the increased hiring of contract workers empirically.

The parameter estimates are informative to understand the magnitude of different channels, but do not tell us which channels are important in driving the empirical patterns that we see. In Section 5.4, we implement counterfactual simulations where for each parameter of interest (say hiring frictions), we set their value to 2009, while allowing other parameters to change. The results show that while "external factors" that are summarized in our model through better market access facilitated adoption, the equilibrium gains in employment and welfare came primarily from "internal factors" related to lower labor hiring costs and improvements in ICT productivity. For example, market access does little to alter the internal composition of workers across contract types and job roles (managerial vs production), whereas hiring frictions significantly impacts exactly this dimension. Put together, lower hiring frictions and better ICT productivity each explain around 6-8% of the rise in real incomes over this time period, while better market access explains around 1% of real income changes. These results therefore illustrate that broadband adoption is not a single-channel shock, but more of a general-purpose technology, whose economic effects depend on the *joint* evolution of multiple frictions faced by firms.

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; Cusolito et al., 2020; Bhuller et al., 2023; DeStefano et al., 2023) by providing causal evidence from a developing country on a wide range of firm outcomes that go well beyond the usual measures of firm performance. Importantly, we unpack precise mechanisms through which broadband adoption reduces multiple frictions, thus enabling firms to reorganize production and scales. Our empirical results are consis-

tent 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 markets (via e-commerce and customer service), how they structure internal operations (via online hiring and training), and how they adapt to scale through contract workers 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. Lastly, from a theoretical standpoint, our key contribution is in extending canonical models of heterogeneous firms (Melitz, 2003) to incorporate how digital infrastructure alleviates multiple constraints within the firm, how they interact to endogenously impact production, along with their aggregate implications in equilibrium.

The remainder of the paper is structured as follows. Section 2 develops the theoretical model, while Section 3 discusses the institutional context and empirical strategy. Section 4 presents the empirical results. Section 5 quantifies the model parameters and examines the the importance of various channels in driving broadband adoption.

2 Theoretical Model

We build a model of heterogeneous firms that embeds endogenous firm productivity alongside standard production inputs in equilibrium. Broadband is a general-purpose technology that can: (i) relax demand-side frictions (market access), (ii) lower hiring frictions for workers; (iii) reshape the composition of production labor (payroll vs. contract), and (iv) raise the productivity of ICT capital in administrative tasks. These channels jointly determine the factor prices faced by firms that in turn determine firm production, which in turn pins down adoption and entry thresholds.

2.1 Consumer Preferences and Demand

A representative household has Cobb-Douglas utility over two sectors manufacturing and non-manufacturing, $j = \{m, n\}$, given by:

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

so sectoral spending is $P_j C_j = \beta_j I$. Within manufacturing, varieties are imperfect substitutes with elasticity $1 + \sigma_d$:

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

Demand for variety i is given by:

$$p_i q_i = \left(\frac{p_i}{P_m} \right)^{-\sigma_d} \cdot \underbrace{\beta_m I}_{= P_m C_m}, \quad P_m = \left(\int_{i \in \Omega} p_i^{-\sigma_d} di \right)^{\frac{-1}{\sigma_d}}$$

2.2 Firm Production

Firm production consists of inputs (M) used in production — capital and labor, and those in managerial productivity Z of the firm (such as ICT capital and managerial workers). Output is given by the Cobb-Douglas production function: $Y = Z^{\alpha_Z} M^{\alpha_M}$.

$$\begin{aligned}
M &= \left[K_p^{\frac{\sigma_m}{1+\sigma_m}} + L_p^{\frac{\sigma_m}{1+\sigma_m}} \right]^{\frac{1+\sigma_m}{\sigma_m}} && \text{(Production Inputs)} \\
L_p &= \left[L_c^{\frac{\sigma_l}{1+\sigma_l}} + L_s^{\frac{\sigma_l}{1+\sigma_l}} \right]^{\frac{1+\sigma_l}{\sigma_l}} && \text{(Labor Inputs)} \\
Z &= z \cdot \left[\theta_Z^{\frac{1}{1+\sigma_z}} K_a^{\frac{\sigma_z}{1+\sigma_z}} + L_a^{\frac{\sigma_z}{1+\sigma_z}} \right]^{\frac{1+\sigma_z}{\sigma_z}} && \text{(Firm Productivity)}
\end{aligned} \tag{1}$$

Production inputs (M) are a CES composite of capital (K_p) and labor (L_p) with an elasticity of substitution $(1 + \sigma_m)$. Similarly, production workers (L_p) are also a CES composite of payroll (s) and contract (c) workers with an elasticity of substitution $(1 + \sigma_l)$. Lastly, managerial inputs that define the firm productivity consist of two components: an exogenous productivity (z); and an 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 $(1 + \sigma_z)$. θ_Z is the productivity of ICT capital relative to administrative workers.

Capital (both for administrative and production purposes) can be rented at a marginal cost r and workers are paid a wage w. Let λ_l be an additional marginal cost incurred by firms for hiring workers. These could reflect, for example, search and matching frictions in the labor market. Let λ_s be an additional wedge for hiring payroll relative to contract workers. This implies that the effective wages paid by a firm for hiring managerial, payroll, and contract workers are given by: $\{w_a, w_c, w_s\} = \{\lambda_l w, \lambda_l w, \lambda_s \lambda_l w\}$. Lastly, λ_x scales firm revenues i.e., $X(z) = \lambda_x pY$, and can reflect either sectoral productivity or costs related to market access, etc.[5]

Given the above setup, a firm with (exogenous) productivity z chooses inputs $\{L_a, L_s, L_c, K_a, K_p\}$ to maximize profits, given by:

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

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

$$\begin{aligned}
p_k M_k^*(\widetilde{z}) &= \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_k X(\widetilde{z}) && \textit{(Inputs)} \\
Y(\widetilde{z}) &= \left[\frac{\lambda_x \sigma_d}{1+\sigma_d} \cdot \frac{\widetilde{z}}{MC/P_m}\right]^{1+\sigma_d} \cdot C_m && \textit{(Output)} \\
p(\widetilde{z}) &= \frac{1+\sigma_d}{\lambda_x \sigma_d} \cdot \frac{MC}{\widetilde{z}} && \textit{(Prices)} \\
X(\widetilde{z}) &= \Psi \cdot \widetilde{z}^{\sigma_d} && \textit{(Revenues)} \\
\pi^*(\widetilde{z}) &= \frac{X(\widetilde{z})}{1+\sigma_d} = \frac{\Psi}{1+\sigma_d} \cdot \widetilde{z}^{\sigma_d} && \textit{(Profits)}
\end{aligned} \tag{2}$$

where: (i) $MC = \prod_k (p_k/\alpha_k)^{\alpha_k}$ is the marginal cost index for inputs $k = \{Z_A, M\}$; 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;*

[5] Note that while $\{\lambda_l, \lambda_c\}$ reflect differences in marginal costs, they are isomorphic to differences in productivity as well in the absence of separate production and cost data. As we will discuss later, we will therefore be interested in the *relative* values of these parameters between adopters (λ_k^1) and non-adopters (λ_k^0) i.e., $\lambda_k = \lambda_k^1/\lambda_k^0$, with the absolute levels reflecting these productivity differences.

(ii) ICT capital and managerial workers in administrative productivity; and (iii) payroll and contract workers, will be given by:

$$
\begin{aligned}
w_p L_p &= \left(\frac{w_p}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z}) \quad \textit{and} \quad rK_p = \left(\frac{r}{p_M}\right)^{-\sigma_l} \cdot p_M M^*(\widetilde{z}) \\
w_a L_a &= \left(\frac{w_a}{p_z}\right)^{-\sigma_z} \cdot p_z Z_A^*(\widetilde{z}) \quad \textit{and} \quad rK_a = \theta_Z \left(\frac{r}{p_z}\right)^{-\sigma_z} \cdot p_z Z_A^*(\widetilde{z}) \\
w_s L_s &= \left(\frac{w_s}{w_p}\right)^{-\sigma_l} \cdot w_p L_p^*(\widetilde{z}) \quad \textit{and} \quad w_c L_c = \left(\frac{w_c}{w_p}\right)^{-\sigma_l} \cdot w_p L_p^*(\widetilde{z})
\end{aligned} \tag{3}
$$

where: $p_M = \left(p_z^{-\sigma_m} + p_M^{-\sigma_m}\right)^{\frac{-1}{\sigma_m}}$ *is the composite price index of inputs;* $p_z = (w_a^{-\sigma_z} + \theta_Z k_a^{-\sigma_z})^{\frac{-1}{\sigma_z}}$ *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.

2.3 Firm Entry and Broadband Adoption

Impact of broadband adoption. Broadband adoption can impact firm production through multiple channels, such as: demand frictions (λ_x), hiring frictions (λ_l), costs for hiring payroll vs contract workers (λ_s), and increases in the relative productivity of ICT capital (θ_Z). These changes in turn affects firms' marginal costs (MC), and therefore firm production.

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:

$$
z_b^{\gamma} = \frac{(1+\sigma_d)F_b}{\Psi_1 - \Psi_0} \tag{4}
$$

where $\gamma = \alpha_z \sigma_d$. See Appendix B.2.6 for the proof. Intuitively, the threshold productivity is directly proportional to the fixed cost and inversely related to the differences in revenue gains per-unit of productivity.

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

provides analytical expressions that characterize entry and adoption, which then helps generate closed-form solutions for aggregate outcomes in equilibrium. Given these assumptions, the entry threshold (z_e) can be characterized by:

$$z_e^{\gamma} = \frac{(1-\widetilde{\theta})(1+\sigma_d)(F_e+\xi F_b)}{\hat{\Psi}} \tag{5}$$

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 (7). See Appendix B.2.6 for the mathematical proof. Equation (5) has an intuitive meaning. First, note that the entry threshold 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).

2.4 Aggregation in Equilibrium

Consider a 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.[6]

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 aggregate price index in manufacturing is:

$$P_m = \left(\frac{1}{1-\widetilde{\theta}}\right)^{\frac{-1}{\sigma_d}} \cdot \left(\frac{1+\sigma_d}{\sigma_d}\right) \cdot \frac{\widetilde{\nu}}{z_e} \tag{6}$$

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.

[6]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 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:

$$\hat{X} = = \hat{\Psi} \cdot \frac{1}{1-\widetilde{\theta}} z_e^{\gamma-\theta} \quad \text{, where: } \hat{\Psi} = (1-\xi^{\widetilde{\theta}-1})\Psi_0 + \xi^{\widetilde{\theta}-1}\Psi_1 \tag{7}$$

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 entrants.

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:

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

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

$$\Psi_{Lj} = \frac{\alpha_M \sum_o w_{oj}^{-(1+\sigma_l)}}{w_{pj}^{-\sigma_l}} \left(\frac{w_{pj}}{p_{Mj}}\right)^{-\sigma_m} + \frac{\alpha_Z w_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}}, \qquad \Psi_{Kj} = \frac{\alpha_M r^{-(1+\sigma_m)}}{p_{Mj}^{-\sigma_m}} + \frac{\alpha_Z \theta_{Ka} r^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}} \tag{8}$$

See Appendix B.2.8 for the proof.

Non-Manufacturing sector. We assume a representative firm in the non-manufacturing sector. 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 $K_n = 1 - \hat{K}_m$. Put together, equilibrium factor prices are given by:

$$w = \frac{1-\beta_m}{\beta_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_L \frac{\hat{X}}{1-\hat{L}_m}, \qquad r = \frac{1-\beta_m}{\beta_m} \cdot \frac{\sigma_d}{1+\sigma_d} \cdot \alpha_K \frac{\hat{X}}{1-\hat{K}_m} \tag{9}$$

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 (4) and (5); (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 (6); 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 (9).

2.5 Interdependent Channels and The Role of Broadband Adoption

The model makes clear that broadband affects firm behavior not through a single friction, but through a combination of interdependent channels that govern both demand and input use. By relaxing market access frictions (λ_x), broadband adoption enables scale. Simultaneously, improvements in ICT capital productivity (θ_z) alter the tradeoff between ICT capital and managerial labor, while reductions in hiring frictions (λ_l and λ_s) lower the cost of adjusting the workforce, particularly toward payroll employees.

An important insight from the model is that these channels interact to impact production in ways that are not ex-ante obvious. For instance, higher ICT productivity pushes firms to substitute workers for capital, but if broadband lowers hiring costs as well, it may simultaneously increase labor demand. In addition, greater market access scales production and hence, demand for all inputs. The net effect on labor and capital is therefore ambiguous and depends on the joint distribution of these channels, in addition to factor prices and firm entry in equilibrium.

This motivates the need to examine the impact of broadband adoption on firm production empirically, which we do in Sections 3 and 4 below.

3 Data and Empirical Strategy

3.1 Annual Manufacturing Survey (EAM)

Our primary data is an (unbalanced) panel of 12,313 firms in Colombia's formal manufacturing sector 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.

3.2 Supplementary Data

Apart from the EAM, we use other administrative data available from the Ministry of Information and Communication (MinTIC). 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).

3.3 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.[7] We then estimate the following regression specification:

$$Y_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \beta \mathbb{1}(\text{Broadband internet})_{it} + \varepsilon_{it} \tag{10}$$

[7] Broadband internet is defined as a fiber or wifi internet connection with a speed of at least 2 Mbps.

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 (4-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 supply-side availability of broadband interacted with lagged region-industry exposure to it. In other words, the instrument is an 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 $t-1$.[8] 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).[9]

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

[9]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 ser-

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:

$$\mathbb{1}(\text{Broadband Internet})_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \gamma Z_{ijrt} + \varepsilon_{it} \tag{11}$$

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 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

vices, and hence potentially their decision to adopt broadband. Our region-year fixed effects take into account these channels.

Table 1: First Stage

	1(Broadband Internet)	
	(1)	(2)
$\text{Ln(Providers)}_{rt} \times \overline{\text{Int. Exposure}}_{rjt-1}$	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	92820	92820
Firms	11093	11093

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. $\text{Ln(Providers)}_{rt}$ 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 4-digit 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.

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 2SLS results in our analysis, we report results for both the OLS and 2SLS 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 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

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 4-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.

costs, and real value added (measured in thousands of 2010 Colombian pesos). Odd-numbered (even-numbered) columns report the OLS (2SLS) results. The OLS estimates suggest modest gains from adoption, ranging from 6-10% of pre-adoption means across these indicators of firm performance. In comparison, the 2SLS estimates range from 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 2SLS estimates. Interpreting their magnitudes requires both economic and econometric considerations. First, these differences are neither surprising nor unique to our setting. OLS is likely biased downward due to both attenuation from measurement error as well as heterogeneous gains from adoption across firms. The 2SLS 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 adoption 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 2SLS) provide a cumulative difference in the average outcome variable across years after adopting broadband internet (around 6 on average in our sample). 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 11-14%. 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 ef-

ficiency, something that we confirm in Appendix Table A1, where we consistently find a 0.2σ increase in firm TFP that is estimated using various methods in the literature (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Wooldridge, 2009).

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 and changes in contractual arrangements, while Table 5 presents the results for capital investments.

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.

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 entirely by hiring more production workers (Column 8), with marginally lower professional and technical workers (Column 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 managerial and technical workers (Columns 4 and 6) with a corresponding increase in production workers (Column 8).

Contractual arrangements. We also observe the nature of the contractual relationship of workers within a firm across three types of contracts: (i) permanent, payroll 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 of workers hired directly by the firm, either on payroll (Column 2) or on temporary contracts (Column 4). A compositional analysis conditional on firm-size, reported in Panel B, suggests a reallocation of labor *away* from hiring through third parties (Column 6) and towards hiring workers directly on temporary contracts instead (Column 4).[10]

[10] Appendix Tables A2 and A3 show a similar pattern on occupational composition and contractual arrangements with wage-bill instead of firm-size.

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)	2.42***	18.60***	0.93***	1.05	0.13	-2.83*	1.37***	20.37***
	(0.43)	(5.71)	(0.18)	(2.18)	(0.11)	(1.64)	(0.30)	(3.92)
Annualized $\triangle Y$		3.10		0.18		-0.47		3.40
Panel B: Conditional on L								
1(Broadband)			0.26**	-4.08***	-0.17*	-5.18***	-0.09	9.26***
			(0.13)	(1.52)	(0.10)	(1.46)	(0.15)	(2.03)
L			0.27***	0.28***	0.12***	0.13***	0.60***	0.60***
			(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)
Control Mean	38.45	38.45	10.41	10.41	3.37	3.37	24.66	24.66
Annualized $\triangle Y$				-0.68		-0.86		1.54
N	92828	92828	92828	92828	92828	92828	92828	92828
No. of firms	11094	11094	11094	11094	11094	11094	11094	11094
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 regressions include firm, region-year and 4-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.

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, while we do not see any change in managerial workers overall (Column 4, Table 3), Appendix Table A4 suggests a reallocation of hiring workers on contracts within the firm (Column 4) as opposed to from third-parties (Column 6). Similarly, production workers are also more likely to be hired on payroll and temporary contracts directly by the firm, instead of being outsourced to third-parties (see Appendix Table A6). Lastly, the decline of workers in technical and professional roles (Column 6, Table 3) is primarily driven by a decline in salaried and indirectly hired workers in these roles (see Appendix Table A5).

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 outsourcing hiring of workers through third-parties and directly on payroll or contracts within the firm,

Table 4: Impact on Worker Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	1.49***	8.40*	0.21	8.96***	0.72***	1.07
	(0.34)	(4.55)	(0.27)	(3.01)	(0.22)	(2.51)
Annualized $\triangle Y$		1.40		1.49		0.18
Panel B: Conditional on L						
1(Broadband)	0.21	-1.34	-0.36	4.66*	0.15	-3.32
	(0.26)	(3.09)	(0.24)	(2.78)	(0.20)	(2.25)
L	0.53***	0.53***	0.24***	0.23***	0.24***	0.24***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	22.47	22.47	9.49	9.49	6.06	6.06
Annualized $\triangle Y$		-0.22		0.78		-0.55
N	92828	92828	92828	92828	92828	92828
No. of firms	11094	11094	11094	11094	11094	11094
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 regressions include firm, region-year and 4-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.

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. Instead of 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), trans-

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 4-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.

portation equipment (Column 6), and land and building investment (Column 8).

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 imports in total costs.[11] 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 9 p.p. (Column 2, p-val: 0.11). This is primarily driven by export-behavior: the probability of being an exporter increases by 12 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). Both the magnitudes (as

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

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 4-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.

compared to exports) are small and statistically insignificant at conventional values.

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 Section 4.5, where broadband adoption increases the likelihood that firms participate in e-commerce, use websites to engage customers, and send or receive online orders.

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 20%, 5%, and 30% respectively each year after the adoption of broadband internet. These patterns suggest that broadband increases communication within the firm (especially in administrative roles, see Appendix Table A7), which also potentially enables firms to scale production (especially in output, see Appendix Table A8), consistent with the patterns discussed in previous sections.

These results complement earlier findings on expansion in export markets. In particular, the increase in freight and transportation expenses 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

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 4-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.

the interpretation that broadband enables market expansion—rather than merely substituting offline with online sourcing.

4.5 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 this 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 14% annual increase in the computer expenditure of a firm, with a 5-6 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 examines *how* firms use the internet and reports the effects of broadband adoption on a

Table 8: Impact on Computer Usage and Expenditure

	Comp. Exptd.		Usage: Comp.		Internet	
	(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 4-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.

wide range of digital practices. Each outcome variable is a binary variable that takes the value 1 after a firm first reports using the internet for the activity of interest, and 0 otherwise.

Online information and transactions. Panel A focuses on information acquisition and online transactions. Adopting broadband does not appear to increase 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. There is perhaps suggestive evidence that firms might use broadband for obtaining information about government agencies and programs (Column 6). While the magnitude is large and similar between the OLS and 2SLS estimates, the latter is not statistically significant at conventional values.

Online service and sales. Panel B shifts to external-facing commercial practices. Adopting broadband increases the probability of having a firm website by 12 p.p. (Column 2), sending or receiving online orders by 10 p.p. (Column 6), and participating in e-commerce related activities by 13 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 reinforce the evidence from prior sections on expanded participation in

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**	0.13*
	(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	0.33	0.33
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 4-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.

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 16 p.p. (Column 2), employee training by 13 p.p. (Column 4), and usage of workflow VoIP tools (like video confer-

encing facilities, for example) by 20 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 (see 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 previously.

These patterns also align with the model from Section 2, which posits that broadband simultaneously affects (i) demand-side frictions (λ_x), (ii) ICT productivity (θ_z), and (iii) hiring and contracting frictions $\{\lambda_l, \lambda_s\}$. As discussed previously, the net empirical effect is not obvious because these channels interact in subtle ways. The empirical analysis presented above demonstrate patterns consistent with broadband as a "general-purpose" technology, that lowers firms' costs across internal and external operations, allowing them to access new markets, workers, and capital, to scale their operations. Yet they do not reveal *which* channels are quantitatively dominant. This highlights the need to structurally estimate the theoretical model to decompose the observed firm-level and aggregate outcomes into underlying changes in key barriers and frictions. We explore this decomposition — and its general-equilibrium consequences — in Section 5 below.

5 Quantifying the Impact of Broadband Adoption

We estimate the underlying structural parameters by mapping moments from firm-level administrative and production data to the model simulated ones. The goal is twofold: first, to discipline the relative importance of each broadband channel; and second, to evaluate their aggregate effects through general equilibrium.

This section proceeds as follows. Section 5.1 discusses the parameterization of the model, while Section 5.2 describes the estimation strategy and identification. Section 5.3 reports the parameter estimates, highlighting how each channel contributes quantitatively to the observed shifts in firm behavior. Lastly, 5.4 presents counterfactual simulations to illustrate how the economy would respond under alternative broadband adoption scenarios.

Table 10: List of Parameters and Targeted Moments

Parameter	Value	Details	Targeted Moment
α_L	0.7	Labor share in non-manufacturing	Battisti et al. (2024)
β_m	0.21	Exp. share on manf.	Manuf. share in private consumption
α_Z	0.22	Exp. share on admin. inputs	Estimated from EAM data
θ	4.25	Shape parameter of prod. dist.	Estimated from EAM data
$1+\sigma_d$	2.2	EoS b/w products in demand	Broda and Weinstein (2006)
$1+\sigma_m$	3.7	EoS b/w K_p and L_p	Zarate et al. (2024)
$1+\sigma_l$	4.29	EoS b/w L_c and L_s	Estimated from EAM data
$1+\sigma_z$	1.56	EoS b/w L_a and K_a	Estimated from EAM data
$\{\theta_Z\}^i$	-	Rel. prod. of ICT capital	Ratio of ICT expenditure and managerial wage bill
$\{\lambda_x\}^i$	-	Dist. of market access	Frac. of workers in formal manuf. & ratio of avg. sales b/w adopters and non-adopters
$\{\lambda_l\}^i$	-	Marginal cost of hiring workers	Ratio of wage bill on prod. workers and capital expenditure
$\{\lambda_s\}^i$	-	Marginal cost of hiring payroll rel. to contract workers	Ratio of wage bill on payroll and contract workers

5.1 Parameterization

We begin by discussing the calibration of the model. All parameters in the model can be classified into three categories, namely: (a) parameters of the production function and the productivity distribution $\mathcal{P} = \{\alpha_L, \alpha_Z, \beta_m, \theta\}$; and fixed costs of entry and adoption $\mathcal{F} = \{F_e, F_b\}$; (b) parameters related to the elasticity of substitution in consumption and production, $\mathcal{S} = \{\sigma_d, \sigma_m, \sigma_l, \sigma_z\}$; and (c) parameters that change with the adoption of broadband, $\mathcal{L} = \{\theta_Z^i, \lambda_x^i, \lambda_l^i, \lambda_s^i\}_{i\in\{0,1\}}$.

Starting with $\mathcal{P}$, we set α_L, the labor share in non-manufacturing, equal to 0.7 following Battisti et al. (2024); and $\beta_m = 0.21$ using the share of manufacturing in private consumption. We set $\alpha_Z = 0.22$, which is calculated as the residual expenditure share in sales after accounting for the expenditure shares of production labor and capital i.e., $\alpha_Z = 1 - \alpha_M$. Lastly, following the literature, we estimate the shape parameter of the Pareto distribution $\theta = 4.25$ top match the top 10% tail of the sales distribution.[12]

The set of parameters in $\mathcal{S}$ reflect the elasticities of substitution. On the demand side, we set $\sigma_d = 1.2$ following the median value in Broda and Weinstein (2006). We set the elasticity of

[12]This value is consistent with that in the literature, which range between 4-6 across contexts and countries.

substitution between labor and capital $(1+\sigma_m) = 3.7$, following Zarate et al. (2024) who estimate it for Colombia. $\{\sigma_l, \sigma_z\}$ govern the substitution between payroll and contract workers, and ICT capital and managerial workers respectively. Following Acemoglu et al. (2004), we estimate these parameters by estimating the following regression for a firm i in year t, similar to Equation (10):

$$\ln\left(\frac{E_c}{E_s}\right)_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \beta \ln\left(\frac{L_c}{L_s}\right)_{it} + \varepsilon_{it} \tag{12}$$

where E_c/E_s is the ratio of the wage bill on contract workers relative to payroll workers and L_c/L_s is the corresponding ratio of contract to payroll workers. Rearranging Corollary 1.1, note that $E_c/E_s = (L_c/L_s)^{\frac{\sigma_l}{1+\sigma_l}}$. Therefore, from the above equation, $\sigma_l = \frac{\widehat{\beta}}{1-\widehat{\beta}}$. We instrument L_c/L_s with the rollout of broadband (Z) as in Section 3.3. This gives us a value of $(1+\sigma_l) = 4.29$, indicating that payroll and contract workers are substitutes in production.

We then estimate σ_z in a similar way by estimating the following regression:

$$\ln\left(\frac{E_{L_a}}{E_{K_a}}\right)_{it} = \alpha_i + \alpha_{st} + \alpha_{jt} + \beta \ln\left(\frac{L_a}{K_a}\right)_{it} + \varepsilon_{it} \tag{13}$$

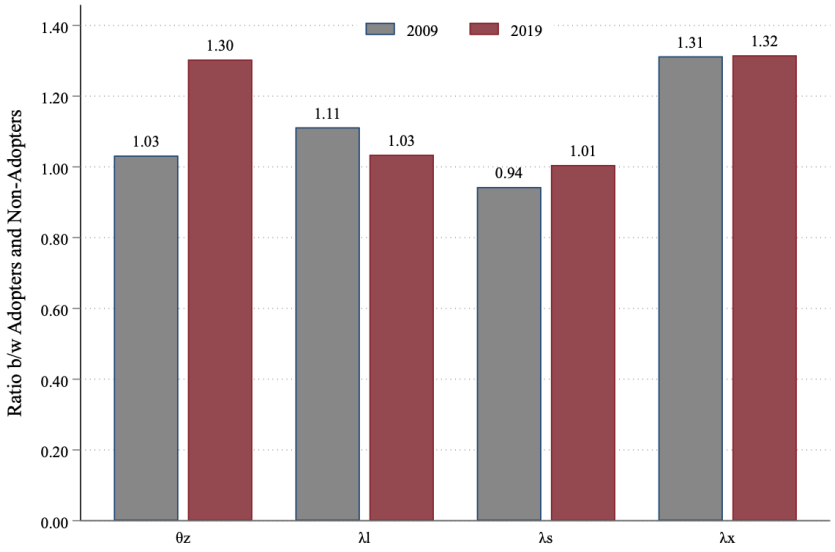
where E_{L_a} is the wage bill on managerial workers, E_{K_a} is the firm expenditure on computers, and L_a and K_a are the number of managerial workers and computers respectively. This yields a value of $(1+\sigma_z) = 1.56$, indicating a relatively stronger complementarity between managerial workers and ICT capital.

5.2 Estimation Strategy

The remaining parameters related to the fixed costs (2 parameters) and distortions in market access and input use for adopters and non-adopters (8 parameters) are calibrated using 10 moments in the data. From Corollary 1.1, note that for non-adopters and adopters $i = \{0, 1\}$: (i) λ_s^i can be identified using the ratio of the wage bill for payroll and contract workers $(w_s L_s / w_c L_c)$; (ii) λ_l^i can be identified using the labor to capital expenditure ratio $(w_p L_p / r K_p)$; and given λ_l^i (iii) θ_Z^i can be identified using the expenditure on ICT capital relative to managerial workers $(r K_a / w_a L_a)$. Turning to market access, λ_x^1 is identified using the ratio of average sales between adopters and non-adopters, while λ_x^0 is calibrated to match the share of workers in the formal manufacturing sector. Lastly, we use the fraction of entrants and adopters, along with Equations (4) and (5) to identify the fixed costs $\{F_b, F_e\}$.

We then use an algorithm to simulate these moments in two steps: first, we guess the parameter vector $\mathcal{W} = \{\mathcal{L}, \mathcal{F}\}$. Given $\mathcal{W}$, we solve for equilibrium wages and prices in equilibrium. To

Figure 2: Parameter Estimates in 2009 and 2019



Notes: The above figure reports the parameter estimates for the ratios θ_z, λ_l, λ_s, and λ_x for 2009 (first gray bars) and 2019 (second maroon bars) respectively. For a parameter of interest k, we define the ratio of the parameter between firms that do and do not adopt broadband internet i.e., $k = k^1/k^0$.

do this, we normalize the mass of total labor and capital in Colombia to be equal to 1, and use the overall price index in the economy $P = (P_m/\beta_m)^{\beta_m}(P_n/(1-\beta_m))^{1-\beta_m}$ as the numeraire. This allows us to obtain a vector of moments from the model, denoted by $M(\mathcal{W})$. The data counterpart is denoted by M_{data}. We choose the parameter vector $\widehat{\mathcal{W}} = \arg\min g(\mathcal{W})' g(\mathcal{W})$, where $g(\mathcal{W}) = (M(\mathcal{W}) - M_{data})/M_{data}$. We estimate the parameters $\widehat{\mathcal{W}}$ separately for 2009 and 2019 respectively.

5.3 Parameter Estimates

We now present estimates the four key parameters of interest, namely: $\{\theta_Z, \lambda_l, \lambda_s, \lambda_x\}$. As noted earlier in Section 2, in the absence of separate data on production and costs, these parameters can reflect *both* production or cost differences since they are identified from the ratios of related expenditures (see Corollary 1.1). To see this more clearly, assume that payroll and contract workers have a relative productivity of θ_s and a (true) relative distortion in marginal cost $\widetilde{\lambda}_s$. From Corollary 1.1, the expenditure ratio $w_s L_s / w_c L_c$ will be equal to $\theta_s \widetilde{\lambda}_s^{-\sigma_l} \equiv \lambda_s^{-\sigma_l}$. This implies that our estimated value of λ_s captures *both* productivity and cost differences. To separate them, we assume that the production technology between adopters and non-adopters remains the same i.e., $\theta_s^0 = \theta_s^1$ so that the *ratio* of $\lambda_s \equiv \lambda_s^1/\lambda_s^0$ between adopters and non-adopters captures changes in the underlying distortions in hiring payroll relative to contract workers i.e., $\widetilde{\lambda}_s/\widetilde{\lambda}_c$.

We follow a similar strategy to define θ_z, λ_l, and λ_x ratios between adopters and non-adopters.

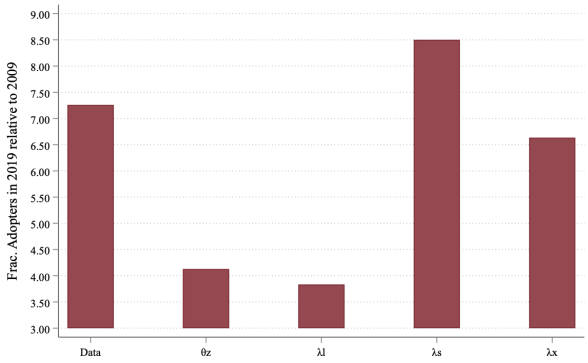
Figure 2 reports the values of these parameters separately for 2009 (gray bars) and 2019 (maroon bars). Three key insights emerge. First, relative productivity of ICT capital (θ_Z) is consistently greater than 1 and increases over time by around 30 p.p.. This suggests that broadband improves the efficiency of digital inputs in administrative tasks, consistent with firms substituting toward ICT capital in response to improved connectivity. Second, the estimates for hiring workers is mixed. The marginal cost of hiring workers (λ_l) is greater than 1, but declines by around 8 p.p. (7.2%) between 2009-19. On the other hand, the relative marginal cost of hiring payroll workers relative to contractual ones increases from 0.94 to 1.01 over time, reflecting the rise of hiring contract workers relative to payroll ones. Lastly, adopters face approximately 30% lower barriers to accessing markets and consumers than non-adopters, a gap that slightly widens over time. This is consistent with broadband enabling firms to serve more geographically dispersed markets or engage more efficiently with clients.

5.4 Decomposing the Impact of Broadband Adoption

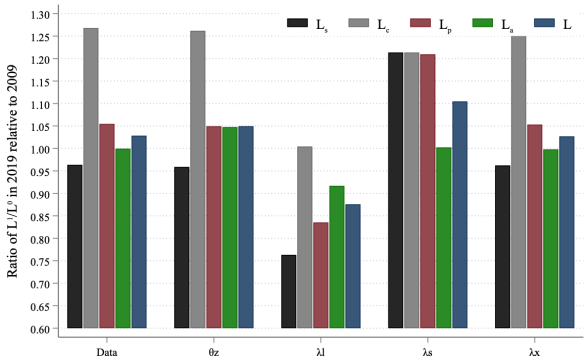
With parameter estimates in hand, we now use the model to assess how rapid broadband adoption between 2009-19 impacted the economy through each of its component channels. Specifically, we implement a series of counterfactuals that selectively remove one channel at a time, holding the others fixed. This allows us to quantify how broadband affects firm adoption, input allocations, and macroeconomic aggregates through market access (λ_x), labor frictions (λ_l, λ_s), and ICT productivity (θ_z). For a parameter $k = \{\theta_Z, \lambda_l, \lambda_s, \lambda_x\}$, we fix k to its value in 2009 and simulate the model by allowing other parameters to evolve according to their 2019 values. To be clear, note that each parameter k in year t is actually a ratio between adopters and non-adopters i.e., $k_t = k_t^1/k_t^0$. Therefore, in the counterfactual, we set the *gains* in broadband adoption from parameter k to be equal to its value in 2009 i.e., $k_{2019}^1 = k_{2019}^0 \times k_{2009}$.

Adoption of broadband. Figure 3 presents the results. We start by examining the fraction of firms who adopt broadband internet. Figure 3(a) (and Figure 1) show that the adoption rate increased from around 12% to 84% between 2009-19 — a 7x increase. Counterfactuals suggest that two channels were pivotal. If the productivity of ICT capital relative to administrative labor (θ_z) had not increased, the adoption rate would have risen only about fourfold. A very similar attenuation arises if we hold hiring frictions (λ_l) at their 2009 level. Each of these channels therefore account for roughly half of the observed expansion in broadband adoption. By contrast, fixing market access (λ_x) dampens adoption only modestly—from 7x to 6.5x, implying that improved market access explains about 10% of the rise in broadband adoption. Finally, because the rela-

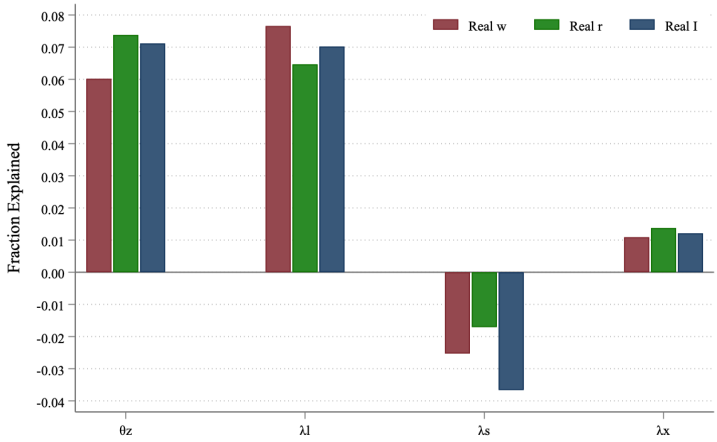
Figure 3: Impact on Adoption, Labor Demand, Factor Prices, and Welfare



(a) Fraction of Adopters



(b) Types of Workers



(c) Change in Real Factor Prices and Welfare

Notes: Figure (a) plots the ratio of the fraction of firms that adopted broadband in 2019 relative to 2009. Figure (b) plots how the ratio of different types of labor between adopters and non-adopters changes between 2009 and 2019. These include payroll workers (black bars), contract workers (gray bars), total production workers (maroon bars), managerial workers (green bars), and total firm size (blue bars). For both Figures (a) and (b), first set of bars indicate the data, while the remaining four sets reflect counterfactual adoption rates after fixing θ_z, λ_l, λ_s, and λ_x to their values in 2009 respectively. Figure (c) calculates the percentage change in real wages (maroon), rental rates (green), and income (blue) between 2009-19 that is explained by the respective parameter of interest.

tive cost of payroll workers (λ_s) actually *increased* over this period, a counterfactual in which λ_s remained at its (lower) 2009 level would have produced even higher adoption (around 8.5x).

Composition of workers. Figure 3(b) examines how these channels shaped the composition of employment. To do so, for a type of worker o (payroll, contract, production, managerial, and total), we calculate the ratio of workers between adopters and non-adopters in year t i.e., $L_t = L^1_{ot}/L^0_{ot}$. Figure 3(b) then shows how L_t changes between 2009 and 2019. The raw data

indicates that adopters shifted toward heavier reliance on contract workers over time, with a 25% increase relative to non-adopters; and away from payroll labor, which declined by about 5%. Firms with broadband also increased their production workers (by 5%) between 2009-10, with managerial employment remaining relatively unchanged. This is consistent with the empirical patterns discussed previously in Section 4.1. The model's counterfactuals help unpack the source of these changes across various channels.

Absent gains in ICT productivity, adopters would have expanded managerial (and hence total) employment by about 5%. Without reductions in hiring frictions, adopters would have employed 12.5% fewer workers overall, driven by declines of 8.3% in managerial and 15-20% declines in payroll, contract, and production labor. Conversely, had relative payroll costs remained at their (lower) 2009 level, adopters would have employed 21% more payroll workers with lower reliance on contractual ones (5%). Market access improvements, while important for adoption, did little to alter internal labor composition. These comparisons highlight how broadband's effect on organizational structure depends on the interplay between ICT substitution in administration and the relative costs of hiring and contracting workers. In other words, while increases in ICT productivity enabled firms to skew organizational productivity away from managerial workers, increasing access to workers more generally (along with their composition between payroll and contracts) enabled adopters to grow across all types of workers (including managerial ones), resulting in a much smaller increase in total firm size overall.

Factor prices and welfare. In Figure 3(c), we finally to turn to examining how various channels impacted overall real factor prices (wages and rental rates) and real income, which is our metric of welfare in the model. Let $\triangle m$ be the percentage change in an outcome variable m (say real income) between 2019-19. For each counterfactual simulation, we can then calculate $\triangle m^k$ as well, which measures the change in the outcome variable m holding channel k fixed. Therefore, $\triangle_k = 1 - \triangle m^k / \triangle m$ is the fraction of change in the outcome variable that is explained by the change in k between 2009-19. From Figure 3(c), ICT productivity or hiring frictions explain around 6-8% of the growth in factor prices and income, together account for most of the welfare gains from broadband. Because payroll costs (λ_s) increased over time, real incomes would have been higher in the counterfactual with 2009 levels, underscoring the dampening effect of payroll vs contracting rigidities. Market access improvements again play a secondary role at the aggregate level, explaining only around 1% of the observed increase in real factor prices and income.

Discussion. Taken together, these counterfactuals underscore the utility of the model in decomposing broadband's impact into various channels. They demonstrate that while demand-side access facilitated adoption, the equilibrium gains in employment and welfare came primarily from

changes in internal frictions — reductions in hiring costs and improvements in ICT productivity. At the same time, the increase in payroll costs muted some of these benefits. These results illustrate that broadband adoption is not a single-channel shock but a general-purpose technology whose economic effects depend on the joint evolution of multiple frictions. Without a structural framework, it would be difficult to reconcile the simultaneous rise in adoption, the reallocation of labor toward contracts, and the aggregate gains in welfare, all through a single channel.

6 Conclusion

This paper examines how the diffusion of broadband internet transformed Colombian manufacturing firms. Using rich panel data spanning over a decade, we document that adoption reshaped production, organization, and management practices along multiple margins: firms expanded sales and exports, hired more frontline production workers, primarily on contracts, and increased investments in capital, internal communication, and transportation. Embedding these patterns in a general equilibrium model of heterogeneous firms with endogenous firm productivity allows us to map the empirical changes into structural parameters. The estimates show that broadband simultaneously reduced barriers to market access, hiring, and contracting, and raised the productivity of ICT capital. Counterfactual simulations demonstrate that reductions in hiring frictions and improvements in ICT productivity account for much of the gains in adoption, aggregate employment and real income gains observed over the decade.

The broader implication of this paper is that broadband operates as a "general-purpose" technology. Its economic importance lies not in shifting a single margin, but in altering several frictions in interdependent ways. Without a model capable of capturing these interactions or rich data that can measure them, it would be difficult to reconcile channels through which firms realize operational gains from adopting broadband, along with their aggregate implications. From a more policy standpoint, the results highlight the value of complementing digital infrastructure with investments in complementary capabilities—such as workforce training, managerial practices, and ICT capital, which would allow firms to fully exploit internet connectivity. More generally, the framework developed here offers a template for analyzing the economic consequences of emerging digital technologies, from cloud computing to artificial intelligence, whose productivity effects also arise from the joint mitigation of multiple organizational constraints and market frictions.

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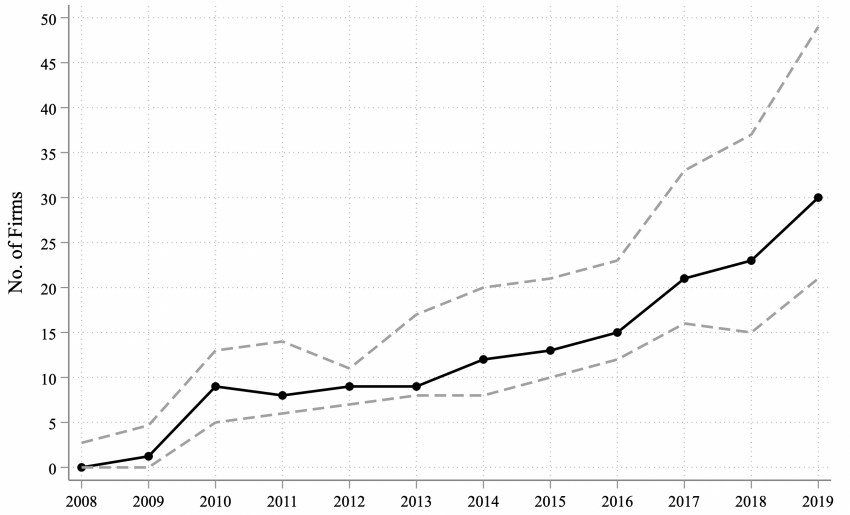
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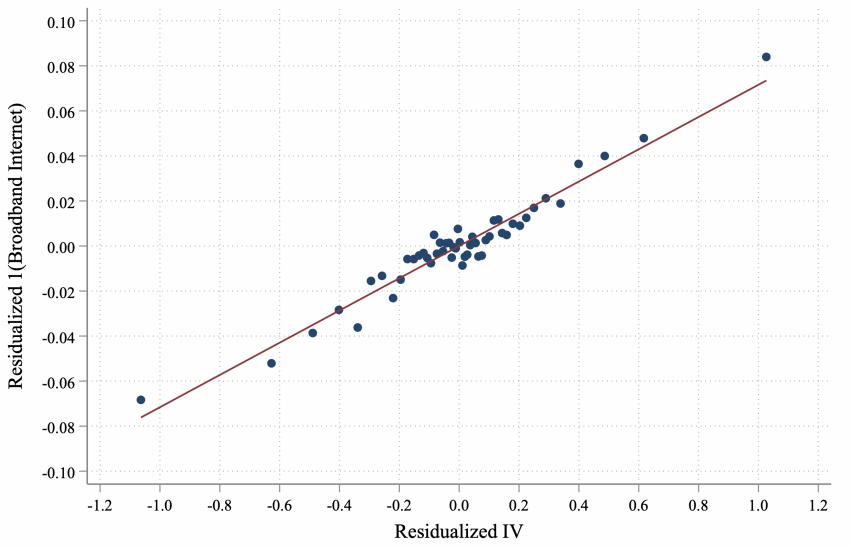
A Tables and Figures

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 4-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 Wage Bill Across Worker Types

	Total		Managers		Prof./Tech.		Workers	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Unconditional								
1(Broadband)	0.28***	2.75***	0.13***	0.38	0.05***	0.12	0.17***	2.53***
	(0.06)	(0.79)	(0.03)	(0.36)	(0.01)	(0.17)	(0.05)	(0.68)
Annualized $\triangle Y$		0.09		0.04		0.04		0.12
Panel B: Conditional on wL								
1(Broadband)			0.04*	-0.52**	0.03**	-0.07	0.04	1.22**
			(0.02)	(0.25)	(0.01)	(0.15)	(0.04)	(0.51)
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 $\triangle Y$				-0.05		-0.02		0.06
N	87626	87626	87626	87626	87626	87626	87626	87626
No. of firms	10806	10806 .	10806	10806	10806	10806	10806	10806
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 4-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 A3: 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 4-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 A4: Impact on Managerial Worker Contracts

	Salaried		Temp: Direct		Temp: Indirect	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Unconditional						
1(Broadband)	0.47***	-0.05	0.14	1.84*	0.32***	-0.83
	(0.14)	(1.58)	(0.09)	(1.04)	(0.07)	(0.84)
Annualized $\triangle Y$		-0.01		0.31		-0.14
Panel B: Conditional on L						
1(Broadband)	-0.07	-0.61	-0.08	1.61*	0.15**	-1.00
	(0.09)	(1.03)	(0.08)	(0.89)	(0.06)	(0.73)
L	0.58***	0.58***	0.24***	0.24***	0.18***	0.18***
	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	6.85	6.85	2.12	2.12	1.14	1.14
Annualized $\triangle Y$		-0.10		0.27		-0.17
N	92828	92828	92828	92828	92828	92828
No. of firms	11094	11094	11094	11094	11094	11094
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 4-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)	0.12	-2.52*	-0.01	0.62	0.02	-1.02*
	(0.09)	(1.33)	(0.05)	(0.61)	(0.04)	(0.60)
Annualized $\triangle Y$		-0.42		0.10		-0.17
Panel B: Conditional on L						
1(Broadband)	0.04	-0.65	-0.04	1.19**	0.00	-0.54
	(0.05)	(0.67)	(0.04)	(0.57)	(0.03)	(0.52)
L	0.64***	0.64***	0.20***	0.20***	0.16***	0.16***
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)
Control Mean	2.18	2.18	0.76	0.76	0.32	0.32
Annualized $\triangle Y$		-0.11		0.20		-0.09
N	92828	92828	92828	92828	92828	92828
No. of firms	11094	11094	11094	11094	11094	11094
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 4-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)	0.90***	10.96***	0.08	6.50***	0.38**	2.92
	(0.24)	(3.08)	(0.20)	(2.12)	(0.18)	(1.95)
Annualized $\triangle Y$		1.83		1.08		0.49
Panel B: Conditional on L						
1(Broadband)	0.28	1.65	-0.25	1.47	-0.02	-3.12*
	(0.19)	(2.23)	(0.18)	(1.99)	(0.16)	(1.71)
L	0.46***	0.46***	0.25***	0.25***	0.30***	0.30***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Control Mean	13.44	13.44	6.61	6.61	4.60	4.60
Annualized $\triangle Y$		0.28		0.25		-0.52
N	92828	92828	92828	92828	92828	92828
No. of firms	11094	11094	11094	11094	11094	11094
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 4-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 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 4-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. * is p<0.1 ** is p<0.05 and *** is p<0.01.

Table A8: 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 4-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.

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:

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

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:

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

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

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

$$L_p = \left[L_s^{\frac{\sigma_l}{1+\sigma_l}} + L_c^{\frac{\sigma_l}{1+\sigma_l}}\right]^{\frac{1+\sigma_l}{\sigma_l}} \qquad \text{(Labor Input)}$$

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

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

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:

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

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

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

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:

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

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:

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

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

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

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:

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

■

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: $\{w_c, w_s\} = \{1, \lambda_s\} \cdot \lambda_l w$.

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:

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

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:

$$\hat{X} = \hat{\Psi} \cdot \frac{z_e^{\gamma-\theta}}{1-\widetilde{\theta}}, \quad \text{where: } \hat{\Psi} = (1 - \xi^{1-\widetilde{\theta}})\Psi_0 + \xi^{1-\widetilde{\theta}}\Psi_1 \tag{14}$$

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:

$$\begin{aligned}\pi_1(z) = \frac{\Psi_1}{1+\sigma_d} z^{\gamma} - F_b \geq \pi^0(z) = \frac{\Psi_0}{1+\sigma_d} z^{\gamma} \\ z_b^{\gamma} = \frac{(1+\sigma_d)F_b}{\Psi_1 - \Psi_0}\end{aligned} \tag{15}$$

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:

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

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:

$$P_m = \left(\frac{1}{1-\widetilde{\theta}}\right)^{\frac{-1}{\sigma_d}} \cdot \left(\frac{1+\sigma_d}{\sigma_d}\right) \cdot \frac{\widetilde{\nu}}{z_e} \tag{16}$$
$$\text{where: } \widetilde{\nu} = \left[(1-\xi^{1-\widetilde{\theta}})\nu_0^{-\sigma_d} + \xi^{1-\widetilde{\theta}}\nu_1^{-\sigma_d}\right]^{\frac{-1}{\sigma_d}}$$

■

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:

$$\hat{L}_m = = \frac{\sigma_d}{1+\sigma_d} \cdot \Psi_L \cdot \hat{X} \tag{17}$$
$$\text{where: } \hat{\Psi}_L = (1-\xi^{1-\widetilde{\theta}})\Psi_{L0} + \xi^{1-\widetilde{\theta}}\Psi_{L1}$$
$$\Psi_{Lj} = \frac{\alpha_M \sum_o w_{oj}^{-(1+\sigma_l)}}{w_{pj}^{-\sigma_l}} \left(\frac{w_{pj}}{p_{Mj}}\right)^{-\sigma_m} + \frac{\alpha_Z w_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}}$$

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

$$\hat{K}_m = \frac{\sigma_d}{1+\sigma_d} \cdot \Psi_K \cdot \alpha_M \hat{X} \tag{18}$$
$$\text{where: } \hat{\Psi}_K = (1-\xi^{1-\widetilde{\theta}})\Psi_{K0} + \xi^{1-\widetilde{\theta}}\Psi_{K1}$$
$$\Psi_{Kj} = \frac{\alpha_M r^{-(1+\sigma_m)}}{p_{Mj}^{-\sigma_m}} + \frac{\alpha_Z \theta_{K_a j} r_{aj}^{-(1+\sigma_z)}}{p_{zj}^{-\sigma_z}}$$

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:

$$I = \frac{I^m}{\beta_m} = \frac{\sigma_d}{1+\sigma_d} \cdot \frac{\hat{X}}{\beta_m} \tag{19}$$

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:

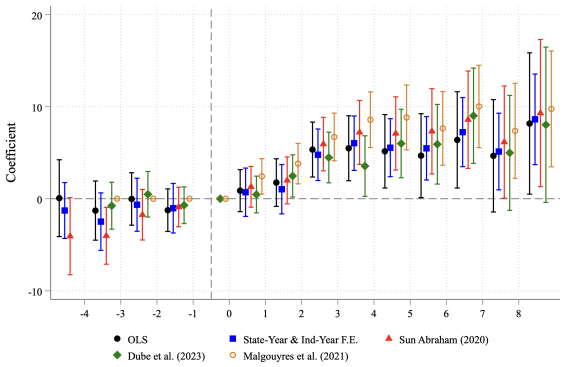
$$Y_{it} = \alpha_i + \alpha_t + \sum_{d=-4}^{d=4} \beta_d 1(D_{it} = d) + \varepsilon_{it} \tag{20}$$

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.

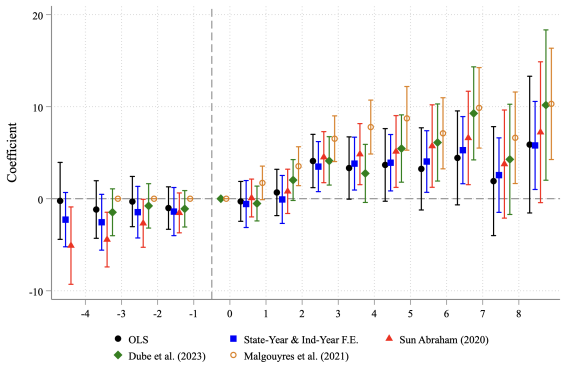
Figure C1 reports the plots from the above specification for four key outcome variables of firm performance, namely: (i) real value of production (Figure C1(a)); (ii) real revenues (Figure C1(b)); (iii) real costs of production (Figure C1(c)); (iv) real value-added (Figure C1(d)); (v) total workers (Figure C1(e)); and (vi) real capital expenditure (Figure C1(f)). 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.

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).

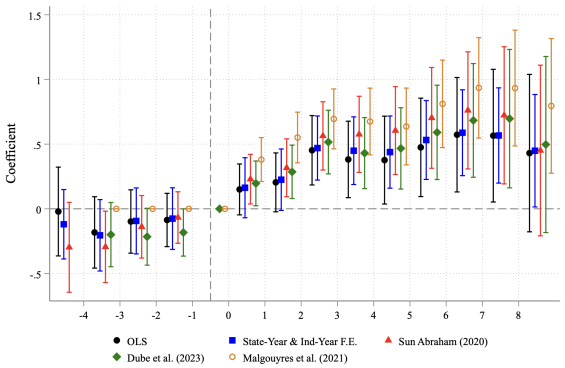
Figure C1: Impact of Internet Adoption on Firm Performance



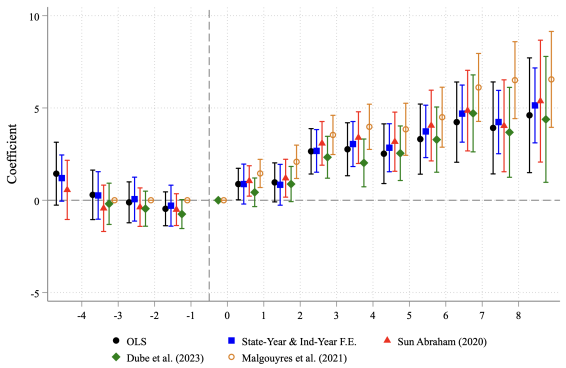
(a) Real Value of Production



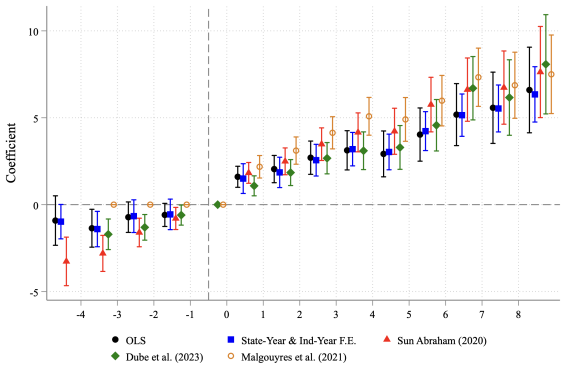
(b) Real Revenues



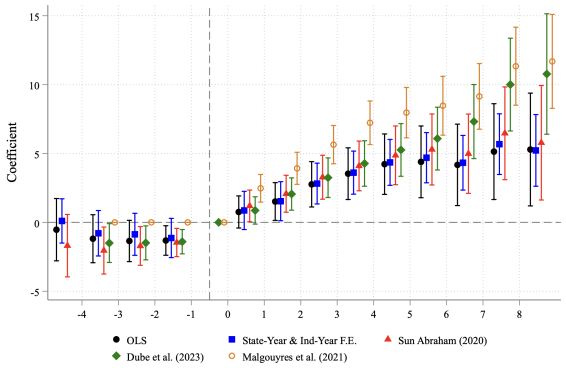
(c) Real Costs of Production



(d) Real Value Added



(e) Total workers



(f) Real K

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.