The Economic Impact of Internet Connectivity in Developing Countries*

Jonas Hjort
UCL
& BREAD & CEPR

Lin Tian
INSEAD
& CEPR

Abstract

Firms, workers, and consumers in developing countries are increasingly connected to each other and the rest of the world through the internet. Can this connectivity transform poor economies, as techno-optimists hope, or are there more deeply rooted barriers to economic development? Research on the topic is growing rapidly. In this article we provide an overview of existing evidence on the extent to which, and how, internet connectivity affects economic development. Not surprisingly, estimates vary widely with the context, particular outcome, and form of internet studied. Overall the literature points towards sizeable economic impacts in many—though not all—settings.

*jonas.hjort@gmail.com, lin.tian@insead.edu. We are grateful to Philippe Aghion, Peter Bergman, Victor Couture, Laura Derksen, Pushan Dutt, Mark Dutz, Antonio Fatas, Amit Khandelwal, Clement Mazet, Kiki Pop-Eleches, Eric Verhoogen, Robert Willig, and Chris Woodruff for helpful suggestions; to Jason Chen, Krishna Gambhir, Krishna Kamepalli, and Xuan Luo for excellent research assistance; and to the Private Enterprise Development in Low-Income Countries (PEDL) program for funding. Suggestions and feedback very welcome.

1 Introduction

When the internet in a form resembling the one we know today was created in the early 1980s, the world was a different place. Over 40 percent of the global population lived in absolute poverty: today, less than 10 percent do so. Brazil, China, and South Africa exported goods worth around 10 percent of their GDP in 1980: China's and South Africa's export share (but not Brazil's) has since more than doubled. In these and many other ways, economies—especially those of some developing countries—have transformed in tandem with the spread of internet connectivity. Roughly half the world now uses the internet, including 35 percent of Africans and 24 percent of South Asians, and access has accelerated in low-income countries. Worldwide, there are 14 broadband subscriptions per 100 people.[1]

This paper provides an overview of the nascent yet already sizeable empirical body of research on the economic impact of internet connectivity in developing countries. Few economists would expect internet connectivity to explain a large share of the economic progress made by poor countries since the early 1980s. Internet use remained low in the 1990s, rapidly growing only thereafter; concurrently, economic growth accelerated in many parts of the developing world in the 1980s and (even more so) 1990s. The forces that constrain economic activity and job creation in the "global South" are complex and some are likely difficult to address through technological means. In some contexts, Information and Communication Technology (ICT) can conceivably even stymie economic development, for example by reducing longer-term job growth through automation or a shift in activity away from manufacturing (Rodrik, 2016). However, many countries in the developing world are making significant investments in internet infrastructure, with the hope that connectivity can facilitate economic progress.

Researchers have documented notable and often large correlations between internet connectivity and aggregate measures of economic progress, such as for instance a country's total exports. Causal evidence on the economic impact of the "greatest invention of our time" (The Economist, 2012) in developing countries is more limited, but growing remarkably rapidly. Many high- and middle-income countries collect the type of labor force, firm, consumption, and educational attainment data needed to examine internet's impact in local economies. In the last 10-15 years, researchers (and some statistical agencies) have begun to collect suitable microeconomic data from low-income countries too. With access to such data and the arbitrary variation in local internet access that often arises from the gradual and partly geography-based roll-out of internet infrastructure across space and

[1] These numbers come from *Our World in Data*'s most recent data. The World Bank definition of absolute poverty is used. Fifty percent of East Asians and thirty-three percent of Latin Americans use the internet.

time, researchers have been able to convincingly estimate the causal impact of the internet in particular contexts. Increasing access to local administrative data registries and the growing feasibility of randomizing access suggests that evidence is likely to accumulate even more rapidly in the coming years.

To organize the literature, we develop a taxonomy of potential mechanisms driving the economic impacts of internet connectivity. The broadest distinction we make is between supply-side and demand-side forces. The former emphasize internet's impact on firm or factor productivity and production costs. Some supply-side forces can link internet connectivity relatively directly to labor productivity, whereas others are related to other aspects of firm performance. We further divide material on the labor productivity impact of internet into three parts: internet connectivity directly affecting workers' on-the-job productivity, internet-induced human capital accumulation, and internet-induced changes in firm-worker matching. Internet may influence firm level productivity for example by facilitating adoption of (other) technologies. We distinguish between two broad forms of demand-side forces through which internet connectivity may affect economic activity—by directly expanding firms', workers', or consumers' market access, and by addressing information frictions.

We first lay out a simple theoretical framework that highlights these different pathways to economic development in Section 2. The framework includes internet connectivity in a production function that highlights how producer—typically firm—outcomes may respond to the technology. For example, does internet substitute or complement labor or other inputs and technologies in the production process? Does it increase productivity? Does it help producers access bigger or better markets? The framework is kept highly stylized—it can broadly represent any production setting (including, for example, farms)—but enables clear expression of such hypotheses, and thus to organize and interpret the studies we cover.

To present the corresponding empirical evidence, we start by discussing studies that primarily expand understanding of supply-side mechanisms linking internet to economic outcomes.[2] Section 3 first covers evidence on internet connectivity affecting labor productivity, before summarizing the evidence on firm productivity more broadly. The second half of our overview on the empirical evidence of internet's impact on developing economies is in Section 4, which lays out existing findings that primarily expand understanding of demand-side mechanisms. We distinguish between market access channels and information friction channels. Finally, in Section 5 we briefly summarize the few stud-

[2] We emphasize "primarily": data constraints and the multi-function nature of the technology have made it difficult for many past studies to establish the particular theoretical mechanisms underlying their findings in detail so our allocation of studies to sections is necessarily loose.

ies that show direct evidence on how internet connectivity ultimately affects economic development itself, as measured by consumption or proxies for economic growth.

This paper focuses on research on developing countries, referencing studies of advanced country contexts only where comparison is informative and possible. Similarly, we focus primarily on firms and workers—the production side of the economy, broadly defined—but reference studies on consumption where especially relevant.[3] Some existing overview pieces cover related topics: for example, Goldfarb & Tucker (2019) survey the research on "digital economics" in rich countries and Draca et al. (2007) the micro and macro literature on the impact of ICT on productivity in rich countries. Our focus is narrower: the economic impact of internet connectivity. We pay special attention to issues that may amplify or reduce the consequences of internet connectivity in developing economies, such as information frictions (see, e.g., Allen, 2014). We cover studies of relatively direct pathways from connectivity to economic outcomes. Zhuravskaya et al. (2020) survey the literature on the political impact of internet connectivity and social media. Atkin & Khandelwal (2020) and Verhoogen (2020) provide overviews of the broader literature on firm-level upgrading and how distortions alter the impact of trade in developing countries, respectively. Their overlap with this paper is modest. The World Bank's World Development Report for 2016 provides a more expansive overview of evidence on the causes and consequences of ICT adoption in developing countries with a focus on policy recommendations (World Bank, 2016).

2 Theoretical Background

To fix ideas, we present a simple model that relays the most salient mechanisms through which internet connectivity can affect economic outcomes. We organize the discussion through a production function framework somewhat akin to the one in Verhoogen (2020) but adapted here to focus on internet connectivity. The model is kept intentionally simple and general to elucidate the impacts of internet connectivity within and beyond firm boundaries—such as firm-level outcomes, labor income and wage inequality, and effects

[3] As we discuss in sub-sections 4.1 and 5, some of the best existing evidence on economic impacts of internet in poor countries comes from settings in which connectivity enables *consumers* to use internet-enabled technologies, such as e-commerce or mobile money, but where the associated increase in economic activity nevertheless requires firms or producers to reach consumers through the same technologies. Of course, use of internet technology on the demand-side of an economy can affect economic activity in and of itself (for example by enabling buyers' search for (offline) sellers). There is little evidence of economic impact of internet connectivity through such pure consumer-side channels however. Conversely, many of the studies we cover document ways in which internet connectivity improves firm or producer performance regardless of whether consumers simultaneously use the technology.

on the wider economy—through various components built into the framework. To do so, we impose a minimal set of assumptions on the production function, the factor market, and the output market.

2.1 Set-up

Consider an economy that consists of many firms, indexed by j. Each firm produces with the following production function:

$$\begin{aligned} Y_j &= F(L_j, M_j, K_j; \theta) \\ &\equiv A_j(\theta) \left(A_j^L(\theta, \nu) L_j(\theta) \right)^{\alpha^L} \left(A_j^M(\theta) M_j(\theta) \right)^{\alpha^M} \left(A_j^K(\theta) K_j(\theta) \right)^{\alpha^K}, \end{aligned} \tag{1}$$

with $\alpha^L + \alpha^M + \alpha^k = 1$.[4] In the production function, Y_j represents the output, $L_j(\theta)$ denotes the aggregate labor inputs, $M_j(\theta)$ is a composite of intermediate inputs, and $K_j(\theta)$ is a composite of all other production inputs, including physical capital and management capital. Note that $L_j(\theta)$, $K_j(\theta)$, and $M_j(\theta)$ represent quality adjusted quantity of production inputs: $L_j(\theta)$, for example, can be interpreted as efficiency units of workers that firm j hires. A_j, A_j^L, A_j^M, and A_j^K are technological parameters. In $A_j^L(\cdot)$, the parameter ν denotes potential firm-to-labor mismatch, where greater extent of mismatch reduces labor productivity. Finally, θ represents the level internet connectivity in the economy, which is assumed to be exogenously given—i.e., conditioning on internet being available in the country, firms take internet technology as given and do not selectively adopt the technology in their production.[5] Given the specification in (1), internet connectivity, θ, can potentially affect firm's total factor productivity and factor-specific productivities. It can further affect labor productivity by affecting the effect of firm-to-worker mismatch on labor productivity. Finally, we also allow internet connectivity to impact the set of production inputs available to the firm.

The factor market is governed by the following supply curves:

$$W_j^L = S(L_j, Z^L; \theta); \tag{2}$$

[4] We work with a standard Cobb-Douglas production function to illustrate different hypotheses on the impact of internet connectivity. This discussion, however, can be applied more generally to other production frameworks.

[5] There is limited empirical evidence on the determinants of internet adoption for firms in developing countries. Existing literature shows that firm internet take-up may be correlated with their export status (Clarke & Wallsten, 2006) and the adoption of digital technology in manufacturing firms is correlated with productivity growth (Cusolito et al., 2020).

$$W_j^M = S(M_j, Z^M; \theta); \tag{3}$$

$$W_j^K = S(K_j, Z^K; \theta), \tag{4}$$

where W_j^L, W_j^M, and W_j^K respectively reflect the prices of labor, intermediate material, and other production inputs; Z^L, Z^M and Z^K denote all external factors in the labor, material, and other inputs markets, respectively. Similar to the production function, we allow internet technology θ to affect factor prices.

In the output market, firms can sell their output through two channels: a traditional offline market and an online platform. Let P_j^{offline} and P_j^{online} denote firm j's output price in the traditional market and on the online platform, respectively.[6] The demand curves the firm faces are given by:

$$P_j^{\text{offline}} = D(Y_j^{\text{offline}}, Y_j^{\text{online}}, Z^y, \eta; \theta); \tag{5}$$

and

$$P_j^{\text{online}} = D(Y_j^{\text{online}}, Y_j^{\text{offline}}, Z^y, \eta; \theta), \tag{6}$$

where Y_j^{offline} and Y_j^{online} denote firm's demand on the offline platform and the traditional offline market respectively, and Z^y includes all external factors in the output market. η is a parameter denoting the extent of information frictions in the output market for firm j. In particular, η can be interpreted as the difference between real product quality and the quality observed by the consumers, where greater η lowers the firm's output demand. The set of functions reflect the potential impact of internet connectivity on firm demand.

We finally assume that each firm faces a schedule of additional costs, which include an entry cost f_j^{entry}, fixed production cost f_j^{fixed}, a fixed cost of online distribution $f_j^{\text{online}}(\theta)$, which is a function of internet connectivity, and a variable cost of online shipping costs $f_j^{\text{variable}} > 0$, which is a fixed proportion of the online price. The firm's decision is to choose the amount of each input used for production, i.e., L_j, M_j, and K_j, in addition to the output share to be sold through online vis-a-vis offline markets, in order to maximize profit. Formally,

$$\begin{aligned} \max_{L_j, M_j, K_j, Y_j^{\text{offline}}, Y_j^{\text{online}}} \quad \Pi_j \quad = \quad & P_j^{\text{offline}} \cdot Y_j^{\text{offline}} + (1 - f_j^{\text{variable}}) P_j^{\text{online}} \cdot Y_j^{\text{online}} - W_j^L \cdot L_j \\ & - W_j^M \cdot M_j - W_j^K \cdot K_j - f_j^{\text{entry}} - f_j^{\text{fixed}} - f_j^{\text{online}}, \end{aligned} \tag{7}$$

[6]We do not impose that the firms must charge the same price when selling their output to the final consumers and to other firms as intermediate inputs.

$$\text{s.t.} \qquad Y_j^{\text{online}} + Y_j^{\text{offline}} \leq F(L_j, M_j, K_j; \theta). \tag{8}$$

2.2 Impact of internet Connectivity

In the set-up above, we allow internet connectivity to affect economic outcomes through multiple channels, namely the production function, the factor market, and the output demand. The former two channels emphasize internet's impact on firm or factor productivity and production costs; we label them *supply-side* forces. The latter, on the other hand, is related to a firm's ability to access different markets, and is thus interpreted as a *demand-side* force. Most of impacts documented in the literature appear to operate at least in part through these two broad channels.

2.2.1 Supply-side Forces

Under our framework, the supply-side effect of internet connectivity can be summarized as follows: better internet connectivity improves firm productivity, i.e., $\frac{dY_j}{d\theta} > 0$. However, this total effect of internet on firm productivity can be realized through several channels. We emphasize below the most common ones documented in the literature and briefly mention other possible channels.

Internet and Worker Productivity

Internet connectivity can assist workers, acting as labor-augmenting or labor-saving technical change. Defining labor productivity as $\frac{\partial Y_j}{\partial L_j}$, we can summarize the labor-productivity-enhancing effect of internet technology as a second-order effect on output through labor productivity, i.e., $\frac{\partial^2 Y_j}{\partial L_j \partial \theta} > 0$.

The literature documents multiple forms of internet-worker interactions and illustrates the associated productivity implications. First, internet connectivity can enhance labor productivity *directly*, making internet adoption a labor-biased technical change. Formally, we have $\frac{\partial}{\partial \theta}\left(\frac{\partial Y_j}{\partial L_j}\right) > 0$. This can be achieved, for example, through an increase in $A_j^L(\theta)$, where $\frac{dA_j^L}{d\theta} > 0$.

Additionally, internet access may facilitate human capital development, for example through on-the-job training or other training opportunities outside the workplace. This can also increase workers' productivity, i.e., $\frac{dL_j}{d\theta} > 0$.

Finally, internet can increase labor productivity through better firm-to-worker matching. This possibility is especially salient in labor markets where worker quality or firm-to-worker match quality is not perfectly observed. Through the lens of our model, we have $\frac{\partial A_j^L}{\partial \nu} < 0$, which denotes the negative effect of mismatches on labor productivity, and $\frac{\partial^2 A_j^L}{\partial \nu \partial \theta} < 0$, which denotes that internet connectivity reduces the extent to which labor market mismatches affect the labor productivity.

Internet and Technology Adoption

In addition to labor, internet technology can interact with other production factors within a firm. Such interactions can similarly be expressed as a second-order effect on output through the productivity of intermediate materials and other production inputs, i.e., $\frac{\partial^2 Y_j}{\partial M_j \partial \theta} > 0$ and $\frac{\partial^2 Y_j}{\partial K_j \partial \theta} > 0$.

In response to such productivity changes, firms may act on the intensive margin—changing the amount of the existing set of production inputs—or the extensive margin, by adopting new technologies or using different intermediate inputs.

Internet's Other Supply-Side Productivity Effects

Internet connectivity can also affect the firm's total factor productivity (TFP). The model represents this as a direct impact of internet on firm productivity, i.e., $\frac{\partial A_j}{\partial \theta} > 0$.

2.2.2 Demand-side Forces

Internet connectivity can also affect economic outcomes by easing demand-side constraints. We consider two broad forms of demand-side constraints: market access barriers and information frictions.

Internet and Market Access

Internet can give firms access to markets that are otherwise inaccessible. The most studied example is e-commerce, whose rise was facilitated by high-speed internet. E-commerce offers firms an online platform to sell their products, in addition to the traditional offline market. Engaging in e-commerce can expand the market a firm can access, but also incurs costs. Improvements in internet connectivity can increase the benefits and/or reduce the costs of engaging in e-commerce.

In our model, internet can reduce the fixed cost of online distribution, which determines if a firm decides to sell its products online: $\frac{\partial f_j^{\text{online}}(\theta)}{\partial \theta} < 0$. Internet connectivity can also increase total demand for the firm's output through the online distribution platform: $\frac{\partial Y_j^{\text{online}}}{\partial \theta} > 0$. In addition to providing the opportunity to directly sell output online, internet connectivity may also increase offline demand for the firm's products, $\frac{\partial Y_j^{\text{offline}}}{\partial \theta} > 0$. Furthermore, this may also generate additional gains through competition effects in general equilibrium. If internet reduces the cost of reaching customers equally across all firms, i.e., $\frac{\partial (Y_j^{\text{offline}} + Y_j^{\text{online}})}{\partial \theta} = \frac{\partial (Y_{j'}^{\text{offline}} + Y_{j'}^{\text{online}})}{\partial \theta}$, $\forall j \neq j'$, then this will lead to allocative efficiency gains for the economy as a whole as the most productive firms are now able to serve more customers.

Internet and Other Forms of Information Frictions

Other forms of information frictions may also characterize the output market, for example buyers may not know all sellers' prices or the relevant match qualities. The parameter η that denotes the extent of such information frictions illustrates this market feature. Greater η lowers the firm's output demand, whereas better internet may reduce the extent to which such frictions affect the output market. Formally, we have $\frac{\partial (Y_j^{\text{offline}} + Y_j^{\text{online}})}{\partial \eta} < 0$ and $\frac{\partial^2 (Y_j^{\text{offline}} + Y_j^{\text{online}})}{\partial \eta \partial \theta} < 0$.

3 The Supply-side Impact of Internet Connectivity

In this section, we discuss empirical literature that focuses primarily on the supply-side mechanisms linking internet connectivity to firm performance and other economic outcomes. We first summarize evidence on the impact of internet on labor productivity in Section 3.1, before discussing the impact on other aspects of firm productivity in Section 3.2.

3.1 Internet and Labor Productivity

3.1.1 Internet as labor-biased technical change

Internet connectivity can plausibly make workers either more or less productive relative to other less labor-intensive ways to produce. Empirically, internet appears to be a labor-biased form of technical change in most developing country contexts. Chiplunkar & Goldberg (2022) examine the employment impacts of expansion in *mobile* internet coverage—enabled by upgrading of 2G to 3G networks—in 14 low- and middle-income countries, where mobile networks are by far the most common way to access the internet. Employing an instrumental variable strategy that relies on the slower expansion of 3G networks in regions with a higher frequency of lightning strikes per square kilometer, they find that

3G coverage substantially increases employment rates. They estimate for example that a 10 percentage point increase in 3G coverage increases the fraction of individuals who are employed by 2.1 percentage points

Chen et al. (2019) examine a policy reform in China around 2000 that increased internet speeds. Comparing firms and workers in prefectures that were more versus less intensively exposed in a difference-in-differences approach, they document significant increases in workers' wages and firm productivity in response to the internet-upgrading program. Almeida et al. (2017), Poliquin (2021), and Tian (2019) also exploit a roll-out of new internet infrastructure, using Brazil's comprehensive administrative data on workers and wages to examine the evolution of labor productivity during the country's gradual broadband expansion. They find that broadband access increases workers' wages on average.[7] Many studies provide more descriptive but otherwise comparable evidence, with similar findings.[8] Khanna & Sharma (2018), for example, use firm-level data from the Indian manufacturing sector for the period 2000–2016 and find that labor productivity is positively correlated with investments in both IT and R&D.

These findings pointing towards a direct impact of internet connectivity on wages and employment have important implications. A few studies go a step further and relate such labor market impacts to how "downstream" welfare proxies ultimately respond. Bahia et al. (2020) examine how the roll-out of mobile broadband affects labor market outcomes, household consumption, and poverty in Nigeria. They use micro data that combines information from three waves of longitudinal household survey with information on the deployment of mobile broadband services between 2010 and 2016. These data enable the authors to infer when each local area gained internet access. Using a difference-in-differences approach tracking individual households, they show that in the Nigerian context, internet connectivity increases labor force participation and employment. Bahia et al. (2020) also document a simultaneous increase in consumption and fall in the proportion of households living in poverty. We return to this in Section 5.

Some studies in this strand of work uncover important heterogeneity in internet's wage and productivity effects across demographic groups. Several find that internet connectivity appears to especially benefit female workers. Chiplunkar & Goldberg (2022)

[7] Poliquin (2021) for example finds that a firm's wages increase by 2.2 percent following broadband adoption on average; that upper-level employees benefit more than employees at lower wage levels but wage inequality among workers decreases or is unchanged; and that both new hires and firms' existing employees benefit from the broadband adoption.

[8] An exception is Dutz et al. (2017). They find a negative correlation between increased internet access in Brazil and average wages. However, they also find evidence pointing towards internet access shifting employment away from trade, public administration, and public utilities and into sectors such as finance and manufacturing with potential for future output expansion.

show that 3G networks greatly increase female labor force participation rates—by 4.9 percentage points from a 39 percent base rate—while the impact on male labor force participation rates (whose base rate is 80 percent) is nill or slightly negative. However, the authors also show that 3G coverage affects the *types* of jobs men and women hold differently. A stark pattern is for example that men transition away from unpaid agricultural work into operating small agricultural enterprises, while women are more likely to take unpaid jobs in agriculture and to operate more small businesses in all sectors.

Chun & Tang (2018) study how Vietnamese firms taking up ICT technologies affects their demand for female and skilled labor. The researchers instrument a firm's adoption of ICT with a province level time varying index measuring the quality of ICT that changes partly as the result of central government initiatives. They find suggestive evidence that firms that increase their ICT use also increase their female labor share.[9] Dutz et al. (2017) document similar evidence in Brazil. They find that employment growth from internet arrivals in different areas of Brazil is greater among low-skilled and female-filled jobs.[10] This is consistent with the evidence on adoption of computerized machinery and the relative wages and employment of women in Mexican firms documented in Juhn et al. (2013).[11] The internet-induced improvements in labor market outcomes in Nigeria and Jordan, shown in Bahia et al. (2020) and Viollaz & Winkler (2021), respectively, were also especially large for women.[12] In contrast, Bahia et al. (2021), using Tanzanian data, find no effect of access to mobile broadband on overall female labor force participation or wage employment, but that access causes high-skilled women to shift out of farm work into self-employment and family enterprises.[13]

Internet technology may be more complementary with (or less substitutable for) higher skilled workers or those specializing in work usually associated with highly educated workers, such as non-routine tasks. Formally, this would imply $\frac{\partial^2 Y}{\partial\theta\partial L_{nonroutine}} > \frac{\partial^2 Y}{\partial\theta\partial L_{routine}}$.

[9] Specifically, Chun & Tang (2018) find that a 10 percent increase in a firm's number of computers connected to broadband internet is associated with an increase in the firm's share of female workers of about 3.5 percentage points.

[10] See Dutz et al. (2012a) for results on countries in other regions.

[11] Using a panel of Mexican establishments, Juhn et al. (2013) show that the tariff reductions associated with NAFTA incentivized more productive firms to modernize their technology, which reduces the need for physically demanding tasks (that have greater relative demand for male workers). As a result, the relative wage and employment of women specializing in blue-collar tasks increased.

[12] Instrumenting internet adoption with the interaction between distance to the nearest 3G tower and pre-roll-out internet access cost, Viollaz & Winkler (2021) find that a 1% increase in internet access in Jordan increases female labor force participation by 0.83 percentage points, which is largely driven by an expansion in online job search by female workers.

[13] Zhao (2020) also finds that availability to internet is associated with a 5 to 7 percentage point increase in the probability of self-employment in rural China, possibly by weakening the financial and transaction constraints.

If internet technology raises the (relative) marginal productivity of highly skilled or non-routine workers, this will tend to increase labor market inequality—a trend that has been documented in some rich country contexts.[14]

The evidence on internet technology's skill bias in developing countries is more mixed. Khanna & Sharma (2018) show descriptive evidence of complementarity between ICT and non-routine tasks contributing to labor productivity growth in India. Almeida et al. (2017) use data from Brazil, where municipalities gradually gained increased access to internet technology between 1999 and 2006. They estimate how changes in technology affect demand for routine skills by examining how hiring evolves across different industries—which are differentiated by their internet technology intensity—and municipalities with differential access to internet, as access increases. They find that technology-intensive industries located in cities with earlier access to internet reduce their reliance on routine tasks labor. Chen et al. (2019) find that Chinese firms in more skill intensive industries and with more educated workers accrue greater benefits from the adoption of high-speed internet. Dutz et al. (2017) also find evidence that, within the manufacturing sector in Brazil, internet access appears to raise wages in medium- and high-skill jobs, but not in low-skill jobs. Finally, by comparing households in Tanzania who gain coverage to mobile broadband with those not affected by the coverage roll-out, Bahia et al. (2021) show evidence that broadband availability induces increased labor force participation and wage employment among young, educated men.

In contrast, Cariolle et al. (2019)—using a sample of ∼30,000 firms in 38 poor countries but a less conclusive empirical strategy—show results indicating that greater internet use by manufacturers may increase employment of production workers more than non-production workers. Hjort & Poulsen (2019) show that the gradual arrival of fast internet infrastructure in Africa appears to increase employment rates even for less educated worker groups, although their estimates are considerably larger for more-educated workers. Brambilla (2018)'s model of ICT progress and labor markets, which allows for firm heterogeneity and wages that vary across firms, provides a possible explanation of this finding. The employment benefits accruing to less educated individuals may be part

[14] Broadband internet and related internet technologies have been shown to improve the labor market outcomes and productivity especially of skilled workers in the US and Europe (see, e.g., Autor et al., 1998, 2003; Goldin & Katz, 2007; Autor et al., 2008; Atasoy, 2013; Michaels et al., 2014; Akerman et al., 2015; Barrero et al., 2021). Acemoglu & Autor (2011) and Michaels et al. (2014) find evidence that, when the labor market is categorized into three groups by skill, middle-skill workers are the most substitutable with ICT in rich countries. Katz et al. (1999), Bond & Van Reenen (2007), and Goldin & Katz (2007) provide overviews of the skill-biased technical change literature on rich countries' labor markets. Research on new technologies' factor bias in developing countries has mostly focused on how technology-driven improvements in agricultural productivity affect the movement of labor in and out of agriculture (see, e.g., Foster & Rosenzweig, 2010).

of the reason why the internet-induced improvement in labor market outcomes in Nigeria shown in Bahia et al. (2020) are (especially) large in rural areas. Marandino & Wunnava (2017) estimate the impact of an expansion ICT program in Uruguay and find that having a laptop significantly increases the family labor income by 27% for all those household below median income, likely due to the associated access to internet. The quantile regressions shows further that the positive effect is larger for households at the lower quantiles (e.g., 49% at the 10th and 33% at the 20th quantiles). Overall the evidence so far suggests that the skill bias of internet technology varies considerably by context. More research, especially on the possible reasons explaining the differences between developed and developing economies, is needed.

3.1.2 Internet and human capital development

In the previous sub-section we saw evidence that internet connectivity can increase labor productivity by converting the "efficiency units" of a worker into more output, that is, $\frac{\partial}{\partial \theta}\left(\frac{\partial Y}{\partial L}\right) > 0$. There is also evidence that internet can increase the productivity embodied in workers themselves through human capital development: $\frac{dL}{d\theta} > 0$.

One possibility is that internet connectivity facilitates on-the-job training. Hjort & Poulsen (2019) find evidence consistent with this: in six African countries included in their sample, connected firms were differentially more likely to provide on-the-job training to their employees after submarine internet cables increased internet speeds on the continent. Using Tunisian firm level manufacturing data, Mouelhi (2009) also finds suggestive evidence of complementarity between ICT and firms' investments in their workers' human capital.

A related literature examines the human capital development effect of internet at home or in schools. Bianchi et al. (2020) study the 2004-2007 roll-out of the "largest education-technology intervention in the world to date," which connected high-quality teachers in urban areas of China with more than 100 million students in rural primary and middle schools through the use of satellite internet. Comparing individuals across both birth cohorts and locations, they show that exposure to the program in middle school significantly improved students' long-run academic achievement, labor market outcomes, and internet and computer use, but may have had a mild negative impact on noncognitive traits. Using these results, the authors estimate that the program reduced urban-rural education and earnings gaps by a remarkable 21 and 78 percent.[15]

[15] Relatedly, Malamud & Pop-Eleches (2011) find that Romanian children who win a voucher to purchase a computer display significantly lower school grades but show improved computer skills and cognitive skills, though they do not study the extent to which these effects are driven by internet access.

Exploiting the gradual roll-out of internet access in Peru, Lakdawala et al. (forthcoming) provide evidence that schools that gain access to internet connections display moderate, positive gains in math test scores in the short run, and that the effects grow for subsequent cohorts. Focusing on a particular learning tool function of internet in schools, Derksen et al. (2019) report evidence from an experiment randomizing student access to Wikipedia in Malawian boarding schools. Like Lakdawala et al. (forthcoming), they find a significant relative increase in test scores among students in the treatment group. They also find particularly pronounced positive effects among low achievers. In contrast, in an experiment also conducted in Peru, Malamud et al. (2019) find no effect of providing home high-speed internet access on student test scores or grades, though they do find an improvement in digital proficiency. Bessone et al. (2020) similarly find no effect of mobile internet on test scores. They use a heterogeneity-robust event study design to study impacts of the rollout of 3G mobile internet availability across Brazilian municipalities.[16]

Internet connectivity can affect educational achievement also through less direct channels. Oster & Steinberg (2013) show that the establishment of ICT service centers—which provide desirable jobs, and need reliable internet access to operate—promote enrollment in nearby primary schools in India. Siebert et al. (2018) study a social media-based teacher-parent feedback program in rural China and find positive effects of the program on test scores.

3.1.3 Internet and firm-worker matching

Another channel through which internet can affect labor productivity is firm-worker matching. This is especially plausible in labor markets with frictional unemployment where search frictions constrain the matching process, and where worker quality and firm-worker match quality is hard to observe or infer. In the framework in Section 2, the parameter ν_{ij} represents the extent of mismatch between worker i and firm j: for instance, the inverse of the arrival rate for a match between worker i and firm j. Better internet connectivity can effectively expedite the arrival rate for a match. Formally, we would then have $\frac{\partial^2 A_j^L}{\partial \nu_{ij} \partial \theta} < 0$.

The most direct evidence on such a mechanism comes from rich country labor mar-

[16] There is a parallel literature on the effect of ICT on educational attainment in rich countries with mixed findings. Faber et al. (2015) for example find that even large changes in available broadband connection speeds have no effect on educational attainment in England. To estimate the causal effect of upgrades in ICT on educational outcomes, they exploit boundary discontinuities across usually unobserved exchange station catchment areas. They attribute the precisely estimated net zero effect to opposing student time-supply and productivity-per-unit-of-time-spent-studying responses. Goolsbee & Guryan (2006) study a California program to subsidize internet access in schools and find no significant effects on student performance. Vigdor et al. (2014) find that household internet access is negatively associated with student performance in South Carolina.

kets. Using National Longitudinal Survey of Youth (NLSY97) data for 2005-8 in the US, Kuhn & Mansour (2014) show that unemployed people who look for work online are re-employed about 25 percent faster than comparable workers who do not search online.[17] Investigating more directly, Bhuller et al. (2020) combine the plausibly exogenous roll-out of broadband infrastructure in Norway with comprehensive administrative data on hiring firms, job seekers, and vacancies. This allows testing of key predictions from standard search and matching models.[18] The paper finds that broadband internet increases the speed of matching: more firms recruit online, vacancy duration is shorter, and fewer firms fail to fill posted vacancies. These changes in firm-working matching ultimately benefit workers, who earn 3 percent higher starting wages; see 3 percent longer employment duration; and a 2.4 percent higher re-employment rate after job loss. Lederman & Zouaidi (2020) take a different but related approach and attempt to quantify the relationship between the "incidence of the digital economy"—internet usage—and long-term frictional unemployment across countries, finding a robust negative relationship between the two.

Causal evidence is lacking, but as search frictions are severe in developing economies (see, e.g., Abebe et al., forthcoming; Bassi & Nansamba, 2019; Hardy & McCasland, 2020), internet's potential to impact labor productivity through firm-worker matching may be greater in such labor market contexts. Abebe et al. (forthcoming) randomize two treatments among those who call to inquire about job openings for a clerical position in Ethiopia. One is an upfront application cost reduction. Applicants from the application incentive group have higher cognitive ability relative to the control group. This suggests that technologies that reduce the costs of applying to jobs—like internet may do—can improve selection in contexts like Ethiopia.[19]

[17]The study is descriptive, but the results are robust to a rich set of controls including job-seekers' AFQT scores, which are associated with unobservable ability differences. Interestingly, the result in 2005-8 contrasts with previous results for 1998–2001 (Kuhn & Skuterud, 2004), raising the intriguing possibility that changes in internet technology and/or labor markets themselves have made internet an effective tool for increasing labor productivity through firm-worker matching in the U.S. only recently.

[18]As the authors explain, "while improved matching implies shorter duration of both vacancies and unemployment, improvements in productivity or lower hiring costs [alternative forces that represent competing hypotheses] would lead to longer vacancy duration, and lower search costs for job seekers would increase unemployment duration." (Bhuller et al., 2020)

[19]Groh et al. (2015)'s researcher-organized matching market in Jordan was not successful in creating new matches and jobs, suggesting that internet itself might not do so either. On the other hand, Ahn et al. (2020) presents a different picture. The paper studies the effect of information frictions on job search behavior in Iraq. The variation comes from randomizing the provision of information on a given applicants' ranking for various positions posted on an online job portal. The authors find that the treatment has very little effect on the volume of applications but causes the treated group to target those jobs postings that they are ranked higher in and that the effect is driven by entry-level workers. They go on to conclude that inaccurate beliefs (or more broadly speaking, information frictions) hinder labor market matching. A study by Wheeler et al. (2019) ran a randomized evaluation of training job-seekers to join an online professional networking platform in South Africa. They find that training increased employment from 70% to 77% and the effect

Kelley et al. (2020) present more surprising results from India. One group of randomly selected vocational training graduates were notified about a job portal that sends text messages when jobs become available. A second group received more intensive treatment in the sense of being notified and reminded about job openings more frequently, and a third group received no information. The authors find evidence that access to online job portals gives rise to *voluntary* unemployment—job-seekers with portal access increase their reservation wages and wait for better jobs as opposed to accepting feasible job offers. The results suggest that portal access can aggravate matching frictions through such voluntary unemployment if job-seekers display a mismatch of expectations.[20]

Alternatively, internet connectivity may affect firm-worker matching through firm location decisions, labor mobility, or firm (and worker) market entry and exit. Kim & Orazem (2017) find evidence of a positive relationship between broadband availability and new firms choosing to locate in rural areas in the U.S.[21] Similarly, Alfaro & Chen (2015) show that countries with better internet connectivity are more likely to attract multinationals—even conditional on a wide range of other country characteristics—and that the marginal effect of internet and other forms of ICT accessibility appears to be larger in developing countries. This finding is important in light of growing evidence of considerable benefits to suppliers and workers of working with or for multinationals (see, e.g., Alfaro-Urena et al., 2019a,b; Méndez-Chacón & Patten, 2021).[22] How internet connectivity influences the economic impact of multinationals in developing countries is a promising area for future research.

Hjort & Poulsen (2019) document a large and significant increase in net firm entry, notably in sectors that use ICT extensively (e.g., finance), shortly after the arrival of submarine internet cables in in South Africa. Strazzeri (2020) uses a similar research design with other data and finds a large positive effect of access to fast internet on out-migration in Nigeria.[23] The response is particularly strong for migration out of Africa and is greater for individuals comprising the lower part of the wealth distribution. The increase in human mobility points towards African firms facing changes in the size and skill composition of their labor supply when fast internet becomes available.[24]

persisted for at least twelve months.

[20]Relatedly, Lederman & Zouaidi (2020) also document suggestive evidence that the relationship between internet usage and long-term frictional unemployment is more negative in poor countries.

[21]The estimated broadband effect is largest in more populated rural areas and those adjacent to a metropolitan area, suggesting that this effect may increase with agglomeration economies, possibly via labor market pooling, similarly to Tian (2019)'s findings in Brazil.

[22]Adverse effects of working for a multinational corporation have also been shown in some contexts, for example those studied in Bossavie et al. (2020) and Boudreau (2021). See also Tanaka (2020).

[23]Kolko (2012) finds more suggestive evidence of the opposite relationship in the U.S.

[24]Hjort & Poulsen (2019) find little job displacement across space within African countries with the arrival

3.2 Internet and Firm Productivity

3.2.1 Internet and Technology Adoption

Internet connectivity may interact with production factors other than labor and facilitate firm technology adoption. Such interactions can, similarly to those with labor, be denoted as a second-order effect on output through productivity of materials and other intermediate production inputs, i.e., $\frac{\partial^2 Y_j}{\partial M_j \partial \theta}$ and $\frac{\partial^2 Y_j}{\partial K_j \partial \theta}$. In response to such productivity changes, firms may act on the intensive margin—changing how intensively they use existing production inputs—or the extensive margin, by adopting new intermediate inputs or technologies that are were previously inaccessible or unprofitable. We distinguish between two forms of technology adoption: changes in the use of tangible inputs such as machines and intermediate materials, and changes in the use of intangible inputs such as management, organizational practices, and services.

Though plausible, evidence on take-up of new, tangible production inputs in response to internet connectivity is limited. A clear example is D'Andrea & Limodio (2019). Exploiting the staggered arrival of submarine internet cables across African countries, the authors document a significant, relative change in the activities of banks in "treated" countries—in particular more private lending—once access to high-speed internet increases.[25] Relatedly, Mensah & Traore (2021)—exploiting both the staggered arrival of submarine fiber-optic internet cables and subsequent roll-out of terrestrial fiber cable networks across locations in Africa—show that fast internet is associated with an 18 and 12 percentage point increase in the probability of FDI in financial and technology services sectors, respectively. However, the effect is largely concentrated in countries with reliable supply of electricity, highlighting important complementarities between different forms of infrastructure. Houngbonon et al. (2021), also exploiting the connection of countries to submarine fiber-optic cables as well as variation across cities in broadband infrastructure, show evidence that individual firms in Africa are 20 and 12 percentage points more likely to undertake process and product innovation, respectively, when fast internet becomes available, echoing the early work of Dutz et al. (2012a). Digitizing business functions such as sales, distribution, and marketing, are prominent examples of process innovation.

of fast internet in "connected" areas, but Strazzeri (2020)'s analysis uses a longer post-cable arrival data window.

[25]Related evidence has been found in developed country contexts. For example, Magouyres et al. (2019) use the staggered roll-out of broadband internet in France to show that broadband expansion increases firm-level imports by around 25%. They further find that the "sub-extensive" margin (number of products and sourcing countries per firm) is the main channel of adjustment and that the effect is larger for capital goods. Eichengreen et al. (2016) instead analyze the impact of internet on the foreign exchange market. They find that the technology dampens the impact of spatial frictions by up to 80 percent and increases the share of offshore trading by 21 percentage points.

Houngbonon et al. (2021) also show that households are much more likely to operate non-farm businesses when fast internet becomes available, while Atiyas & Dutz (2021) show suggestive but informative evidence of a relationship between use of internet-related digital technologies (smartphones and inventory control/point of sales software) and higher levels of labor productivity, sales, and employment among micro firms in Senegal.

In contrast, there is a substantial body of evidence on how internet connectivity affects the organization of production and trade in developing countries. Tian (2019) shows that internet access allows firms in urban areas to reorganize production in ways that enhance collaboration and facilitate division of labor, thus increasing productivity by 8 percent. To do so she exploits the gradual roll-out of broadband infrastructure across Brazilian cities and micro level data on firms. She then uses a spatial general equilibrium model to quantify the extent to which such internet-induced division of labor may explain cities' productivity advantage.

Bloom et al. (2014) examine the effect of working from home on call center workers' productivity through a randomized experiment at Ctrip, a 16,000-employee Chinese travel agency. Employees in a some departments were asked to choose either to work from home or from the office. Among those who preferred to work from home, half were randomly selected to do so. This group was about 13% more productive than those who worked at the office: the treatment group worked longer hours and devoted more time to each task (call), and were also less likely to leave the company. Jensen et al. (2020) find, using an experiment in Kenya, that increasing the visibility of monitor activity improves remote workers' performance on task dimensions not being directly paid for. However, there is also evidence that internet-enabled monitoring of remote workers can worsen performance in some contexts. In a randomized experiment with trucking companies in Liberia, de Rochambeau (2020) explores managers' demand for a low-cost monitoring technology—GPS trackers, how the technology affects worker productivity, and correlation between the two. She finds an increase in monitored drivers' speed (without adverse effects on accident rates), but also that managers decline free installation of monitoring devices on 35% of randomly chosen trucks. The paper interprets this finding through a principal-agent model in which monitoring intrinsically motivated workers may reduce productivity.

Internet access can also affect firms' organizational form and make-or-buy decisions, for example by altering communication and coordination frictions (see, e.g., Antràs et al., 2006; Garicano & Rossi-Hansberg, 2006; Aghion et al., 2019; Gokan et al., 2019). The existing empirical evidence is descriptive and comes from advanced economies. Abramovsky & Griffith (2006) show that, in the U.K., internet-technology-intensive firms purchase more services on the market and offshore. Similarly, Bartel et al. (2005) demonstrate a positive relationship between U.S. firms' use of ICT technology and the extent to which they outsource services.[26] How internet connectivity influences firms' organizational choices and thereby the type and extent of production that takes place in developing countries is a promising area for future research.

3.2.2 Internet, Firm Productivity, and Performance

We are not aware of studies causally linking firms' *physical* productivity to internet connectivity in developing countries. However, several studies provide evidence on the relationship between internet access and firm performance—that is, $\frac{dY_j}{d\theta}$—by estimating internet-augmented production functions. Hjort & Poulsen (2019) adapt De Loecker (2011)'s estimation method to show that Ethiopian manufacturing firms became 13 percent more productive after the arrival of submarine internet cables. In earlier work, Commander et al. (2011) establish a strong positive relationship between "internet capital" and firm productivity in both Brazil and India. More descriptively, Cariolle et al. (2019) show evidence of a positive and large association between internet use and firm performance in a sample of 30,000 firms in 38 developing and transition countries, as well as indications of a less clear relationship between internet connectivity and firm performance in richer countries.[27] Wamboye et al. (2015) also show evidence suggestive of returns to internet access using data on 43 Sub-Saharan African countries for the period 1975-2010 i.e., a positive marginal effect of ICT on labor productivity growth conditional on reaching a critical penetration rate which is attributed to network effects created by higher penetration. Abreha et al. (2021) study the transition from 2G to the 3G broadband network standard in Ethiopia in 2008, and find results consistent with competition intensifying, markups shrinking, and higher growth in productivity, wages, and employment. DeStefano et al. (2018) show evidence that broadband access increases firm size (measured by either sales or employment) but not productivity in the U.K.

These studies do not provide direct evidence on *how* internet connectivity affects firm productivity and performance—a promising area for future research. Unobserved or

[26] Jiao & Tian (2019) document a similar pattern in the U.S. Using elevation of local terrain to predict broadband quality, the paper finds that U.S. firms may be more likely to build subsidiary plants at locations with better internet connectivity with the firm headquarters. Gokan et al. (2019) present a model demonstrating that internet can plausibly also have the opposite effects on firms' organizational choices.

[27] Cariolle et al. (2019) instrument for internet access with firms' vulnerability to seismic shocks on telecommunications submarine cables at the nearby seabed, finding that 10 percent higher incidence of internet access is associated with 36 percent higher annual sales, 26 percent higher sales per worker, and 12 percent more permanent workers employed at the firm. The descriptive evidence the paper provides is arguably easier to interpret. See also Paunov & Rollo (2015).

hard-to-measure ways in which internet connectivity improves labor productivity, management practices, or the organization of production—as discussed in sub-section 3.1 and 3.2.1—are plausible possibilities. However, it may also be that firms for example can use the internet to increase the quality of their products, or to sell more per unit of marketing cost. In the next section we summarize the existing evidence on demand-side forces through which internet connectivity may affect economic activity in poor countries.

4 The Demand-side Impact of Internet Connectivity

In this section we discuss empirical research that presents evidence on how internet affects economic development through demand-side forces.

4.1 Internet and Market Access

Internet connectivity may enable firms to reach new and more desirable markets. A direct way this can occur is through e-commerce. We expect online sales to increase with connectivity—e-commerce is for example technologically possible only with relatively fast internet—that is, $\frac{\partial Y_j^{\text{online}}}{\partial \theta} > 0$. Offline sales may also be affected, positively or negatively.

Fan et al. (2018) study how e-commerce affects trade between regions and spatial inequality in China. The authors estimate a general equilibrium model of inter-city trade, disciplining the parameters using stylized features of the data, and ensuring that the model performs well in estimating non-targeted moments. Adding e-commerce induces welfare gains by reducing the price index and nominal wage index. Online sales platforms are predicted to increase overall inter-city trade, but reduce offline trade.

Internet connectivity appears to also enable firms to expand their sales through exporting and importing. Hjort & Poulsen (2019) find evidence of a notable increase in direct exports when submarine internet cables reach Africa.[28] Clarke & Wallsten (2006) show evidence that developing countries with higher internet penetration appear to export more to developed countries but not to other developing countries.[29] In contrast, Cariolle et al. (2019) do not find evidence of internet technology adoption affecting firms' exports in developing countries.

[28] Using data from 43 African countries for the period 1996 to 2006, Hinson & Adjasi (2009) also show a positive relationship between internet connectivity and exports in Africa. They attribute this to internet reducing the market entry and search costs associated with exporting.

[29] Exploiting the staggered roll-out of broadband internet, Malgouyres et al. (2019) document "technology-induced" trade in France between 1997 and 2007 and show evidence that broadband expansion increases imports by around 25 percent.

If internet use affects exports and sales, this may occur in part through supply-side channels—for example by dampening internal-to-the-firm barriers to productivity growth—but it would be surprising if the technology does not directly expand access to foreign buyers.[30] Hjort et al. (2020) show that the (large) impact of a brief training program designed exclusively to teach small and medium-sized Liberian firms how to sell to large buyers is concentrated among firms with internet access. Part of the explanation may be that "connected" firms can access formal tenders that are publicized online.

One way in which internet connectivity can facilitate firms' access to new markets is by reducing entry costs and/or the fixed cost of operating in a given market. Freund & Weinhold (2004), for instance, present a model with imperfect competition and market specific fixed costs of trade in which internet enhances export growth. The paper then goes on to show supportive but descriptive empirical evidence on web hosts and exports from 56 countries for the period 1995 to 1999. Lewis-Faupel et al. (2016) study the hypothesis that $\frac{\partial f_j^{\text{entry}}(\theta)}{\partial \theta} < 0$ and/or $\frac{\partial f_j^{\text{fixed}}(\theta)}{\partial \theta} < 0$ more directly, in the context of electronic procurement mechanisms for public works projects. The technology was adopted gradually across states in in India and Indonesia so the authors use a difference-in-difference approach to estimate the impact on projects' price and quality. They find that regions with electronic public procurement are more likely to have contract winners from outside the region. The paper ultimately concludes that e-procurement facilitates entry from higher quality contractors, improves product quality, and reduces delays.

Distance reduces trade. However, there is growing evidence that internet connectivity dampens this negative relationship—that is, $\frac{\partial f_j^{\text{variable}}(\theta)}{\partial \theta} < 0$. Using data from China's leading e-commerce platform, Fan et al. (2018) show that the distance elasticity for online trade is only about one-third of that for offline trade. Lendle et al. (2016) compare the effect of geographic distance on trade between the same 61 countries in the same basket of goods on eBay versus in total. They find the effect of distance to be on average 65 percent smaller on eBay. Similarly, Hortaçsu et al. (2009) use transactions data from eBay and MercadoLibre—another large online marketplace—to show that distance curbs online trade to a lesser extent than has been observed in studies of offline commerce between trade partners. Blum & Goldfarb (2006) show that *gravity*—the negative relationship between distance and trade—holds also in the case of digital goods consumed online. They find evidence that distance does not influence online trade for products such as software, but still matters for "taste-dependent" digital products such as music and games.

[30] In ongoing work, David Henning finds what appears to be some of the most convincing evidence to date on how internet access affects exporting. He studies a government program that expanded terrestrial fiber-optic internet cables deeper into Colombia's interior and documents increased exporting from these rural areas. Contact the author @djhenning@g.ucla.edu for more information.

In contrast, Duch-Brown et al. (2021), using data on consumer electronic products from ten European countries, find that online markets are currently not more integrated than traditional markets.

By expanding firms' market reach through e-commerce, internet appears to lower the prices and expand the variety consumers face. Dolfen et al. (2019) show that, in the U.S., the gains stem mostly from substituting to merchants that are available online but not locally.[31] Couture et al. (2021) combine survey and administrative microdata to estimate how China's nation-wide e-commerce program affects rural households. The program expands e-commerce to villages that already have internet access by subsidizing nearby entrepôts. Through a pioneering experiment that randomized program roll-out among 100 villages, the authors find no significant production or income effects of the program. The consumption gains that occur are are driven by lower retail costs resulting from reduced logistical barriers to shipping goods.

There is growing and nuanced evidence on how e-commerce affects consumption inequality. Couture et al. (2021) find that the consumption gains are concentrated among richer households in rural China, and Dolfen et al. (2019) find that higher-income consumers gain more also in the U.S. Fan et al. (2018) provide evidence that more remote and smaller cities gain more in China, but Dolfen et al. (2019) show that consumers in more densely populated counties benefit the most in the U.S.

4.2 Internet and Information Frictions

Information frictions are pervasive in developing countries' input and output markets. Allen (2014) for example shows that roughly half the observed regional dispersion in the prices of agricultural goods in the Philippines is due to information frictions (see also Jensen, 2007; Allen, 2014; Startz, 2016; Bai, 2018; Jensen & Miller, 2018; Hansman et al., 2020).[32] Information frictions—a distinct phenomenon from barriers to *accessing* markets—can take many forms: sellers may lack information about the price their output would command in different markets; input-buyers or final consumers may lack information about (other) firms' product quality; and sellers and buyers may struggle to communicate or to "find" each other, to name a few. Some forms of information frictions especially hamper international trade. Many appear ex ante amenable to internet-based

[31] See also Jo et al. (2019) for similar results obtained using Japanese data.

[32] Like Allen (2014), Steinwender (2018) shows evidence indicating that information frictions cause arbitrage opportunities to exist in equilibrium. Studying the "internet of the 19th century"—the establishment of the transatlantic telegraph cable—she finds that the average volatility of the transatlantic price difference for cotton fell substantially after the establishment of the telegraph network, while average trade flows increased and became more volatile.

technological solutions or work-arounds.

Suppose that internet connectivity reduces information frictions between firms and consumers, potentially improving allocative efficiency. In our framework, this channel is illustrated through the η_j. η_j—which denotes the extent of information frictions—can for example capture the difference between real product quality and the quality observed by consumers. Better internet connectivity may improve search and communication in the output market and thus increase demand, i.e., $\frac{\partial^2 (Y_j^{offline} + Y_j^{online})}{\partial \eta \partial \theta} < 0$.

Using micro-level survey data from the Indian state of Kerala, Jensen (2007) shows that the adoption of mobile phones by fishermen and wholesalers was associated with a dramatic reduction in price dispersion and near-perfect adherence to the Law of One Price. This improved overall market performance and benefited consumers. Similarly, using detailed data from Reuters Market Light (RML), a text message service in India, Parker et al. (2016) find that, besides reducing geographic price dispersion, providing daily price information to market participants may also increase the rate at which prices converge across India over time. We are not aware of studies estimating the causal effect of internet connectivity itself on price dispersion.

In contexts where buyers have a degree of monopsony power, internet connectivity can—in addition to relevant price information—provide sellers with an outside option, thereby potentially increasing local prices. This may in turn incentivize sellers to produce more. Goyal (2010) examines the impact of direct interactions between farmers and buyers. Internet kiosks with information on daily wholesale prices displayed gave farmers an opportunity to eliminate hub agents/middlemen who could potentially collude. The program was implemented in a subset of rural Indian districts, enabling a difference-in-difference approach. The author finds a significant increase in soy prices, the area under cultivation, and the volume of sales in districts with kiosks relative to those without. Similarly, Ritter & Barreto (2014) analyze the impact of a program that subsidized internet access in rural and remote areas of Peru, and find evidence that the program increased the prices farmers receive for their products.

Internet connectivity may also reduce uncertainty over product quality. Chen & Wu (2020) study t-shirt exports on the Alibaba trading platform and examine the role of an online reputation-scoring system in signaling quality. They find that, controlling for observable product and exporter characteristics, an improved seller reputation (as measured by the substance of reviews and ratings) is associated with both higher export volume and higher export revenue. Quantifying a dynamic reputation model with heterogeneous cross-country information frictions, they conclude that the online reputation mechanism studied increases aggregate exports by 20 percent through reallocation towards "superstars" (see also Elfenbein et al., 2019; Klein et al., 2016). Rauch & Trindade (2003) add informational trade barriers to a standard trade model to show how internet and other ICT can improve the match quality of international trade partners, thereby leading to increased integration of labor markets.

Internet connectivity can also expand the choice set of sellers and buyers by making search for and communication with trade partners easier. Akerman et al. (forthcoming) for example demonstrate this in a trade model with variable elasticity of demand.[33] Combining firm-level production data with province-level information on internet penetration across Chinese provinces from 1999 to 2007, Fernandes et al. (2019) show evidence that internet helps sellers improve communication with both buyers and input suppliers; sellers benefit not just from better communication but also from establishing a visible virtual presence. They also present results indicating that internet-induced trade ultimately improves overall firm performance. Hjort et al. (2020) show related evidence that Liberian firms with access to internet can more easily "convert" knowledge of how to bid on contracts from large buyers into actual sales. Lendle et al. (2016) attribute the lower distance effect on the eBay platform compared with that in traditional trade flows discussed in Sub-section 4.1 to decreased search costs related to language and institutional barriers.[34]

Though internet appears to lower entry barriers and communication costs, adverse counteracting forces have also been documented. Bai et al. (2020) explore how information frictions affect the firm dynamics of exporters operating on Aliexpress. The platform gives small and medium-sized firms access to markets abroad, but also appears to congest the market. The authors show that current sales as opposed to product quality predicts future sales and hence hypothesize that the same frictions that cause visibility to not be aligned with quality also generate misallocation on the platform. Using randomly generated demand shocks, the paper identifies how sales history itself affects firm dynamics and show that shock-induced growth is concentrated at the top of the firm-size distribution (see also Bar-Isaac et al., 2012). Bai et al. (2020)'s counterfactual analyses suggest that (further) alleviating information frictions and reducing the number of firms can help to improve allocative efficiency online.

[33]The model in Akerman et al. (forthcoming) predicts that internet adoption will enlarge exporters' and importers' choice sets and thereby making demand more elastic with respect to trade costs and thus distance. They use data and variation from the roll-out of broadband access points in Norway to show consistent empirical patterns.

[34]See also Goldmanis et al. (2010); Jolivet & Turon (2019) on the effect of internet on consumers' search costs in developed countries.

5 The Overall Impact of Internet Connectivity

This paper distinguishes between the different broad pathways through which internet connectivity may affect economic development, grouping together research that primarily informs supply-side mechanisms in Section 3 and work that primarily informs demand-side mechanisms in Section 4. In this section we highlight a handful of empirical studies that additionally and relatively directly examine how "downstream" measures of economic development itself—such as consumption or local income growth—ultimately respond to internet connectivity.

Quite a few studies convincingly estimate the effect on consumption of specific internet-enabled technologies (rather than internet connectivity itself) through model-based approaches[35], and a few do so more directly. Jack & Suri (2014) show that access to mobile money decreased consumption poverty by two percentage points in Kenya.[36] In contrast, Couture et al. (2021) finds that expansion of e-commerce in China has little effect on income to rural producers and workers.

Different areas of Sub-Saharan Africa got access to basic internet at different times starting in the early 2000s. Exploiting variation arising from the gradual arrival of submarine cable connections and using nighttime satellite image luminosity as a proxy for economic activity, Goldbeck & Lindlacher (2021) estimate that basic internet availability leads to about a two percentage point increase in economic growth.[37]

As we briefly discussed in Sub-section 3.1.1, Bahia et al. (2020) show evidence that the gradual roll-out of mobile broadband in Nigeria between 2010 and 2016 increased labor force participation and employment. The paper also shows that household consumption simultaneously increased and poverty decreased. Households that had at least one year of mobile broadband coverage experienced an increase in total consumption of about 6

[35]For example, Dolfen et al. (2019) build a general equilibrium model to quantify a gain to consumers equivalent to about 1 percent of consumption in the U.S. following the expansion of e-commerce, while Fan et al. (2018) through a similar approach estimate an overall welfare gain from e-commerce of about 1.6 percent on average in China.

[36]Using data from household surveys and a difference-in-difference approach, Jack & Suri (2014) show that negative income shocks had differential impact on users' and non-users' consumption. The authors find that the technology—which users could access on "non-smart" phones, but whose broader infrastructure requires internet connectivity—enabled greater risk sharing and hence greater ability to smooth out consumption in the face of negative income shocks, and that the effects were especially pronounced for individuals in the bottom quartile of the income distribution. Suri (2017) provides an overview of evidence on the impacts of mobile money in developing economies.

[37]Hjort & Poulsen (2019)'s similar analysis of the later arrival of fast internet estimates a 3.3 percent increase in economic activity. Kolko (2012) finds a positive relationship between broadband expansion and local economic growth in the U.S., especially in areas with low population densities. A number of studies also highlight that the overall economic impact from ICT development is much larger in the US than Europe (see, e.g., Inklaar et al., 2005; Greenstein & McDevitt, 2011; Bloom et al., 2012).

percent. Masaki et al. (2020) document a similarly striking result. Combining household expenditure surveys with data on the location of fiber-optic transmission nodes and coverage maps of 3G mobile technology, they show that 3G coverage is associated with a 14 percent increase in total consumption and a 10 percent decline in extreme poverty in Senegal.[38] Finally, Bahia et al. (2021) use a similar empirical approach to study the effect of mobile broadband roll-out in Tanzania and find a comparable increase in household consumption and decline poverty in this setting.

An innovative new study by Suri & Bhattacharya (2022) takes a different approach, focusing directly on *use* of the internet among the poor. Collaborating with a telcom in Kenya, the authors provided free phone data to a randomly chosen subset of poor individuals who had not used data in the year preceding the study, but had a data-enabled phone and a contract with the telcom. They find moderately increased use of data, but no impact on a wide range of economic outcomes (such as employment, consumption, etc). These findings suggest that subsidizing and encouraging use of existing mobile internet access among priced-out (or reluctant) individuals may not be effective in settings like Kenya.[39]

The findings of Suri & Bhattacharya (2022) are especially interesting in light of those of Roessler et al. (2021). They present results from an experiment in Tanzania in which a randomly chosen subset of women that did not own phones were given a basic phone, a cash grant, or a smartphone. They find no effect on women's empowerment, but also that smartphones increased households' annual per capita consumption by 20 percent. The smartphone effect size is 3 times greater than that of basic phones and 3.6 times greater than cash grants, pointing towards a key role for internet access. The paper also finds that smartphone *use* and induced occupational change were import routes to higher consump-

[38]While more descriptive than Bahia et al. (2020), the results in Masaki et al. (2020) are robust to controlling for household demographics and spatial characteristics, and to an instrumental variable approach that relies on distance to 3G coverage in neighboring areas.

[39]There is on the other hand evidence that subsidizing take-up among poor households can be effective in the U.S. Zuo (2021) is to our knowledge the only study to convincingly estimate how subsidized internet causally affects poverty, consumption, income or other welfare-proxies in rich countries. He demonstrates that a service providing discounted broadband increased earnings—as well as employment rates—among qualifying low-income families in the U.S. Beem (2021)—like the studies of internet's impact in Africa by Hjort & Poulsen (2019); Bahia et al. (2020); Masaki et al. (2020); Bahia et al. (2021); Goldbeck & Lindlacher (2021)—focuses on internet infrastructure. He exploits plausibly exogenous variation in the deployment of wired broadband connections across U.S. counties arising through the activities of the Federal Communication Commission's Connect America Fund Phase II. Beem (2021) finds persistent gains in the number of firms, establishments, entrepreneurs, employment levels, and average annual wages in treated counties, and ultimately concludes that the the benefits from CAF II outweigh the costs by a factor of 42. See Subsection 4.1 for related evidence focusing on e-commerce. Through a more descriptive approach, Dutz et al. (2012b) put the 2008 U.S. consumer surplus benefits from home broadband on the order of USD 32 billion per year.

tion.

6 Conclusion

This paper summarizes existing research on the economic impact of the rapid and continuing spread of internet connectivity in developing countries. We start with a stylized model laying out different pathways through which internet can affect economic development in Section 2, and then present the corresponding empirical evidence. In Section 3 we review studies focusing primarily on supply-side mechanisms. Several studies have for example shown evidence that internet connectivity can directly make workers and other input factors more productive in some contexts. In Section 4 we cover research focusing primarily on demand-side mechanisms, such as internet influencing firms', workers', and consumers' ability to access markets or search for and communicate with each other. Finally, Section 5 summarizes a handful of studies that attempt to directly estimate how internet connectivity ultimately affects downstream measures of economic development itself. These studies and the research they build on point toward substantial economic impacts of internet connectivity in many, though not all, developing country contexts.

We highlight some promising future research directions throughout the paper. These include better understanding:

- contextual determinants of the skill bias of internet technology
- how internet affects search and matching frictions in highly frictional labor and firm-to-firm markets
- how the economic impact of multinationals changes with internet connectivity
- how the technology influences firms' organizational choices and thereby the type and extent of production that takes place in developing countries
- the channels through which internet affects firms' productivity
- when internet connectivity increases learning in schools and when it doesn't

We hope and expect that it won't be long until much more is known about these and the many other important questions surrounding the role of what may be our time's most profound technological innovation in poor economies.

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