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Spillovers in ICT Adoption from Formal to Informal Firms

Evidence from Zambia

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Abstract

This paper examines spillovers in the use of digital technologies from formal to informal businesses by exploring differences in geographic proximity. Using a unique set of geocoded data from the 2019 World Bank Enterprise Surveys in Zambia, the findings indicate that closer geographic proximity to formal firms is associated with a significantly higher likelihood of digital adoption by informal businesses. The finding holds for various types of digital technologies, ranging from computers, tablets, and cell phones to mobile money transactions, and is robust to various measures of geographic proximity and model modifications. The results vary by the owner's level of education and business age. The results also suggest that the spillovers in information and communications technology use can be explained by competition in the local market and learning through enhanced interactions.

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Spillovers in ICT Adoption from Formal to Informal Firms: Evidence from Zambia

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1 Introduction

Informality is pervasive in the developing world, accounting for about one-third of GDP and around 70 percent of employment (Loayza, 2018; Medina and Schneider, 2019). A large informal sector tends to be associated with low productivity, threatening developing economies' long-term growth potential (Ohnsorge and Yu, 2021). Firm-level survey evidence shows that the average informal firm[2] in developing economies is only one-quarter as productive as the average firm operating in the formal sector (Amin and Okou, 2020).

The drivers behind the differences in productivity between the formal and informal sectors have been well examined. Some studies point to the formal and informal sectors catering to their own unique markets (Perry et al, 2007; La Porta and Shleifer, 2014). Other more recent studies point out that productivity differences between formal and informal firms largely reflect differences in observed characteristics: informal businesses tend to be smaller, are run by less educated individuals, employ less educated workers, and have limited access to finance, which, in turn, prevent them from adopting new technologies (World Bank 2019a).[3]

Empirical evidence suggests that digital technologies, which are often not scale-intensive, benefit small firms, including those in the informal sector, by improving their access to markets (Jensen 2007, Muto and Yamano 2009). Paunov and Rollo (2016) show that cell phone use at the industry-level positively improves sales for informal businesses. However, technology adoption remains low in informal businesses, and other supporting registration efforts, such as management training through business advisory services, vouchers, and other financing approaches, have yielded limited success (McKenzie and Woodruff 2008; Fafchamps et al. 2014; De Mel et al. 2011). The limited success of those programs is largely due to the limited skillsets of informal business owners, management practices, and constrained access to finance (Aga et al. 2021; Aberra et al. 2022). There is little evidence on the drivers of ICT adoption by informal businesses. This paper

[2] Typically defined as an unregistered firm.

[3] Past studies at the firm level have suggested that informality can limit access to conventional bank credit because of a lack of documentation for assets and inadequate financial statements, resulting in a lack of investment in capital goods and technology advancement (e.g., Koeda and Dabla-Norris,2008). Investment (and capital stock) per worker tends to be subdued in informal businesses as informal businesses may be unwilling to adopt technologies that would make them more visible to tax and other authorities (Dabla-Norris and Inchauste 2008; Gandelman and Rasteletti 2017). New evidence further suggests that firms are less willing to favor technology adoption as they rely more on temporary workers than formal workers (Michie and Sheehan 2003; Castro Silva and Lima 2022; Cirillo et al. 2021).

aims to fill this gap by assessing the impact of geographic proximity between formal and informal firms on ICT adoption by informal businesses.

Using a unique set of geocoded data from the 2019 World Bank Enterprise Surveys in Zambia allows to examine these ICT spillovers from formal to informal businesses.[4] Geographic proximity is measured as the distance of an informal business to its closest formal firm. Informal businesses operating closer to formal firms have greater exposure to the formal firms' business activities, their customer base and network, and potential value chain linkages. This geographic proximity reflects the benefits of these complementary forces.

The results suggest that geographic proximity to formal firms is associated with a significantly higher likelihood of digital adoption by informal businesses. The finding holds for various types of digital technologies, ranging from computers, tablets, and cell phones to mobile money transactions, and is robust to different assumptions of informality and geographic distance. These effects vary by the firm owner's level of education, and firm age. Informal businesses run by more educated owners or younger in age—benefit more from potential technology spillovers of neighboring formal firms. In addition, we find that the role of geographical proximity in generating spillovers in ICT use can be explained by greater competition in the local market and by learning from formal businesses.

This paper contributes to the literature on the crucial role of geographic proximity for technology adoption and productivity advancement. For instance, Carboni (2013) applies a spatial autoregressive model to manufacturing firms in Italy and finds that geographical and industry proximity have positive effects on firms' ICT investments. Hjort and Poulsen (2019) exploit the gradual arrival of submarine internet cables on the coast to show the positive impact of internet access on employment, firm entry, and productivity in Africa. Using a similar approach, Houngbonon et al. (2022) show a positive effect of access to high-speed internet on innovation at the firm level. Combining information on the GPS location of firms with the location of the internet backbone in Senegal, Cirera et al. (2022) explore the contribution of digital infrastructure to the adoption of technologies through the effects of the proximity to better quality internet service.

[4] As shown in the following section, the level of digital adoption in Zambia is notably higher in formal firms than in informal businesses. Given the differences, it is assumed that technological spillovers pass from formal firms to informal businesses.

Further, this paper also contributes to the wider literature on firms' technology adoption. In particular, it contributes to recent studies that highlight the role played by value-chain linkages on technology adoption.[5] For instance, Almeida and Fernandes (2008) find that trade linkages are important channels for the transfer of technology. Firms that import intermediate inputs tend to acquire new technology from their machinery suppliers. Giunta and Trivieri (2007) use a sample of Italian firms and find that subcontracting, exports, and collaboration between firms are all significant determinants of ICT adoption. Other studies, such as Haller and Siedschlag (2011) and Grazzi and Jung (2019), demonstrate that larger, skill-intensive, and exporting firms are more likely to adopt ICT.

Lastly, this paper contributes to the literature on the implications of interactions—either through subcontracting or geographical clustering—between informal and formal firms.[6] Thus far, the evidence suggests that interactions with formal firms bring benefits to informal businesses (or workers), but the size of the benefits depends on the informal businesses' existing productivity level and absorption capacity. For instance, Moreno-Monroy, Pieters, and Erumban (2014) find that subcontracting with formal firms, which is also a form of a value-chain linkage, is positively related to employment growth in the most modern segments of the informal sector. Chhair and Newman (2014) show that geographical clustering of formal and informal firms generates productivity spillovers from formal firms to informal businesses in Cambodia. In contrast, Tran and La (2018) demonstrate that informal businesses in Viet Nam experience negative externalities of co-location with formal firms in terms of productivity, largely due to the lack of absorption capacity in the informal sector. In addition, Ramachandran and Sasidharan (2021) find a

[5] Other factors that can contribute to firms' technology adoption include firm capabilities (including workforce quality; entrepreneurial ability and learning), linkages to FDI, access to finance, product market competition, access to infrastructure, and intellectual property rights policy. See Acemoglu and Akcigit (2012), Cirera and Maloney (2017), Cirera et al. (2022), Delera et al. (2022), and Verhoogen (forthcoming) for supporting evidence and reviews. At the country level, theory and empirical studies underscore the following factors that contribute to the speed at which a country adopts technologies: the country's human and physical capital endowment (e.g., Chari and Hopenhayn 1991, Brezis, Krugman, and Tsiddon 1993; Basu and Weil 1998), type of government (or government capabilities; Cirera and Maloney (2017), degree of patent protection (e,g., Zheng, Huang and Yang 2020), and adoption of predecessor technologies (Comin and Hobijn 2004).

[6] There are some studies analyzing value-chain linkages between formal and informal firms. For instance, Böhme and Thiele (2014) combine household and enterprise surveys from six West African countries to study value-chain linkages between formal and informal firms. They find evidence that informal firms are more likely to purchase goods from formal firms (i.e., backward linkage).

statistically significant and positive impact of the geographical clustering of formal and informal firms in India on the productivity of formal firms, but no significant effect for informal businesses.

The rest of the paper is structured as follows. Section 2 describes the data, provides a descriptive analysis of the informal sector in Zambia, and presents the empirical strategy. Section 3 discusses the baseline results and a series of robustness checks. Section 4 shows the heterogeneous effects of geographic proximity across firms. Section 5 analyzes potential spillover channels and, finally, Section 6 concludes.

2 Data and Empirical Strategy

a. Data

The analysis employs the World Bank Enterprise Survey (WBES), the World Bank Micro Enterprise Survey (WBMES), and the World Bank Informal Sector Enterprise Survey (WBISES) for Zambia conducted in 2019. Even though the surveys were conducted in parallel to each other by the same implementing agency, some differences exist. While all three surveys gather information on the performances of firms and the business environment in which they operate, they differ with respect to the assumptions of formality and the sampling approach.

The WBES differentiates informal from formal firms by using the information on the registration status of the entity. In the context of Zambia, informal businesses are defined as those that are either: (1) registered with Zambia's Patents and Companies Registration Agency (PACRA) but do not hold a council permit and are not registered with Zambia Revenue Authority (ZRA); (2) are not registered with PACRA but hold a council permit; and (3) not registered with PACRA and do not have a council permit. The WBISES captures informal businesses, while the WBES and WBMES survey formal firms.[7]

The WBES is a nationally representative survey where a stratified random sampling approach is applied to formally registered firms that have five or more employees, have at least 1 percent of private ownership, and do not have legal status as cooperatives. The sample size in Zambia is 601 firms. Formal micro-enterprises, which are defined as employing fewer than five workers,

[7] See Appendix Table A.1 for details on the registration status by survey types.

comprise the WBMES and follow a sampling methodology that is similar to the WBISES. To deal with the challenges associated with sampling informal businesses and ensure representativeness, the WBMES and the WBISES follow an adaptive cluster sampling approach (Aga et al., 2023) where all business activity (formal and informal) is fully enumerated within the primary sampling unit, which consists of 150 by 150m geographical areas. Throughout the enumeration, 8,438 businesses were discovered, out of which 97 met the criteria and were randomly selected for the WBMES, and 914 informal businesses were randomly sampled for an interview as part of the WBISES. All three surveys contain geo-location data for each firm which are utilized for this analysis.

b. Context and Descriptive Results

The informal sector in Zambia can be described as pervasive and with low levels of productivity. Between 40 and 47 percent of official GDP comes from the informal sector and about three-fifths of the total employment. Two out of three firms in Zambia are competing against unregistered firms, while one-third of formal firms view the practices of their informal competitors as obstacles to their businesses (World Bank 2019b). However, there is also a large labor gap between formal and informal firms in Zambia. As shown in Figure 1, monthly sales per worker in informal businesses are significantly lower than those in formal firms of a similar size.

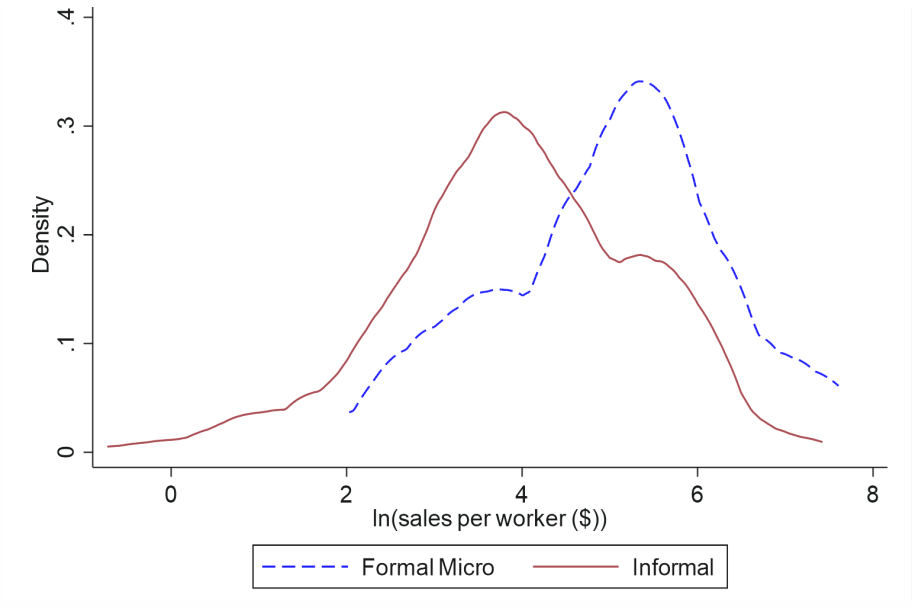

Figure 1: Productivity of Formal and Informal Firms in Zambia

Notes: Figure shows the density (y-axis) of monthly sales per worker (in logs) in formal micro firms (blue dotted line) and informal (red line) businesses in Zambia in 2019 (Aberra et al., 2022).

Adoption of digital technologies varies by firm type as shown in Table 1. In general, micro firms report higher shares of ICT adoption than informal businesses. One exception is the use of tablets, where only 3.8% of micro firms report using tablets in contrast to 8.91% of informal businesses. This suggests potential substitution effects between computers and tablets. The use of websites is the only digital technology that is captured in all three surveys. Not surprisingly and in line with other findings (Jolevski and Islam, 2019), formal non-micro firms have the highest share of websites created. Given the relatively higher level of digital adoption among formal firms (regardless of their size), it is plausible for us to assume that the spillover effect on digital adoption occurs from formal to informal sectors in Zambia. This is further confirmed by the fact that 94% of informal businesses sell to individuals instead of firms in Zambia.

Table 1: Digital Variables by Survey Type (in %)

	Formal		Informal
	5+ Employees	Micro (1-4)	
Sample Size	600	97	914
Use of Computers		28.25	5.36
Use of Tablets		3.80	8.91
Use of Cell-/Smartphone		76.33	58.26
Website/Social Media	57.14	40.69	5.51
Mobile Money (MM)		50.64	42.71

Notes: All variables, except the number of firms, are in % of all firms. Sampling weights applied. The number of firms may vary for some variables. Note that there are additional digital variables for formal firms. "Formal" covers businesses included in in the World Bank Enterprise Survey (WBES). "Micro" covers businesses included in the World Bank Micro Enterprise Survey (WBMES), and "Informal" covers businesses included in the World Bank Informal Sector Enterprise Survey (WBISES).

Table 2: Summary Statistics

	Micro	Informal
Distance of Informal to Closest Formal Firm (Baseline)		0.96
Distance of Informal to Closest ES Firm		1.43
Distance of Informal to Closest Formal Firm (Enumerated)		0.68
Distance of Informal to Closest Formal Firm with Website		1.81
Number of Informal Businesses Within Square		12.49
Num. of People Who Worked Last Month	2.23	2.04
Years in Operation	5.25	3.30
Age of Main Owner	35.60	37.72

Owner's Education (1=above secondary)	0.59	0.12
Prior Experience in Same Type of Business (1=yes)	0.24	0.24
Sector Dummy (1=manuf, 0=services (inc. retail))	0.09	0.07
Formal Labor Productivity (log)		10.43
Informal Labor Productivity (log)		5.56
Elevation		1249.02
Nighttime Lights Emission		35.46

Notes: Sampling weights applied. "Formal Micro" covers formal micro-businesses included in the World Bank Micro Enterprise Survey (WBMES), and "Informal" covers businesses included in the World Bank Informal Sector Enterprise Survey (WBISES). Baseline estimates match the closest informal firm to the closest formal firm that was interviewed.

The main variable of interest is the geographic proximity of informal businesses to formal firms. Geographic proximity is captured by the distance to the closest formal firm. Table 2 shows the summary statistics where distance is represented in kilometers.[8] The baseline measure is the distance between informal businesses and the closet formal firms regardless of their size (i.e., combining both firms from WBMES and WBES). Additional distance measures are constructed and explained in detail in the robustness, heterogeneity, and spillover channel sections.[9]

A potential endogeneity concern when using geographic proximity is that location choice of firms may be linked with their decision to adopt digital technologies. However, studies have shown that technology transfer is not the only (or main) reason for firms' location choice.[10] While the decision to locate the business in a specific district may be driven by the owner's technology adoption consideration (e.g., access to infrastructure), the realization of the location (that is the distance to

[8] Distances were calculated between each of the 9,039 (which is the sum of all observations across all three surveys) businesses enumerated with one another, after which, the closest formal firm is singled out for the following empirical analysis.

[9] It is possible that the baseline distance measure is not the best proxy for the geographic proximity between formal and informal firms, as the captured formal firm might not necessarily be the closest one. However, the additional information recorded is essential for us to conduct additional tests to understand the spillover channels. As a robustness, the distances calculated to all enumerated formal firms is used, independent on whether they were surveyed or not, and reported the results in Table 10.

[10] As suggested by Marshall's theory, there are three main mechanisms for co-agglomeration: labor market pooling, access to suppliers and consumers, and inter-firm knowledge spillovers. Inter-firm knowledge spillover is often not the main reason for a firm's co-agglomeration (co-location) decision. For instance, Howard, Newman and Tarp (2016) find that technology transfers are not the most important agglomerative force in Viet Nam. Studying the geographic clustering patterns of formal and informal firms in Cali, Colombia, García Cruz and Moreno-Monroy (2015) show that co-location occurs mainly between small formal and informal firms, rather than with large formal firms. Their results also suggest that technology spillover is not the main determinant of firms' location decisions. Howard et al. (2016) show that 68 percent of informal businesses are located in existing fixed premises with a majority being located in household premises. These premises are unlikely to have been chosen strategically.

the closest formal firm) cannot be solely determined by the owner. It depends also on other factors such as the formal firm's decision and the availability of specific locations. Finally, a large share of informal businesses in the sample operates from their own house, which is indicative of their limited ability to re-locate. To check the robustness of the results, additional analyses using different measures of distance and the subsample where informal firms operate in fixed premises are conducted. The additional results support the validity of the approach.[11]

c. Empirical Methodology

The estimation of the spillover effects of ICT adoption from formal to informal firms uses a logit model. The specification of the estimation is the following:

$$Adoption_i = \beta_0 + \beta_1 Distance_i + \beta_2 X_i + \varepsilon_i, \quad (1)$$

Where $Adoption_i$ denotes whether informal business *i* adopts a specific ICT technology (1 = yes, and 0 otherwise), such as computers, tablets, cell phones, mobile money, and website. $Distance_i$ denotes the distance of informal business *i* to the closest formal firm, which was captured either by the standard WBES or the WBMES (see above for details).

X_i is a vector of controls that captures the characteristics of informal business *i* that can affect the digital adoption decisions. Such characteristics include the number of workers in the last month, the number of years in operation, and a sector dummy as well as the owner's age, education, and prior experience in the same type of business. In an extension of the model, labor productivity is included.[12] Lastly, city dummies and clusters to control for city-specific effects of the three cities included in the surveys are incorporated.

In an extension, an interaction term is added to study how the distance effect varies by observable characteristics of informal businesses, which is formulated as follows:

$$Adoption_i = \beta_0 + \beta_1 Distance_i + \beta_2 Heterogeneity_i + \beta_3 Distance_i \times Heterogeneity_i + \beta_4 X_i + \varepsilon_i, \quad (2)$$

[11] See section 3b for details.

[12] Labor productivity is calculated as annual sales divided by the number of workers in log. Missing values are filled with annual sales from two years ago.

Where $Heterogeneity_i$ is either the owner's level of education or years in operation. The other variables follow the same structure as in the equation before.[13]

3 Empirical Results

This section presents the baseline results and a series of robustness checks using alternative definitions of the main variables of interest, additional controls, and an alternative sample.

a. Baseline Model

The baseline model, presented in Table 3, includes the full model using the distance between an informal business to both types of formal firms, namely micro (<5 employees) and larger enterprises. The top rows show the dependent variables, which are dummies that capture the adoption of a specific digital technology. The first column shows the results on the adoption of computers (PC), with the following columns providing the effects on the adoption of tablets, mobile phones, mobile money, and own website.

The results in columns (1)-(4) show a statistically significant and negative effect between the distance to the closest formal firm and the digital adoption of informal businesses. Hence, a larger distance leads to a lower adoption level of these digital technologies, suggesting that there are spillovers from formal firms to informal businesses in the use of computers, tablets, mobile phones, and mobile money.[14] The lack of a significant effect on the creation of own websites can be attributed to the informal status of these businesses, as they might be reluctant to create a website to avoid being detected by tax or other government authorities. As shown in Table 1, only 5.5 percent of all informal businesses create a website.

As for the control variables, a higher number of people working in the informal business is associated with a higher likelihood of technology adoption. The same holds for the owner's education and his or her prior experience, although the latter is only statistically significant for PC

[13] There are some exceptions to the structure. For instance, the same variables from the control matrix are excluded, but included in the heterogeneity matrix.

[14] While reverse spillovers are possible, they are less likely due to the higher level of digital adoption by formal firms than by informal businesses.

adoption. The age of the informal business, measured by years in operation, is associated with less adoption of computers as well as tablets.

Aside from proximity, another channel through which technological spillovers may occur is the size of the market in which the business operates. In particular, the more formal businesses are in close proximity to the informal business, the more opportunities for this business to learn from its formal counterparts. While this premise goes beyond the scope of this analysis, for brevity the results of the density are shown in Appendix B and indicate that greater density is associated with greater adoption of personal computers.

Table 3: Baseline Model

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.596*	-0.741***	-0.180***	-0.202***	-0.197
	(0.349)	(0.130)	(0.028)	(0.073)	(0.414)
Num. of People Who Worked Last Month	0.337***	0.244	0.133***	0.019	0.337***
	(0.109)	(0.186)	(0.048)	(0.082)	(0.019)
Years in Operation	-0.064***	-0.044**	0.001	0.006	-0.006
	(0.018)	(0.020)	(0.013)	(0.022)	(0.018)
Age of Main Owner	-0.016	0.030	0.010**	0.005**	-0.053***
	(0.011)	(0.024)	(0.004)	(0.002)	(0.017)
Owner's Education (1=above secondary)	1.228***	0.108	1.021***	0.114	1.256***
	(0.348)	(0.755)	(0.218)	(0.099)	(0.380)
Prior Experience in Same Type of Business	1.041***	0.707	0.361	0.203	0.971
	(0.041)	(0.503)	(0.303)	(0.586)	(0.694)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.093*	-0.471	0.065	0.268*	-0.074
	(0.616)	(0.824)	(0.133)	(0.158)	(0.388)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

b. Robustness Checks

Several robustness checks are conducted in this section. First, the analysis estimates the same baseline model using additional control variables. Second, a test for location choice as a potential source of endogeneity is conducted. Third, alternative measures of distance are presented to pinpoint the nature of technology spillovers in a more precise way.

Endogeneity concerns

Extending the baseline model by including additional control variables controls for any omitted variable bias and accounts for potential endogeneity concerns. These additional control variables are formal and informal labor productivity, elevation and night lights emission. First, informal labor productivity denotes the productivity of informal businesses and strives to control for a potential endogeneity stemming from more productive businesses implementing more digital technologies (see top rows in Table 4). The effects of distance on different types of digital technologies are in line with the baseline results. In particular, the results indicate statistically significant negative effects of distance on the adoption of various digital technologies, suggesting that the baseline results are not driven by the potential common factor that more productive businesses are more likely to adopt digital technologies. The middle rows show results when formal labor productivity, which is the productivity of the closest formal firm, is included. Formal labor productivity controls for the fact that spillovers might be driven by informal businesses being close to very productive formal firms. The results remain robust to the baseline.

Table 4: Baseline Model with Labor Productivity

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.567*	-0.749***	-0.187***	-0.196***	-0.196
	(0.314)	(0.154)	(0.009)	(0.036)	(0.405)
Informal Labor Productivity (log)	0.056	0.093	0.174***	0.184***	0.044
	(0.064)	(0.117)	(0.017)	(0.038)	(0.130)
Number of Observations	814	814	814	806	600
Distance of Informal to Closest Formal Firm	-0.451**	-0.734***	-0.137***	-0.182**	-0.206
	(0.214)	(0.084)	(0.036)	(0.077)	(0.422)
Formal Labor Productivity (log)	0.031	0.011	0.025	-0.009	-0.041
	(0.044)	(0.125)	(0.054)	(0.047)	(0.036)
Number of Observations	730	730	730	722	556
Distance of Informal to Closest Formal Firm	-0.408**	-0.764***	-0.119***	-0.206***	-0.166
	(0.194)	(0.111)	(0.034)	(0.050)	(0.497)
Formal Labor Productivity (log)	0.003	-0.005	0.047	0.039	-0.080***
	(0.033)	(0.110)	(0.045)	(0.049)	(0.019)
Informal Labor Productivity (log)	0.079	0.113	0.160***	0.201***	0.081
	(0.066)	(0.152)	(0.039)	(0.019)	(0.113)
Number of Observations	664	664	664	657	499

Notes: MM denotes mobile money. Labor productivity is calculated using annual sales. Missing values are replaced by annual sales from two years ago. Control variables are omitted from the table. See Appendix Tables A.2 for full model results. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

The last set of robustness checks include elevation and night lights emission to the model specification. Elevation is measured in units of meters above the sea level and collected by the tablet during the enumeration stage of the survey. Nighttime lights emission is the amount of light captured by VIIRS sensors from satellite imagery over cloud-free skies within a one square-kilometer area in which the informal business is located.[15] While the former captures geographic connectivity, [16] the latter serves as a general proxy for access to infrastructure, such as electricity, which is a crucial constraint on firms' ICT adoption in Zambia.[17] The results, as depicted in Table 5, remain robust to the inclusion of these controls, suggesting that the distance effect is not driven by geographic connectivity or access to infrastructure.

Table 5: Baseline Model with Additional Controls

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.569*	-0.740***	-0.163***	-0.192***	-0.197
	(0.336)	(0.125)	(0.018)	(0.063)	(0.437)
Elevation	0.006	-0.001	0.002	0.001	-0.003
	(0.004)	(0.005)	(0.002)	(0.002)	(0.007)
Number of Observations	900	900	900	890	677
Distance of Informal to Closest Formal Firm	-0.242	-0.690***	-0.165***	-0.191**	-0.046
	(0.566)	(0.205)	(0.026)	(0.075)	(0.588)
Nighttime Lights Emission	0.050*	0.009	0.003	0.002	0.022
	(0.026)	(0.013)	(0.011)	(0.004)	(0.024)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Elevation is captured by the tablet during the interview with the informal business in meters above sea level. Nighttime lights emissions are captured by VIIRS sensors from satellite imagery over cloud-free skies. A higher number indicates more light emission. Control variables are omitted from the table. See Appendix Table A.3 for full model results. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Another endogeneity concern is related to the location choice of informal businesses. The results would be biased if informal businesses strategically decide to co-locate with formal firms to benefit

[15] The nighttime lights emission ranges between 0 and 63, with higher numbers associated with more light emission.
[16] To further ensure our distance measure is not simply capturing remoteness or other geographical features, we divide each city into quadrants and run additional robustness checks using quadrant fixed effects. The results are similar to the results in the baseline, see Appendix Table A.3.3 for results.
[17] Around 14 percent of informal businesses in Zambia report not being connected to the electricity grid and 77 percent report having had a least one power outage last month.

from potential technology spillovers. The survey data reports four different types of premises, namely household, non-household with a permanent structure, non-household with a temporary structure, and non-fixed premises. The statistics are summarized in Table 6. Around 40% of informal businesses operate within their household premises. An additional 27% are located in other permanent structures, whereas around 30% have either no premises or some kind of temporary structure.

Table 6: Summary of Type of Premises: Informal Businesses

Type of Premises	Obs	Percent
Household	415	41.05
Non-household with permanent structure	274	27.1
Non-household with temporary structure	270	26.71
Non-fixed premises, including hawkers	52	5.14
Total	1,011	100

Table 7 shows that the effects of distance on digital technology adoption remain negative and statistically significant when the sample is restricted to informal businesses with permanent structures.

Table 7: Effects of Distance for the Permanent Location Sample

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.840***	-0.691***	-0.194**	-0.172***	-0.387
	(0.141)	(0.201)	(0.093)	(0.037)	(0.440)
Num. of People Who Worked Last Month	0.404***	0.273	0.068	-0.057**	0.391***
	(0.028)	(0.287)	(0.071)	(0.029)	(0.121)
Years in Operation	-0.031	-0.039	0.009	0.013	0.014
	(0.021)	(0.040)	(0.022)	(0.023)	(0.022)
Age of Main Owner	-0.018	0.024	0.002	-0.005	-0.053*
	(0.017)	(0.022)	(0.010)	(0.003)	(0.031)
Owner's Education (1=above secondary)	1.672***	0.163	0.870***	0.072	1.645***
	(0.217)	(0.986)	(0.050)	(0.252)	(0.527)
Prior Experience in Same Type of Business	0.637*	1.080	0.377	0.362	0.136
	(0.383)	(0.739)	(0.608)	(0.664)	(0.265)
Sector Dummy (1=manuf, 0=services (inc. retail))	-0.876	-1.097**	-0.363	-0.260	0.359
	(0.736)	(0.433)	(0.652)	(0.729)	(0.280)
Number of Observations	606	606	606	600	435

Notes: MM denotes mobile money. The "Permanent Location" sample includes firms operating on household premises or non-households with permanent structures. See Table 6 for an overview of the types of premises. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Alternative Distance Measures

Alternative distance measures allow to test whether the results remain robust when the formal firm exhibits different characteristics. The first alternative measure includes the distance of informal businesses to larger formal firms that participated in the World Bank Enterprise Survey (ES). Given that larger firms tend to be more technologically advanced, the use of this alternative distance informs us whether the distance effect is driven by the larger firms in the sample. Meanwhile, the second measure includes all formal firms that were enumerated (i.e., their GPS locations are recorded) regardless of whether they surveyed. Hence, it captures the fact that an informal business might be closer to another formal firm than suggested by the baseline measure. Lastly, the results using the distance to formal firms (micro and large) that have a website are presented to confirm whether the findings are driven by technologically more advanced formal firms.

As shown in Table 8, the alternative distance measures generate results that are in line with the baseline. Throughout the different specifications of the model, the direction and magnitude of the estimates are robust, with statistical significance dropping for the adoption of personal computers when using the model of all enumerated formal firms or the specification with formal firms with websites.[18]

Table 8: Alternative Distance Measures

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm (Baseline)	-0.596*	-0.741***	-0.180***	-0.202***	-0.197
	(0.349)	(0.130)	(0.028)	(0.073)	(0.414)
Distance of Informal to Closest ES Firm	-0.604***	-0.417*	-0.216***	-0.196**	-0.378
	(0.206)	(0.235)	(0.048)	(0.085)	(0.433)
Distance of Informal to Closest Formal Firm (Enumerated)	-0.431	-1.600	-0.271***	-0.342***	-0.224
	(0.504)	(1.281)	(0.024)	(0.095)	(0.633)
Distance of Informal to Closest Formal Firm With Website	-0.399	-0.659***	-0.152***	-0.154***	-0.235
	(0.329)	(0.221)	(0.036)	(0.042)	(0.243)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Each line represents a separate set of estimations with different distance measures included one at a time. The same set of control variables used in the baseline model are include in each set of the regressions here with results

[18] These results remain even when using non-micro firms with websites. Results available upon request.

being omitted from the table. See Appendix Table A.4 and Table A.5 for full model results. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

4 Heterogeneous Effects

a. Owner's Level of Education

In this part, the analysis is extended by examining the effects of distance on the adoption of digital technologies conditioning on the owner's level of education. A binary variable equal to one if the owner's education is above secondary school is interacted with the baseline distance measure following Equation (2) above. Figure 2 depicts the effects of distance by owners' education levels. The dots represent the total effect of distance on the adoption of digital technology (y-axis) for a given level of the owner's education (x-axis). For PC, tablets, phones, and mobile money, there are stronger negative effects of distance on technology adoption if the education level is high. However, the effect is only significant for PC, phones, and mobile money. For the adoption of computers, the education level of the owner matters the most. The effect is not statistically significant for a low level of education, but significantly negative for a high level. This implies that the education level has an amplifying effect on technology adoption. Being close to a formal firm generates a higher level of adoption when the owner is also highly educated.

For the adoption of tablets, the effect of distance on technology adoption is only statistically significant for low levels of the owner's education. This reflects the possible substitution between computers and tablets. The adoption of phones and mobile money is, at least weakly, significant for both levels of education, though the effect of distance is stronger for highly educated owners.

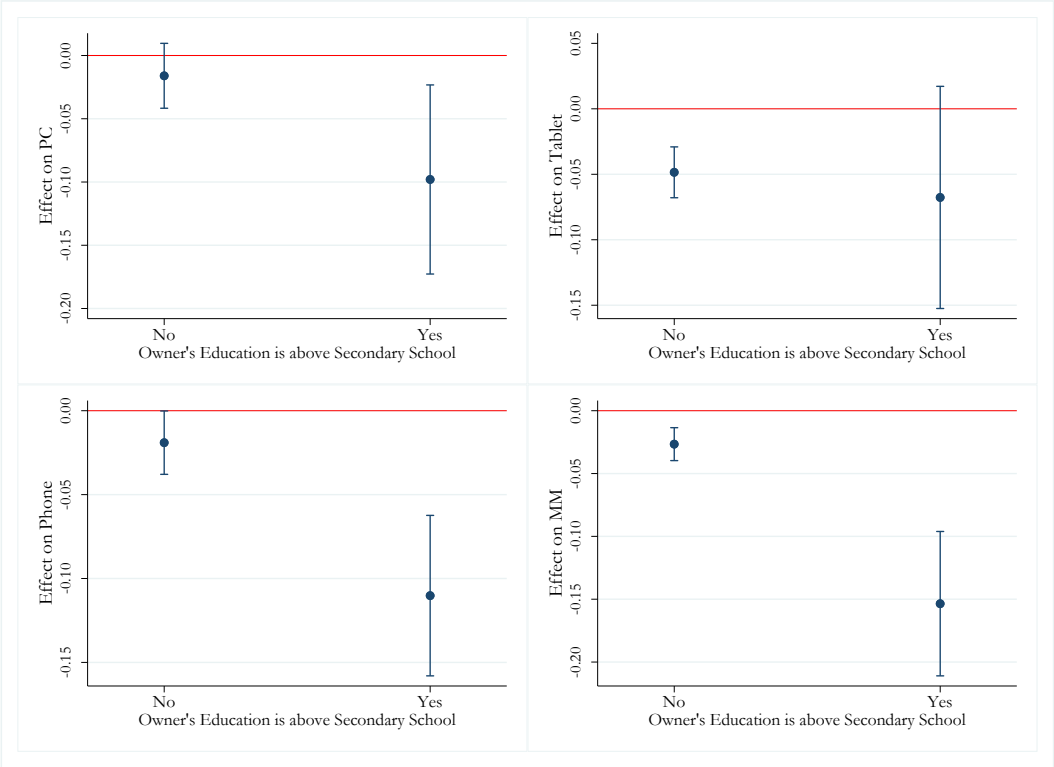

Figure 2: Heterogenous Effects of Distance by Owner's Level of Education

Notes: Figure shows the average marginal effects of the distance of informal businesses to formal firms on different types of digital technologies (y-axis) for different education levels of the owner (x-axis). Each dot denotes the total effect (distance and interaction term) of distance. Adoption of a website is not significant and, therefore, omitted from this graph. Whiskers show 95% confidence intervals. MM denotes mobile money. See Table A. 6 for full model results. Sampling weights applied. Standard errors are clustered at the city level.

b. Business Age

This analysis tests whether older or more established businesses are more likely to adopt digital technologies. The survey was conducted in 2019/2020. Most of the informal businesses are young, having been created one to two years before the survey was conducted, see Figure A. 1. For this reason, 2016 is chosen as the cut-off year between young and old businesses. Figure 3 shows the results. Distance has a statistically significant negative effect on the adoption of computers for informal businesses that were created before 2016. For all other digital technologies, distance does not have a significant effect on the adoption of technology for older or more established firms. In contrast, distance has a statistically negative effect on the adoption of tablets and phones for new businesses. There are no effects of distance on mobile money for any business age.

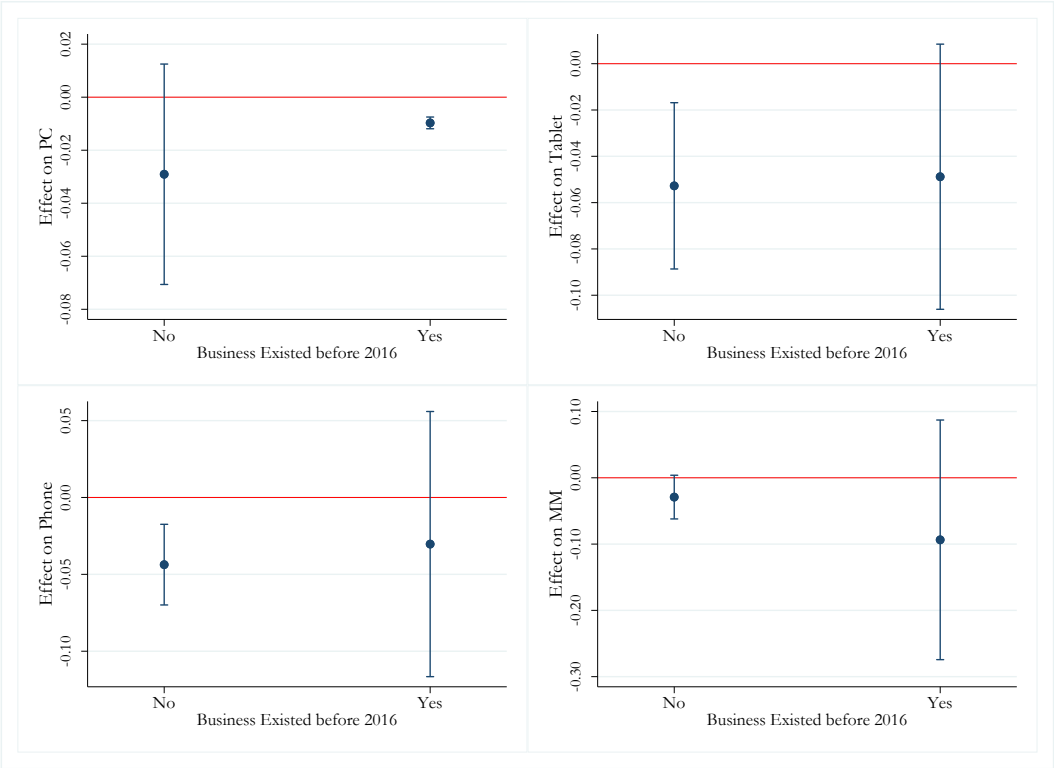

Figure 3: Heterogenous Effects of Distance by Business Age

Notes: Figure shows the average marginal effects of the distance of informal businesses to formal firms on different types of digital technologies (y-axis) for business age (x-axis). Each dot denotes the total effect (distance and interaction term) of distance. Adopting a website is not significant and, therefore, omitted from this graph. Whiskers show 95% confidence intervals. MM denotes mobile money. See Table A.7 for full model results. Sampling weights applied. Standard errors are clustered at the city level.

5 Spillover Channels

The spillovers in ICT use from formal firms to informal businesses that are geographically proximate can be explained either through demand-side or supply-side channels. On the demand side, we analyze the role of competition which increases the returns to technology adoption which, in turn, increases the incentive to innovate. On the supply side, we analyze the role of learning from formal firms.

a. Competition

Since informal businesses are predominantly small, both in size and revenue, they serve mainly local markets. Hence, it is very likely that the degree of competition they face depends on the presence of competing businesses in the location where they operate. Therefore, the total number of informal businesses operating in each enumeration area (i.e., 150 by 150 square meters) can

serve as a proxy for the level of competition these businesses face.[19] The greater the number of other informal businesses in the enumeration area, the greater the competition an informal business faces. Furthermore, the greater the competition is, the more likely a business has to adopt technologies that facilitate market exchange. As shown in Table 9, a higher number of informal businesses within a square leads to statistically significant and positive effects on technology adoption. Hence, more competition in the vicinity of an informal business is associated with a higher level of adoption, which suggests that competition is relevant for digital spillovers.

Table 9: Effect of Number of Informal Businesses within a Square

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Number of Informal Businesses Within Square	0.007	0.036	0.036***	0.037***	0.007
	(0.009)	(0.022)	(0.005)	(0.012)	(0.012)
Num. of People Who Worked Last Month	0.524***	0.314***	0.223***	0.072	0.357***
	(0.051)	(0.119)	(0.063)	(0.108)	(0.075)
Years in Operation	0.070*	-0.012	-0.001	0.030	0.011
	(0.037)	(0.042)	(0.015)	(0.021)	(0.008)
Age of Main Owner	-0.037	0.023	-0.002	-0.011	-0.041**
	(0.034)	(0.029)	(0.007)	(0.008)	(0.019)
Owner's Education (1=above secondary)	2.577***	0.161	1.623***	0.483	2.665***
	(0.338)	(0.644)	(0.436)	(0.311)	(0.339)
Prior Experience in Same Type of Business	1.513**	0.757**	0.602	0.243	0.505
	(0.708)	(0.333)	(0.386)	(0.749)	(0.810)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.851	-0.319	0.283	0.610**	0.391
	(1.385)	(0.715)	(0.198)	(0.238)	(0.478)
Number of Observations	987	987	986	962	721

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

b. Learning from other businesses

Market forces drive businesses to adapt and innovate, and often the low hanging fruit for smaller, less productive firms is implementing what more productive and more sophisticated businesses are doing. This learning process is particularly important when examining the informal and formal sectors together, since the differences between the two are stark. Learning occurs through direct interactions. Proximity reduces the cost of these direct interactions, and thereby enables a greater degree of learning and technology diffusion. To capture the importance of geographic

[19] The analysis is further extended using the sum of both formal and informal businesses in a square as a general proxy for competition. The results are in line with Table 9 and will be provided upon request.

proximity in facilitating these interactions, the analysis introduces two direct measures captured through the surveys. The first one asks whether an informal business visited competitors to see what products they have available for sale, and the second one asks whether the main source of inputs of the informal business is stemming from another business rather than from an individual or self-produce.

Informal businesses are more likely to learn and adopt digital technologies if they visit their competitors and receive their inputs from another business. The latter may suggest that learning can occur through value-chain linkages. For example, if a formal firm requires digital or mobile payments for its products or services, then the informal business is likely to adopt that technology.

The results in Figure 4 indicate that visiting competitors can mitigate the geographic disadvantage borne by informal businesses when they are far away from their formal counterparts. While around 54% of informal businesses visited their competitors in the sample, the effect of distance on the adoption of a digital technology turned statistically insignificant for all types of technologies when such a visit was conducted.

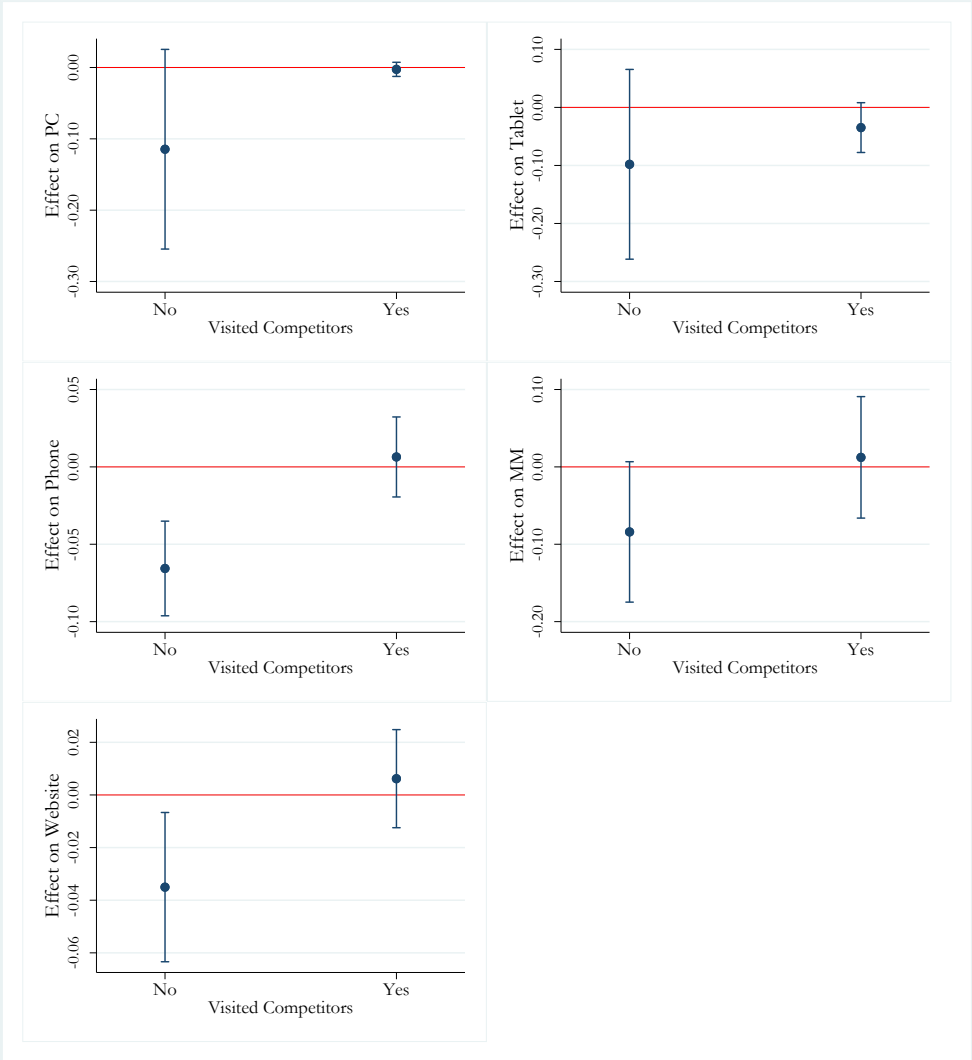

Figure 4: Interaction with Visiting Competitors

Notes: Figure shows the average marginal effects of the distance of informal businesses to formal firms on different types of digital technologies (y-axis) for whether an informal business visited its competitors (x-axis). Each dot denotes the total effect (distance and interaction term) of distance. Whiskers show 95% confidence intervals. MM denotes mobile money. The full results are in Appendix Table A. 8. Sampling weights applied. Standard errors are clustered at the city level.

Similarly, informal businesses which interact with other businesses to obtain their material inputs are also better positioned to overcome the distance disadvantage of learning when it comes to digital spillovers. Table 10 shows forward and backward value-chain linkages by formal micro and informal firms. While 94% of informal businesses sell to individuals instead of firms, they purchase 50% of their inputs, goods, and supplies from other businesses, suggesting backward linkages are more prevalent for informal firms (in line with Boehme and Thiele 2014). This result is also evident for micro firms. Within the different types of businesses, micro firms purchase a larger share of inputs and supplies from larger businesses (37.69%). In contrast, informal

businesses tend to interact more with micro businesses (25.31%) than larger businesses (19.46%). Unfortunately, there is no information on whether these businesses are formal or informal. Furthermore, the data shows that informal businesses and their primary suppliers are loosely linked. Most businesses have been working with the current primary supplier for solely one year (71%).

Table 10: Value-Chain Linkages by Survey Type (in %)

		Formal Micro	Informal
Main Customer	Individuals	92.53	94.11
	Business (<5)	3.29	2.98
	Business (>5)	2.00	2.15
Source of Inputs, Goods, and Supplies	Individuals	40.47	49.73
	Business (<5)	15.03	25.31
	Business (>5)	37.69	19.46
	Self-produce	1.47	3.69

Notes: All variables are in % of all firms. Sampling weights applied. The number of firms may vary for some variables. "Formal Micro" covers formal micro-businesses included in the World Bank Micro Enterprise Survey (WBMES), and "Informal" covers businesses included in the World Bank Informal Sector Enterprise Survey (WBISES).

Results are summarized in Figure 5. While the effect of distance is negative and statistically significant for informal businesses that do not receive inputs from other businesses, the effect turns insignificant for informal businesses that do receive their main inputs from other businesses. This suggest that even informal businesses can overcome the disadvantage of being far away from more technologically advanced formal firms and learn from their peers by establishing value-chain linkages with them.

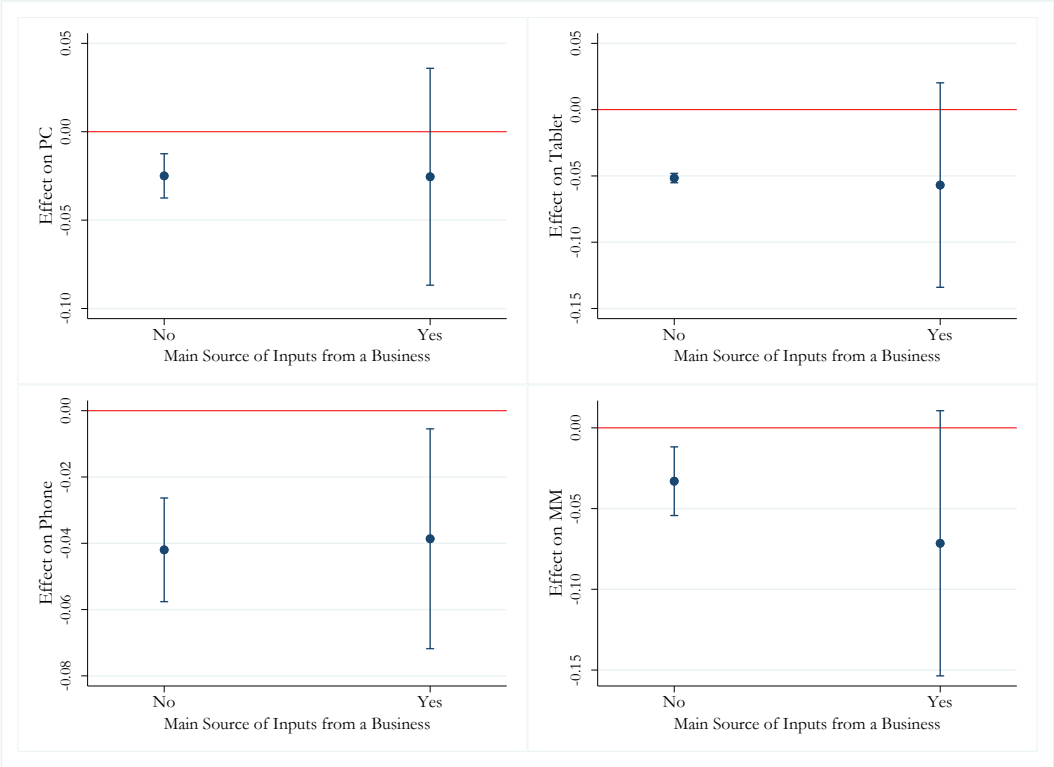

Figure 5: Heterogenous Effects of Distance by Type of Input Source

Notes: Figure shows the average marginal effects of the distance of informal businesses to formal firms on different types of digital technologies (y-axis) for different types of input sources (x-axis). Each dot denotes the total effect (distance and interaction term) of distance. Adoption a website is not significant and, therefore, omitted from this graph. Whiskers show 95% confidence intervals. MM denotes mobile money. See Appendix Table A. 9 for full model results. Sampling weights applied. Standard errors are clustered at the city level.

6 Conclusion

The results suggest that a shorter geographic distance to formal firms is associated with a significantly higher likelihood of digital adoption by informal businesses. The findings hold for various types of digital technologies, ranging from computers, tablets, and phones to mobile money transactions, and are robust to various measures of geographic proximity and model modifications.

The strength of effects depends on a range of factors. First, for most of the digital technologies under consideration, the technology spillover effect from formal firms is more profound in informal businesses whose owner's level of education is higher. Second, the technology spillover effect is stronger for younger informal businesses.

Identifying the underlying channels through which geographic proximity results in digital spillover effects from formal firms to informal businesses is not straightforward. We provide evidence of the role of local market competition and learning from formal firms for these positive spillovers in ICT adoption.

These results have significant implications for policy makers seeking to improve firm-level productivity in the presence of pervasive informality. Rather than having the informal sector operate separately from the formal sector, some co-existence and co-location can help the informal sector modernize. This could be achieved either through providing better public infrastructure, arranging entrepreneurship programs, or establishing institutional arrangements on how they can co-exist.

Last, but not least, the technology spillovers identified here are indicative of linkages between the formal and informal sectors, as opposed to the dualistic view that each segment of the economy caters to its own unique market. These positive spillovers are provided by the formal sector. Understanding the incurred cost merits further analysis.

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Appendix

Appendix A: Tables and Figure

Table A.1: Firm Registration Status by Survey Types

Survey Type	ZRA	PACRA	Municipality
ES	100%	100%	100%
Micro	87%	100%	95%
Informal	0%	~0%	11%

Notes: ES=WBES; Micro=WBMES; Informal=WBISES.

Tables A.2: Baseline with Labor Productivity (Full Model Results)

A.2.1: Informal Labor Productivity

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.567*	-0.749***	-0.187***	-0.196***	-0.196
	(0.314)	(0.154)	(0.009)	(0.036)	(0.405)
Num. of People Who Worked Last Month	0.348***	0.291***	0.186*	0.099***	0.376***
	(0.080)	(0.107)	(0.109)	(0.028)	(0.051)
Years in Operation	-0.057***	-0.041***	0.001	-0.006	-0.018
	(0.014)	(0.014)	(0.007)	(0.014)	(0.024)
Age of Main Owner	-0.020	0.029	0.008	0.004*	-0.056**
	(0.017)	(0.024)	(0.006)	(0.003)	(0.025)
Owner's Education (1=above secondary)	1.158***	-0.062	1.058***	-0.025	1.245***
	(0.357)	(0.829)	(0.307)	(0.147)	(0.325)
Prior Experience in Same Type of Business	0.972***	0.644*	0.050	0.088	0.981
	(0.164)	(0.330)	(0.208)	(0.435)	(0.791)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.199*	-0.799	-0.165	0.080	-0.171
	(0.696)	(1.060)	(0.284)	(0.128)	(0.118)
Informal Labor Productivity (log)	0.056	0.093	0.174***	0.184***	0.044
	(0.064)	(0.117)	(0.017)	(0.038)	(0.130)
Number of Observations	814	814	814	806	600

Notes: MM denotes mobile money. Labor productivity is calculated using annual sales. Missing values are replaced by annual sales from two years ago. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

A.2.2: Formal Labor Productivity

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.451**	-0.734***	-0.137***	-0.182**	-0.206
	(0.214)	(0.084)	(0.036)	(0.077)	(0.422)
Num. of People Who Worked Last Month	0.309***	0.169	0.188**	0.036	0.351***
	(0.080)	(0.212)	(0.090)	(0.103)	(0.034)
Years in Operation	-0.023	-0.049	-0.018***	-0.010	0.001
	(0.043)	(0.037)	(0.002)	(0.019)	(0.029)
Age of Main Owner	-0.025**	0.039*	0.016***	0.006	-0.055**
	(0.012)	(0.023)	(0.004)	(0.004)	(0.024)
Owner's Education (1=above secondary)	1.572***	0.308	1.117***	0.094	1.327***
	(0.190)	(1.063)	(0.193)	(0.141)	(0.395)
Prior Experience in Same Type of Business	1.103**	0.905	0.213	0.169	1.142
	(0.500)	(0.793)	(0.348)	(0.550)	(0.779)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.125	-0.275	-0.171	0.041	-0.025
	(0.823)	(1.156)	(0.244)	(0.439)	(0.156)
Formal Labor Productivity (log)	0.031	0.011	0.025	-0.009	-0.041
	(0.044)	(0.125)	(0.054)	(0.047)	(0.036)
Number of Observations	730	730	730	722	556

Notes: MM denotes mobile money. Labor productivity is calculated using annual sales. Missing values are replaced by annual sales from two years ago. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

A.2.3: Informal and Formal Labor Productivity

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.408**	-0.764***	-0.119***	-0.206***	-0.166
	(0.194)	(0.111)	(0.034)	(0.050)	(0.497)
Num. of People Who Worked Last Month	0.334***	0.236**	0.217	0.120**	0.415***
	(0.050)	(0.099)	(0.144)	(0.059)	(0.037)
Years in Operation	-0.017	-0.047	-0.017	-0.023**	-0.019
	(0.056)	(0.031)	(0.016)	(0.009)	(0.053)
Age of Main Owner	-0.031	0.038*	0.008**	-0.001	-0.055
	(0.024)	(0.022)	(0.004)	(0.003)	(0.036)
Owner's Education (1=above secondary)	1.589***	0.167	1.185***	-0.070	1.398***
	(0.149)	(1.132)	(0.255)	(0.223)	(0.414)
Prior Experience in Same Type of Business	1.024	0.881	-0.057	0.080	1.189
	(0.661)	(0.564)	(0.247)	(0.413)	(0.770)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.272	-0.633	-0.288	-0.074	-0.244***
	(0.919)	(1.419)	(0.245)	(0.285)	(0.075)
Formal Labor Productivity (log)	0.003	-0.005	0.047	0.039	-0.080***
	(0.033)	(0.110)	(0.045)	(0.049)	(0.019)
Informal Labor Productivity (log)	0.079	0.113	0.160***	0.201***	0.081
	(0.066)	(0.152)	(0.039)	(0.019)	(0.113)
Number of Observations	664	664	664	657	499

Notes: MM denotes mobile money. Labor productivity is calculated using annual sales. Missing values are replaced by annual sales from two years ago. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.3: Baseline with Additional Controls (Full Model Results)

Table A.3.1: Adding Elevation

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.569*	-0.740***	-0.163***	-0.192***	-0.197
	(0.336)	(0.125)	(0.018)	(0.063)	(0.437)
Num. of People Who Worked Last Month	0.333***	0.244	0.134***	0.019	0.338***
	(0.111)	(0.187)	(0.050)	(0.083)	(0.020)
Years in Operation	-0.067***	-0.043**	0.000	0.005	-0.005
	(0.020)	(0.017)	(0.013)	(0.022)	(0.019)
Age of Main Owner	-0.017	0.030	0.010**	0.005*	-0.053***
	(0.011)	(0.025)	(0.005)	(0.003)	(0.018)
Owner's Education (1=above secondary)	1.234***	0.111	1.020***	0.109	1.250***
	(0.329)	(0.742)	(0.196)	(0.098)	(0.379)
Prior Experience in Same Type of Business	1.059***	0.708	0.404	0.224	0.977
	(0.053)	(0.504)	(0.345)	(0.607)	(0.686)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.175**	-0.469	0.056	0.263	-0.042
	(0.519)	(0.842)	(0.142)	(0.167)	(0.436)
Elevation	0.006	-0.001	0.002	0.001	-0.003
	(0.004)	(0.005)	(0.002)	(0.002)	(0.007)
Number of Observations	900	900	900	890	677

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.3.2: Adding Night Lights Emission

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.242	-0.690***	-0.165***	-0.191**	-0.046
	(0.566)	(0.205)	(0.026)	(0.075)	(0.588)
Num. of People Who Worked Last Month	0.382***	0.249	0.134***	0.020	0.357***
	(0.129)	(0.196)	(0.046)	(0.082)	(0.033)
Years in Operation	-0.071***	-0.044**	0.001	0.006	-0.002
	(0.022)	(0.020)	(0.013)	(0.022)	(0.012)
Age of Main Owner	-0.018	0.030	0.011***	0.006**	-0.052***
	(0.012)	(0.024)	(0.004)	(0.002)	(0.019)
Owner's Education (1=above secondary)	1.163***	0.081	1.024***	0.114	1.235***
	(0.315)	(0.736)	(0.222)	(0.096)	(0.428)
Prior Experience in Same Type of Business	1.022***	0.695	0.359	0.202	0.969
	(0.067)	(0.489)	(0.304)	(0.588)	(0.691)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.282**	-0.468	0.070	0.271*	-0.145
	(0.586)	(0.813)	(0.151)	(0.159)	(0.435)
Nighttime Lights Emission	0.050*	0.009	0.003	0.002	0.022
	(0.026)	(0.013)	(0.011)	(0.004)	(0.024)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.3.3: Alternative Fixed Effects

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.488*	-0.831***	-0.154	-0.208	-0.340
	(0.251)	(0.141)	(0.115)	(0.147)	(0.269)
Num. of People Who Worked Last Month	0.331***	0.275**	0.146	0.038	0.485***
	(0.088)	(0.120)	(0.090)	(0.086)	(0.161)
Years in Operation	-0.068	-0.041	0.001	0.010	0.016
	(0.096)	(0.027)	(0.018)	(0.020)	(0.054)
Age of Main Owner	-0.019	0.029	0.011	0.004	-0.062**
	(0.024)	(0.019)	(0.012)	(0.016)	(0.025)
Owner's Education (1=above secondary)	1.320***	0.174	0.997***	0.106	1.233**
	(0.346)	(0.940)	(0.321)	(0.200)	(0.508)
Prior Experience in Same Type of Business	1.145**	0.708*	0.377	0.194	1.246*
	(0.482)	(0.416)	(0.314)	(0.353)	(0.720)
Sector Dummy (1=manuf, 0=services (inc. retail))	-0.971	-0.203	0.102	0.320	0.006
	(0.668)	(0.783)	(0.388)	(0.352)	(0.777)
Number of observations	864	794	901	891	615

Notes: MM denotes mobile money. Sampling weights applied. City-quadrant fixed effects are not shown. Standard errors are clustered at the city-quadrant level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.4: Alternative Distance Measures (Full Model Results)

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website	(6) PC	(7) Tablet	(8) Phone	(9) MM	(10) Website
Distance of Informal to Closest ES Firm	-0.604***	-0.417*	-0.216***	-0.196**	-0.378					
	(0.206)	(0.235)	(0.048)	(0.085)	(0.433)					
Distance of Informal to Closest Formal Firm (all, weak)						-0.431	-1.600	-0.271***	-0.342***	-0.224
						(0.504)	(1.281)	(0.024)	(0.095)	(0.633)
Num. of People Who Worked Last Month	0.350***	0.241	0.135***	0.018	0.337***	0.353***	0.272	0.137***	0.022	0.340***
	(0.082)	(0.189)	(0.051)	(0.084)	(0.026)	(0.103)	(0.166)	(0.045)	(0.080)	(0.016)
Years in Operation	-0.061***	-0.041**	0.005	0.009	-0.002	-0.064***	-0.042**	0.002	0.008	-0.004
	(0.018)	(0.020)	(0.015)	(0.025)	(0.024)	(0.019)	(0.020)	(0.013)	(0.024)	(0.023)
Age of Main Owner	-0.019	0.028	0.009*	0.004	-0.055**	-0.015	0.037	0.011**	0.007**	-0.053***
	(0.012)	(0.023)	(0.005)	(0.003)	(0.022)	(0.010)	(0.031)	(0.005)	(0.003)	(0.016)
Owner's Education (1=above secondary)	1.184***	0.101	0.992***	0.090	1.191***	1.290***	0.240	1.057***	0.160*	1.268***
	(0.372)	(0.706)	(0.189)	(0.094)	(0.364)	(0.337)	(0.799)	(0.222)	(0.085)	(0.400)
Prior Experience in Same Type of Business	0.991***	0.652	0.368	0.211	0.987	0.990***	0.672	0.337	0.175	0.975
	(0.008)	(0.518)	(0.318)	(0.601)	(0.743)	(0.004)	(0.420)	(0.305)	(0.581)	(0.697)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.100*	-0.480	0.034	0.247	-0.078	-1.157	-0.526	0.082	0.290*	-0.108
	(0.632)	(0.810)	(0.126)	(0.160)	(0.355)	(0.722)	(0.778)	(0.143)	(0.165)	(0.309)
Number of Observations	901	901	901	891	678	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.5: Alternative Distance Measures (Firms with Website, Full Model Results)

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm With Website	-0.399	-0.659***	-0.152***	-0.154***	-0.235
	(0.329)	(0.221)	(0.036)	(0.042)	(0.243)
Num. of People Who Worked Last Month	0.353***	0.261	0.145***	0.026	0.350***
	(0.088)	(0.167)	(0.046)	(0.087)	(0.037)
Years in Operation	-0.065***	-0.048*	0.004	0.009	-0.005
	(0.021)	(0.026)	(0.015)	(0.023)	(0.023)
Age of Main Owner	-0.020	0.025	0.008**	0.003*	-0.055**
	(0.013)	(0.024)	(0.004)	(0.002)	(0.023)
Owner's Education (1=above secondary)	1.234***	0.062	1.026***	0.119	1.209***
	(0.391)	(0.841)	(0.201)	(0.099)	(0.380)
Prior Experience in Same Type of Business	1.016***	0.707	0.369	0.215	0.978
	(0.055)	(0.480)	(0.320)	(0.602)	(0.710)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.036*	-0.440	0.014	0.231	0.009
	(0.614)	(0.958)	(0.112)	(0.185)	(0.403)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.6: Heterogenous Effects: Owner's Level of Education

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.434	-0.706***	-0.085**	-0.112***	-0.083
	(0.321)	(0.091)	(0.042)	(0.029)	(0.286)
Owner's Education (1=above secondary)	1.680***	0.260	1.896***	0.666***	2.145***
	(0.277)	(0.856)	(0.383)	(0.202)	(0.697)
Interaction Distance x Education	-0.787*	-0.240	-0.683***	-0.569***	-1.403**
	(0.415)	(0.287)	(0.224)	(0.141)	(0.716)
Num. of People Who Worked Last Month	0.348***	0.246	0.148***	0.027	0.341***
	(0.112)	(0.185)	(0.048)	(0.086)	(0.022)
Years in Operation	-0.066***	-0.044**	0.003	0.009	-0.003
	(0.017)	(0.019)	(0.016)	(0.025)	(0.022)
Age of Main Owner	-0.019	0.030	0.012***	0.006***	-0.057***
	(0.012)	(0.025)	(0.002)	(0.002)	(0.021)
Prior Experience in Same Type of Business	1.058***	0.709	0.344	0.189	1.030
	(0.044)	(0.502)	(0.267)	(0.559)	(0.723)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.143*	-0.481	0.064	0.279**	-0.029
	(0.601)	(0.828)	(0.134)	(0.122)	(0.386)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.7: Heterogenous Effects: Business Age

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.627	-0.858***	-0.201***	-0.123*	-0.145
	(0.480)	(0.317)	(0.062)	(0.071)	(0.386)
Business Age (<2016)	-0.947***	0.365	0.016	0.552	0.322
	(0.286)	(0.872)	(0.248)	(0.447)	(0.388)
Interaction Distance x Business Age	0.245	0.299	0.061	-0.273	-0.250**
	(0.624)	(0.356)	(0.263)	(0.485)	(0.117)
Num. of People Who Worked Last Month	0.320***	0.255	0.133***	0.027	0.340***
	(0.105)	(0.158)	(0.048)	(0.076)	(0.025)
Age of Main Owner	-0.017	0.020	0.010***	0.006**	-0.055***
	(0.012)	(0.018)	(0.002)	(0.002)	(0.019)
Owner's Education (1=above secondary)	1.229***	0.231	1.022***	0.140***	1.258***
	(0.377)	(0.593)	(0.250)	(0.049)	(0.393)
Prior Experience in Same Type of Business	1.032***	0.771	0.366	0.218	1.004
	(0.069)	(0.511)	(0.296)	(0.561)	(0.700)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.130*	-0.585	0.056	0.228	-0.100
	(0.628)	(0.864)	(0.122)	(0.170)	(0.388)
Number of Observations	901	901	901	891	678

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.8: Interaction with Visiting Competitors

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-2.875*	-2.164**	-0.294***	-0.390*	-1.380***
	(1.681)	(1.028)	(0.073)	(0.234)	(0.360)
Visited Competitors	-1.360*	-0.118	0.599***	0.404**	0.136
	(0.802)	(1.556)	(0.016)	(0.162)	(0.408)
Interaction Distance x Visited Competitors	2.817	1.772	0.327***	0.440	1.484***
	(1.781)	(1.199)	(0.123)	(0.378)	(0.249)
Num. of People Who Worked Last Month	0.365***	0.231	0.097***	-0.017	0.289***
	(0.067)	(0.191)	(0.034)	(0.078)	(0.036)
Years in Operation	-0.052*	-0.040**	-0.000	0.008	0.008
	(0.031)	(0.016)	(0.010)	(0.024)	(0.019)
Age of Main Owner	-0.022*	0.031	0.013***	0.007***	-0.059***
	(0.013)	(0.028)	(0.002)	(0.002)	(0.021)
Owner's Education (1=above secondary)	1.447***	0.099	1.190***	0.249**	1.490**
	(0.216)	(1.008)	(0.209)	(0.104)	(0.605)
Prior Experience in Same Type of Business	1.171***	0.718*	0.337	0.160	1.074
	(0.162)	(0.435)	(0.255)	(0.585)	(0.796)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.036**	-0.476	0.140	0.348**	0.061
	(0.526)	(0.854)	(0.143)	(0.151)	(0.502)
Number of Observations	899	899	899	889	676

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

Table A.9: Heterogenous Effects of Distance by Type of Input Source

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Distance of Informal to Closest Formal Firm	-0.518***	-0.898***	-0.188***	-0.146***	-0.012
	(0.175)	(0.292)	(0.033)	(0.048)	(0.320)
Input from a Business	-0.282	0.445	0.492	0.753**	-0.416*
	(0.776)	(1.148)	(0.355)	(0.309)	(0.224)
Interaction Distance x Input Business	-0.199	0.207	0.002	-0.150	-0.688**
	(0.579)	(0.181)	(0.109)	(0.230)	(0.298)
Num. of People Who Worked Last Month	0.312***	0.288***	0.146***	0.039	0.307***
	(0.078)	(0.098)	(0.044)	(0.073)	(0.034)
Years in Operation	-0.056***	-0.048***	-0.003	0.003	0.008
	(0.012)	(0.017)	(0.015)	(0.026)	(0.020)
Age of Main Owner	-0.019*	0.031	0.011***	0.006**	-0.054**
	(0.011)	(0.025)	(0.004)	(0.003)	(0.022)
Owner's Education (1=above secondary)	1.281***	-0.017	0.938***	0.007	1.405***
	(0.438)	(0.988)	(0.122)	(0.032)	(0.415)
Prior Experience in Same Type of Business	1.123***	0.693	0.334	0.176	1.154
	(0.040)	(0.493)	(0.309)	(0.585)	(0.859)
Sector Dummy (1=manuf, 0=services (inc. retail))	-0.965	-0.589	0.036	0.237**	0.246
	(0.671)	(0.977)	(0.152)	(0.110)	(0.498)
Number of Observations	897	897	897	887	677

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.

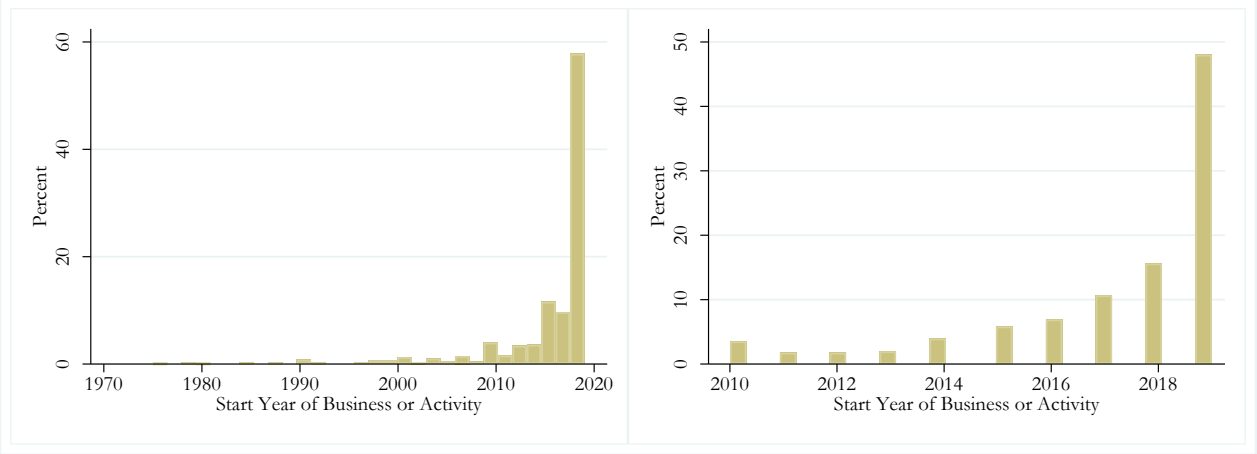

Figure A. 1: Histogram of the Start of the Business Activity

Notes: Figure shows two histograms of the variable on year of start of operations. The left panel shows all years that business or activities originally started. The left panel shows solely starting dates from 2010 onwards. The column for 2019 includes the years of 2019 as well as 2020. Since the survey was conducted from August 2019 to February 2020, some businesses reported 2020 as their start year.

Appendix B: Analysis of Technology Adoption Based on Market Density

Another way to measure potential technology spillovers from formal to informal firms is to use the density of formal firms in an enumeration area. This approach sums the number of formal firms in each enumeration area to generate the main variable of interest. The results in Table B. 1 suggest that the density of formal firms has a positive and statistically significant effect on informal businesses' adoption of computers. Note that a positive sign here is associated with more adoption. Comparing these results with the baseline model, technology spillovers seem to be stronger, defined as having significant effects on most technologies, when using the distance measure. This might have several reasons. First, informal businesses might mainly interact with formal firms that are very close to them. Second, the square measure might cut off nearby formal firms due to the border of the square. For instance, an informal business might have been assigned to a square with a low number of formal firms though the same business is close to formal firms across the border of the square.

Table B.1: Density Model

	(1) PC	(2) Tablet	(3) Phone	(4) MM	(5) Website
Number of Formal Firms within Square	0.105**	0.018	-0.005	0.025	0.137
	(0.044)	(0.107)	(0.090)	(0.092)	(0.138)
Num. of People Who Worked Last Month	0.509***	0.236	0.149*	0.005	0.349***
	(0.057)	(0.208)	(0.082)	(0.093)	(0.055)
Years in Operation	0.060*	-0.017	-0.008	0.019	0.005
	(0.032)	(0.024)	(0.012)	(0.018)	(0.008)
Age of Main Owner	-0.035	0.028	0.006***	-0.001	-0.035**
	(0.033)	(0.023)	(0.002)	(0.005)	(0.016)
Owner's Education (1=above secondary)	2.439***	-0.156	1.333***	0.169	2.583***
	(0.360)	(0.762)	(0.353)	(0.378)	(0.423)
Prior Experience in Same Type of Business	1.546**	0.606	0.459	0.116	0.553
	(0.720)	(0.548)	(0.316)	(0.624)	(0.769)
Sector Dummy (1=manuf, 0=services (inc. retail))	-1.782	-0.573	0.124	0.415**	0.342
	(1.313)	(0.797)	(0.223)	(0.180)	(0.595)
Number of Observations	987	987	986	962	721

Notes: MM denotes mobile money. Sampling weights applied. City fixed effects are not shown. Standard errors are clustered at the city level. *** p<0.01, ** p<0.05, * p<0.1.