International Labour Organization

ILO Working Paper 112

April / 2024

New technologies, e-government and informality

Authors / Juan Chacaltana, Fernanda Bárcia de Mattos, Juan Manuel García

ISBN 9789220405680 (print), ISBN 9789220405697 (web PDF), ISBN 9789220405703 (epub), ISBN 9789220405710 (mobi), ISBN 9789220405727 (html). ISSN 2708-3438 (print), ISSN 2708-3446 (digital)

https://doi.org/10.54394/NEYY5523

Information on ILO publications and digital products can be found at: www.ilo.org/publns

ILO Working Papers summarize the results of ILO research in progress, and seek to stimulate discussion of a range of issues related to the world of work. Comments on this ILO Working Paper are welcome and can be sent to chacaltana@ilo.org.

Authorization for publication: Sangheon Lee, Director of the Employment Policy Department

ILO Working Papers can be found at: www.ilo.org/global/publications/working-papers

Suggested citation:
Chacaltana, J., de Mattos, F., García, J. 2024. *New technologies, e-government and informality*, ILO Working Paper 112 (Geneva, ILO). https://doi.org/10.54394/NEYY5523

Abstract

This working paper studies the complex relationship between technology adoption and informality, leveraging recent cross-country data to analyse the effects of mobile phone subscriptions, internet access, automation and e-government on informal employment, vulnerable employment, and the shadow economy's GDP share. The study delves into the nuanced interplay between technology adoption and informality, suggesting that while technology adoption can reduce informality by enhancing productivity and government capacity, it can also create conditions to increase informality, such as the proliferation of own-account work for example. The paper empirically explores these forces and finds that e-government initiatives in the majority of cases reduce informality. However, while the potential of technology to reduce the shadow economy is clearer, addressing informal and vulnerable employment may require additional policy interventions. This research contributes to the understanding of the multifaceted and multidirectional relationship between technology and informality, and the potential for technology to enhance governance and public service delivery.

About the authors

Juan Chacaltana is a Senior Employment Specialist with the ILO. He previously worked as Regional Economist with the ILO Regional Office for Latin America and the Caribbean and as Employment Specialist with the ILO Office for the Andean Countries. He also was the head of the ILO Formalization Programme for Latin America and the Caribbean as well as Head of the Interagency United Nations MDG Programme on Youth, Employment and Migration in Perú. He holds a PhD in Economics from the Catholic University of Peru and a Master of Science in Economics from Texas A&M University in the United States.

Fernanda Bárcia de Mattos is an international consultant with the ILO and other organizations. At the time of writing, she was a Technical Officer at the ILO's Employment Policy Department. Fernanda has extensive experience in applied research and labour market analysis, with an emphasis on topics such as gender, youth, technology, and wages. She holds dual masters degrees in International Relations and Urban Planning from the University of Southern California and a graduate diploma in Economics from the University of London.

Juan Manuel García is a National Professional Officer with the ILO Regional Office for Latin America and the Caribbean (LAC) and coordinates a project on innovative solutions for formalization in LAC. He has worked extensively in applied research with an emphasis on labour market, productive development, innovation, social policy, and poverty. Moreover, he has vast experience in design, monitoring and performance and impact evaluation of government interventions. He holds a Master in Mathematics Applied to Economics from the Catholic University of Peru.

Table of contents

List of Figures

List of Tables

▶ Introduction

The world has experienced rapid technological progress over the past few decades. Since the turn of the century, mobile phone subscriptions have surpassed one per person.[1] The share of internet users globally has increased tremendously, and automation is a common facet of technological change, with the global stock of industrial robots also rising, according to data on the trade value of robotic imports and other machinery per worker.[2] And especially since the onset of the COVID-19 crisis, artificial intelligence has rapidly advanced across economic sectors, and governments, businesses and research institutions are investing in its applications.

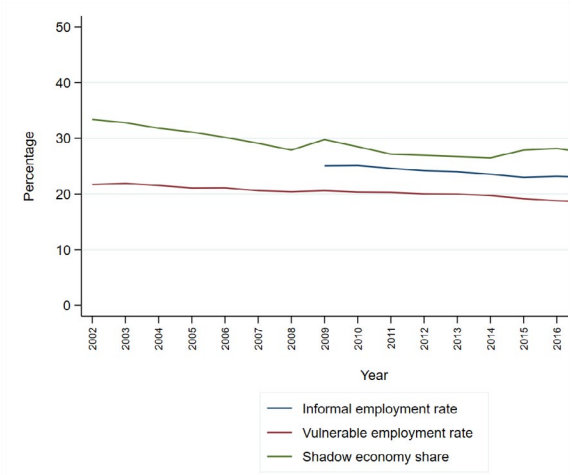
These technologies have reshaped work and employment as we know it and will continue to do so. New technologies often trigger job destruction and creation dynamics, turning certain occupations obsolete, creating new ones and changing the task composition of jobs and their skills requirements. They also lead to new forms of work and employment, as evidenced by the emergence of platform work, which engages workers around the world in web-based jobs or digitally mediates offline work in local areas (ILO 2021b). The impact of technology on work and workers, however, has been uneven. An important dimension relates to the impact on informality.

Informality is associated with unstable jobs and low incomes and limited legal and social protection. It is often employment of last resort and a result of limited opportunities for formal employment. Based on a standard measure using the definition of informal employment, an estimated six in ten workers globally are informally employed in the formal as well as informal sectors (ILO 2018).[3] Moreover, informal production represents a significant share of countries' gross domestic product (GDP). Based on the concept of measurement for the "shadow economy",[4] recent research indicates that this is equivalent to 15–35 per cent of total GDP (Deléchat and Medina 2021; Ohnsorge and Yu 2021). Measures of informality reflected a slow but downward trend up to 2019. Due to the upheavals trigged by the global COVID-19 pandemic, more recent research suggests its prevalence has increased. As indicated in figure 1, the share of the shadow economy reduced from 33.4 per cent to 27.3 per cent between 2002 and 2017 (Medina and Schneider 2019).[5] Survey data of informal employment and vulnerable employment (own-account workers plus contributory family workers), which could be used as a proxy for labour informality because these groups would be highly represented and exposed to informality,[6] show a slight reduction in the same period due to a small decline in developed countries.[7] The slow reduction in informality, however, contrasts with the sharp reduction in the incidence of poverty, which fell from 29.3 per cent to 8.5 per cent in the same period, according to the World Bank.[8]

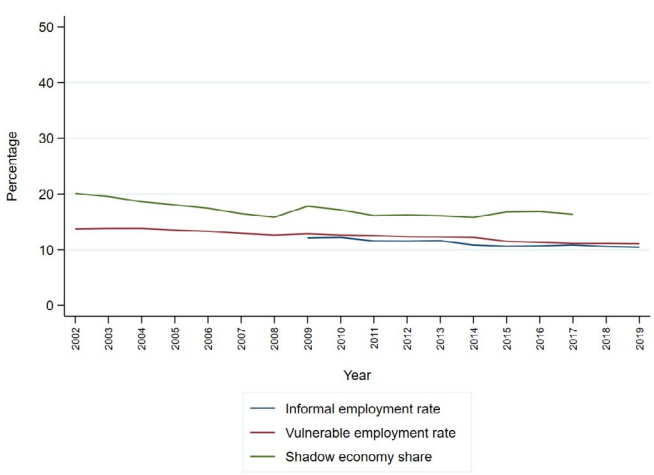
1 The data on internet use and mobile cellular subscriptions used here were derived from the International Telecommunication Union.
2 Trade value of imports was extracted from the United Nations Comtrade bilateral trade statistics database.
3 According to the ILOSTAT database.
4 Note that informality is not the same as the underground economy, the hidden economy, the unobserved or undeclared economy or the shadow economy, although in some literature the latter are used as proxy indicators of informality. In our case, we use the share of the shadow economy only due to data availability as a proxy of informal production, although we acknowledge that these are different concepts. This proxy indicator comes from Medina and Schneider 2019.
5 Note that the rate of informal employment declined in some regions, for example in the Latin American and Caribbean region, from the early 2000s to 2015 (Salazar-Xirinachs and Chacaltana 2018).
6 To use data on vulnerable employment as a proxy is convenient because there is data availability for a wider range of countries than with informal employment data.
7 Because of the variability in the annual data available on informal and vulnerable employment, only the group of countries that have complete data in all years (45 countries for informal employment since 2010 and 63 countries for vulnerable employment since 2002) are included in figure 1. For the shadow economy indicator, we found complete information for 157 countries in the panel data set from Medina and Schneider 2019.
8 World Development Indicators database, accessed 8 August 2023. This indicator refers to the headcount ratio at US$2.15 per person per day.

▶ **Figure 1. Evolution of different measures of informality, 2002–19**

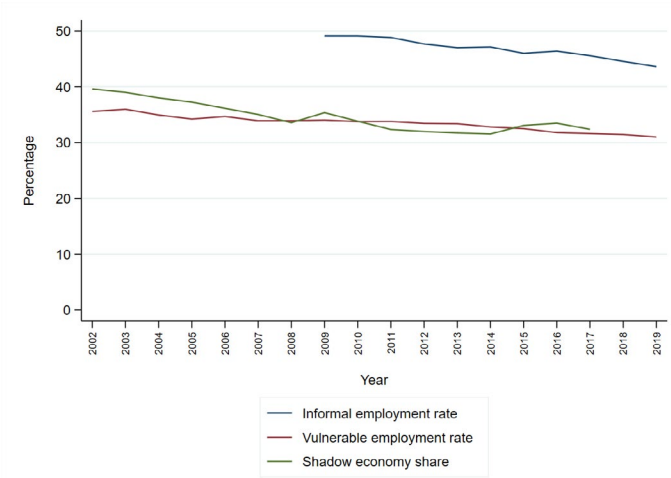
(a) World



(b) Developed countries



(c) Developing countries



Source: ILOSTAT database and Medina and Schneider (2019) database.

Technological developments are affecting labour markets in general and informality in particular by creating new forms of production and work (ILO 2018). In addition, they are creating new possibilities for policymaking. An increasing number of governments are taking advantage of digital technologies for better service delivery, a trend termed "e-government" (Williams 2023; Chacaltana, Leung and Lee 2018). Together, these developments suggest that technologies both encourage informal activity and also support formalisation. The question for these times then is: Can we affect, even control, the direction? To start that discussion, we likely need to know whether technological progress increases or reduces informality.

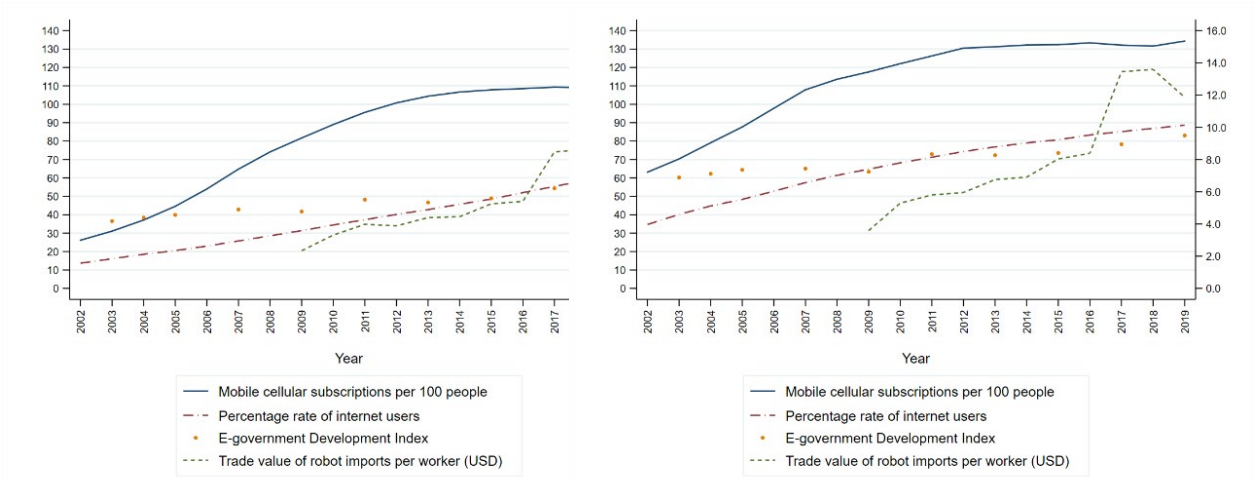
This paper empirically investigates the nature of this relationship using the most recent cross-country data available. It examines informal employment and vulnerable employment as proxy indicators of labour informality and the share of the shadow economy in GDP as a proxy for informal production. We look at what is known about mobile phone subscriptions, internet access and the trade value of robotic imports and other machinery per worker. We also examine the nexus of e-government development and informality.

The next section presents trends in technological progress and informality, including a brief review of related literature. The data and approach to this study are then introduced and the results discussed, followed by our concluding perspective of our findings.

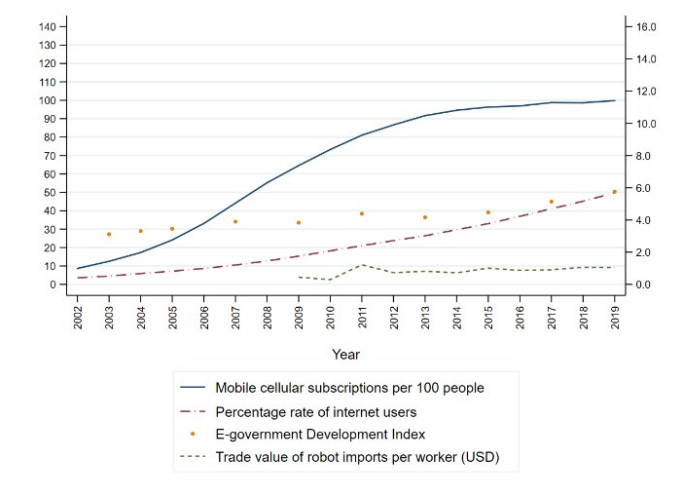
Trends in technology and e-government

In the past few decades, the world has experienced rapid technological progress and dissemination of technologies (figure 2). Mobile phones and the internet have become increasingly accessible to the global population. In 2019, there was more than one mobile phone subscription per person globally, in sharp contrast to fewer than 0.3 in 2009. Over the same period, the rate of internet users increased, from less than 20 per cent of the global population to around 60 per cent. Other technologies also experienced remarkable diffusion, such as automation and digitalisation, including e-government. Although some trends are difficult to quantify, the value of imports of robots and other machinery per worker more than doubled from 2009 to 2019. The E-Government Development Index (EGDI) monitors the status of e-government development of United Nations Member States, including website development patterns and access characteristics, such as the infrastructure and educational levels. The index reflects the digital capabilities of governance and policymaking in a country, encompassing online public infrastructure characteristics (public websites) as well as access characteristics to indicate how a country is using information technologies to promote access and inclusion of its people. The EGDI is a composite score calculated as a weighted average of e-participation, provision of online services, telecommunication connectivity and human capacity. The EGDI database has tracked a substantial rise in the provision of online services, human capital development and improvements in telecommunication infrastructure.

▶ **Figure 2. Evolution of different measures of technology, 2002–19**



(c) Developing countries



Note: The EGDI has been multiplied by 100 and the trade value of robotic imports per worker is plotted on the secondary (right) axis.

Source: International Telecommunication Union, United Nations Comtrade bilateral trade statistics and EGDI database.

Diffusion and access of these technologies are uneven, and important gaps remain. The rise in the rates of internet users and mobile cellular subscriptions appears faster in developing economies, but the levels are higher in developed countries. Globally, mobile cellular subscriptions have reached a level of more than one per individual, and nearly 90 per cent of the world's population is using the internet. That use is driving automation, with the robotic import trade value nearing US$12 per worker in 2019 for the global average, compared to around US$1 in developing societies.

Given that developed regions tend to spearhead technological change by producing and using technologies, the figures on imports likely underestimate the presence of robots and other advanced machinery in these countries and thus also underrate the gap between developed and developing regions, which tend to be "technology takers". Modern robot technology has been present in industries for decades, with the addition of digital capabilities since the 1990s (Fernández-Macías, Klenert and Antón 2020). It is likely that inequalities in robot stock mirror inequalities in the capital-intensity of production across countries. To the extent that the return on traditional capital can be expected to increase with the presence of productivity-enhancing robots (Berg, Buffie and Zanna 2016), capital concentration could further increase.

These disparities are demonstrated in figure A1 in the Annex, which depicts continuous Lorenz curves fitted to the global data. The y-axis describes the distribution (or cumulative share) of various measures of technology adoption: internet users, mobile cellular subscriptions, import of robots and other types of machinery and the EGDI. The x-axis depicts population percentiles. The straight diagonal lines represent perfect equality, while the curved lines present the actual distribution in 2002, 2009 and 2019. The larger the area between the two lines, the greater the inequality. Inequalities in mobile cellular subscriptions are small compared to other indicators and have been declining, with the bottom 55th percentile of the global population corresponding to 33 per cent of internet users in 2009 and 41 per cent in 2019. Gaps are much starker when looking at the import levels of robots and other types of machinery per worker, and the difference has widened since the early 2000s. The bottom 55th percentile of the world's population took in 5.4 per cent of the cumulative share of imports in 2009, but it was a mere 1.3 per cent in 2019. In comparison, the top 90th percentile corresponded to 46.6 per cent in cumulative imports in 2019, which means that the top 10 per cent of the global population accounted for 53.4 per cent of the imports of robots.

▶ 1 Related literature

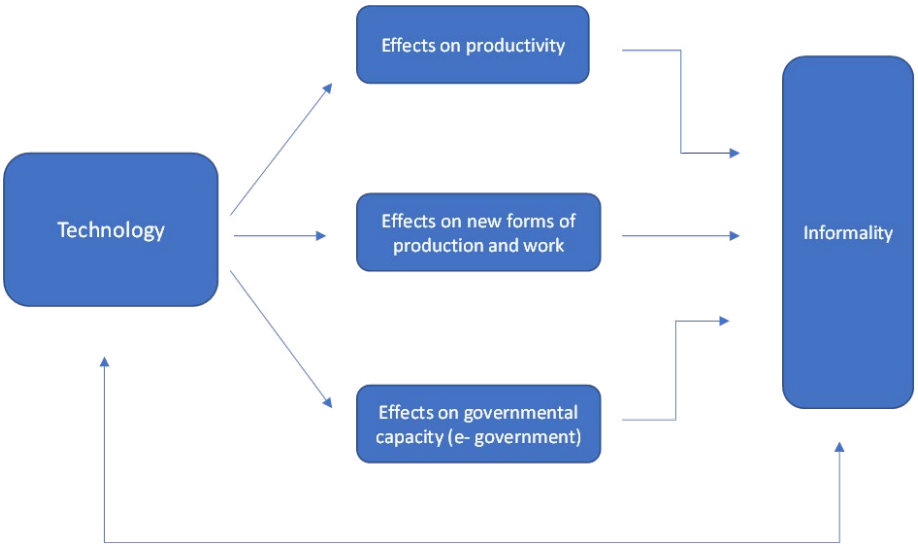
The following summarises the theoretical and empirical evidence we found relating informality and new technologies.

Theoretical perspectives

The theoretical literature distinguishes three main channels through which technologies and informality interact (figure 3). The first channel operates through effects on productivity, while the second relates to new forms of production and work enabled by technologies. Finally, the third channel relates to effects on governmental capacity, particularly linked to digital transformation (including of public services).

The relationship between technologies and productivity is multidirectional. On one hand, technological advances might increase labour productivity, support changes in the structure of economies and propel economic growth, thus increasing formal job creation. On the other hand, technologies could also increase productive inequalities or gaps if a large share of economic units and workers are not able to access and use these technologies, thus increasing productive exclusion and potential informality.[9]

▶ **Figure 3. Conceptual framework**



Source: Authors' elaboration.

[9] This is consistent with the dualist view of the market, whereby the economy comprises the so-called "modern" and "traditional" sectors, in reference to the use of more modern or traditional technologies (Lewis 1954). According to this strand of literature, larger firms tend to have more modern technologies and higher productivity levels, relative to smaller firms, where the majority of employment concentrates, particularly in developing regions. The structuralist view (Infante and Sunkel 2012; Pinto 1970) highlights that this differential access to technology generates "structural heterogeneity" or productive differentials. Some literature indicates that this heterogeneity closely links to within-sector differences, with some businesses at the forefront of technology adoption and many lagging (Kupfer and Rocha 2005).

While this conceptual discussion refers to technologies in general, recent research focuses more specifically on the uneven access and use of information and communications technologies (ICTs) by different workers or economic units, including those in the informal sector. Chen (2016), for instance, conducted a study in Ahmedabad (India), Durban (South Africa) and Lima (Peru) and found that informal workers and enterprises used mobile phones to contact suppliers, buyers and contractors, which thus contributed to greater productivity and income. ICTs also are used as a business platform by informal economic units and own-account workers, such as confirming orders and making appointments (Garcia-Murillo and Velez-Ospina 2017; Chen 2016). Rangaswamy's study (2019) added that many informal workers provide support to informal ICT users, such as the repair and assembly of ICT products.

Some studies have suggested that it is the use of mobile phones, which is a low-cost basic form of ICT nowadays, that is most prevalent among informal own-account workers and businesses, compared to other technologies, such as computers or the internet (Ilavarasan 2019; Chen 2016; Deen-Swarray, Moyo and Stork 2013). Heterogeneity in the informal sector seems to be a determinant of the specific type of ICT usage. A survey of 500 informal enterprises in Dakar, Senegal, found significant disparities in mobile phone and internet use among informal businesses, particularly between those the researchers characterized as "working for survival" and "top performers" (Berrou and Mellet 2018). Bhattacharya (2019) argued that the way in which informal economic units or own-account workers interact with new technologies is intrinsically linked to whether informality is an intentional undertaking originating from entrepreneurial drive or a survival strategy resulting from limited opportunities in the formal sector. In the first case, technologies will be adopted for profit-seeking and business expansion purposes, while in the latter case, technologies have limited appeal, and adoption is often an income-protecting strategy.

The second channel mediates the relationship between technologies and informality relates to the effects of new technologies on new forms of production and work. Several studies indicate that digital technologies have given rise to new patterns of informality, related to new forms of work, including through digital labour platforms (see, for example, Abramo 2022). These encompass web-based platforms that allow employers to post online tenders for geographically dispersed jobseekers who perform the work online (crowdwork) as well as location-dependent platforms that allocate digitally mediated but offline work to a specific geographical area (such as Uber) (O'Higgins and Pinedo Caro 2022; Stefano et al. 2021; Berg et al. 2018). Platform workers are considered own-account, piece-rate pay-as-you-go workers, with unstable income and limited access to legal and social protection. Therefore, they are subject to several of the vulnerabilities of traditional informal workers. Research has shown that workers are more likely to engage in online work in regions with few and low-quality offline opportunities and often engage in these activities out of necessity (Zwysen and Piasna 2023), which is a situation not dissimilar to workers engaging in traditional forms of informal employment.

Informality in the platform economy might relate to various factors (ILO 2022). Many workers complement non-platform income through platforms and may not declare the secondary income for fiscal purposes. Platforms provide avenues for work for self-employed persons who may voluntarily or involuntarily engage in irregular economic activities. Research results for the European Union, reported by the International Labour Organization (ILO 2022), suggest that self-employed persons may not have clarity on their employment status or how to provide services legally, or they may find tax systems complex. There are also issues related to the non-recognition of employment relationships. At the same time, however, this type of work could also potentially reduce informality because it allows traceability of information and activities (sales, for example). Although, for that to happen, some kind of agreement would be needed on the use of the information that platforms have.

For example, estimates suggest that the number of digital work platforms increased fivefold in the past ten years, from around 140 in 2010 to more than 770 in 2020 (ILO 2021a). Although it

is recognised that there has been a marked increase in the number of workers engaged in the platform work, estimates vary widely: between 0.3 and 22 per cent of the adult population, according to surveys in Europe and North Africa. This variance, of course, is indicative of the difficulties associated with measuring this workforce (ILO 2021a).

The rise of the digital economy is associated with the spread of mobile phones and the internet and technological developments that enable digital economic transactions and the exchange of large amounts of data, all of which are dependent on the extent of a country's digital infrastructure.

The COVID-19 pandemic, which imposed restrictions on the movement of people and economic activity, accelerated changes related to new ways of working (ILO 2021a and 2021b). Remote work arrangements brought a rise in e-commerce and services and online freelance work. Digital platforms became an alternative source of income for people who lost their job. Generally, preference to work from home or job flexibility are motivating factors for workers engaged in platform work. Conversely, it can also constitute a "next-best" alternative to unemployment, with workers expressing preference for offline work (Zwysen and Piasna 2023). Businesses, including small and medium-sized enterprises, have been using online forums (delivery platforms and social media) to maintain operations, reach new markets and reduce costs.

The third channel, through which technologies and informality interact, reflects the effect of technologies, particularly digitalisation, on governance and policymaking practices. Some studies to date have found that governments are increasingly using technologies to facilitate transitions from the informal to the formal economy, through so-called e-formality policies (Chacaltana, Leung and Lee 2018). Other study literature mentioned that ICTs might contribute to a reduction of informal economic activity, such as by improving access to information, decreasing the burden of firm and worker registration and allowing for the easier tracking of financial exchanges in an increasingly cashless economy, among other impacts (Remeikiene et al. 2022; Garcia-Murillo and Velez-Ospina 2014 and 2017). Without doubt, though, the COVID-19 pandemic has reinforced the importance of e-government initiatives for regular service delivery and business continuity and has led to the development of new digital tools (Dener et al. 2021; UNDESA 2020).

Empirical studies

In the past decade, several studies conducted an empirical assessment of the relationship between new technologies and informality. These studies focused on several measures of informality, but the majority of them used the shadow economy as a share of GDP. Although most of those studies found a negative relationship between technologies and informality, some found a positive relationship. Moreover, some led a discussion on whether either relationship is linear or non-linear.[10]

Most of the literature we reviewed focused on the correlation between ICT measures and informality, but there was no consensus on the sign of the relationship. Some of those studies found a negative relationship (table 1). For instance, Remeikiene et al. (2022) used panel data from between 1996 and 2015 for 11 post-transition European Union members and suggested that mobile phone subscriptions and human capital decrease the size of the shadow economy in the long run.

Other research, however, found a positive correlation. Kelikume (2021) analysed data from 42 African countries dating to between 1995 and 2017 to examine the relationship between mobile phone use, the internet, financial inclusion, the informal economy, and poverty reduction. He found mobile phone penetration and internet use positively associated with the informal

[10] Here we focus on studies that used measures of ICT like the ones in our study. There were also studies using other indicators: Nevzorova, Kireenko and Leontyeva (2018), for example, used a panel data set of 402 country-year observations from between 2010 and 2015 and they used an indicator of research and development expenditure. They found that this indicator negatively associates with the shadow economy.

economy. Both technologies were also found to positively relate to poverty reduction, with the link between the informal economy and poverty reduction conditional on the level of ICTs. Focusing on the 2000–17 period and using a sample of 45 countries, Ndoya et al. (2023) found that the use of ICTs (mobile phones and the internet) had decreased the spread of the informal economy in Africa. These results were, according to the authors, mediated by financial development, human capital and control of corruption.

Another study on 48 African countries between 2000 and 2015 similarly concluded that the diffusion of the internet and mobile phones negatively and significantly affect the size of the shadow economy (Ghislain and Bate 2022). Their results are in line with what Nguyen, Nguyen and Tran (2023) found in their global study encompassing data from 124 countries dating to between 1996 and 2007. Their analysis showed internet use associating with a decline in the shadow economy while economic uncertainty had the opposite effect. Their findings thus support the hypothesis that informal activities can often be a "next-best" alternative to workers in unfavourable economic scenarios.

Several studies tested the idea that heterogeneity exists in the relationship between ICTs and informality, using the indicator of the shadow economy. Elgin (2013) used worldwide data for 152 countries from between 1999 and 2007 to examine the relationship between internet use and the size of the shadow economy. He concluded that internet use negatively correlates with the size of the informal economy and that as GDP per capita increases, this negative correlation reduces and can become positive at higher GDP per capita levels. Therefore, this relationship might be non-linear. He suggested that ICTs positively link to productivity and that a negative relationship with informality can be expected, particularly in lower-income countries (diminishing marginal returns to productivity). In particular, he highlighted "two opposing effects of internet usage on shadow economy size, one increasing productivity, and thereby reducing [the] shadow economy size, and another one increasing tax evasion thereby increasing shadow economy size" (Elgin 2013, 16).

Other studies proposed that the sign of the correlation depends on the type of technology analysed. Using a panel data set of 170 countries between 2007 and 2011, Garcia-Murillo and Velez-Ospina (2017) suggested that broadband internet negatively associates with informality, whereas mobile phone use positively correlates with the informal sector or the shadow economy. They suggested that mobile phones reduce transaction costs while broadband internet allows people to access more information and find better employment opportunities. Boitan and Stefoni (2023) reached a similar conclusion. Examining a panel data set encompassing 28 European Union countries between 2013 and 2020, they found negative correlations between the shadow economy and the ICT index, internet use, the share of enterprise turnover and e-commerce but positive correlations with high-speed internet coverage.

▶ Table 1. Empirical studies on the relationship between technologies and informality

Paper	Data and method	Sign of the relationship
Elgin 2013	Panel data of 152 countries from between 1999 and 2007	Non-linear. Internet use negatively correlates with the size of the informal economy. As GDP per capita increases, this negative correlation reduces – and can become positive at higher GDP per capita levels.
Garcia-Murillo and Velez-Ospina 2017	Panel data of 170 countries from between 2007 and 2011	Mixed, depending on the type of technology. Broadband internet negatively associates with informality, whereas mobile phone use positively correlates with the informal sector and the shadow economy.
Kelikume 2021	Panel data of 42 African countries from between 1995 and 2017	Positive. Mobile phone penetration and internet use positively associate with the informal economy.
Elbahnasawy 2021	Panel data of 146 countries from between 2001 and 2016	Negative. Negative effect of e-government on the shadow economy. Most of this effect comes from the development of telecommunication infrastructure. Estimates are affected by reverse causality.
Ghislain and Bate 2022	Panel data of 48 African countries from between 2000 and 2015	Negative. The diffusion of mobile phones and the internet negatively link with the shadow economy.
Haruna and Alhassan 2022	Panel data of 42 African countries from between 2003 and 2016	Negative. Digitalisation (EGDI and its components) strongly associates with a decrease in the size of the shadow economy.
Remeikiene et al. 2022	Panel data of 11 post-transition European Union members from between 1996 and 2015	Negative. Mobile phone subscriptions and human capital decrease the size of shadow economy in the long run.
Sacchi, Santolini, and Schneider 2022	Panel data of 149 countries from between 2003 and 2015	Negative. E-participation significantly contributes to reducing the size of the shadow economy.
Boitan and Stefoni 2023	Panel data of 28 European Union countries from between 2013 and 2020	Mixed, depending on the type of technology. Negative correlations between the shadow economy and the ICT index, internet use share of enterprise turnover and e-commerce. Positive correlations with high-speed internet coverage.
Brambilla et al. 2023	Data for Argentina, Brazil and Mexico from between 2004 and 2016	Positive. A district's exposure to robots found to cause relative deterioration of labour market indicators, including informality and unemployment.
Ndoya et al. 2023	Panel data of 45 African countries from between 2000 to 2017	Negative. Basic ICTs (mobile phones and the internet) decrease the spread of the informal sector.
Nguyen, Nguyen and Tran 2023	Panel data of 124 countries from between 1996 and 2017	Negative. Internet use negatively associates with the shadow economy. Results are consistent across income groups and most regions.

Source: Authors' elaboration.

Another strand of literature focuses on the relationship between e-government measures and informality, consistently indicating negative correlation. Elbahnasawy (2021) analysed panel data for 146 countries between 2001 and 2016. He found a negative effect of e-government on the shadow economy. The long-run effect was larger than the short-run effect and mostly related to the development of telecommunication infrastructure. Estimates were affected by reverse

causality.[11] Using panel data from 42 African countries between 2003 and 2016, Haruna and Alhassan (2022) found that digitalisation (measured by the EGDI and its components) strongly associates with a decrease in the size of the shadow economy in Africa.

Sacchi, Santolini and Schneider (2022) used an instrumental variable approach to examine the link between the e-participation attitude of citizens and the shadow economy. Their analysis of 149 countries between 2003 and 2015 found that e-participation significantly contributes to reducing the size of the shadow economy. They highlighted that the "e-participation issue deals with several dimensions: enabling individuals' participation by providing citizens with public information and access to information without or upon demand; engaging citizens in contributions to and deliberation on public policies and services; empowering citizens through the co-design of policy options and the co-production of service components and delivery modalities" (Sacchi, Santolini and Schneider 2022, 465).

To summarise, the empirical evidence suggests the existence of heterogeneity in the relationship between new technologies, ICTs and informality. The correlation between e-government measures and informality is more clearly negative.

[11] Note that there are other studies focusing on bivariate correlations that reach the same conclusions. For example, Williams (2021) examined the uncontrolled correlation between the provision of digital public services and the prevalence of the informal economy. He found a negative correlation: The greater the provision of digital services the lower the prevalence of the informal economy. However, he found only a significant association between e-government and the size of informality when the shadow economy measure was used. However, there was significant correlation in the case of online service completion and digital public services for businesses.

▶ 2 The empirical relationship between technology measures and informality

Data

We used three alternative indicators to gauge informality: (a) the rate of informal employment provided by the ILO through the ILOSTAT database;[12] (b) the rate of vulnerable employment, also provided by the ILO, directly from national Labour Force Surveys;[13] and (c) the size of the shadow economy as a share of GDP, as estimated by Medina and Schneider (2019).[14] The informal employment rate directly measures labour informality as defined by international statistical standards, although there were important data gaps in the series.[15] This led to the inclusion of vulnerable employment as a proxy for informal employment due to the larger data series and its strong correlation. In turn, the size of the shadow economy as a proportion of GDP was used as a proxy of informal production, which complements the informal employment analysis. These alternative measures allow for the testing of estimate robustness of our results.[16]

Three variables were selected to represent the adoption and development of digital technologies related to the production and delivery of goods and services across countries and over time: (a) the yearly rate of internet users in a country, which captures the digital transformation of an economy associated with the private use of telecommunication infrastructure; (b) the yearly rate of mobile cellular subscriptions, which is a basic low-cost ICT among those most prevalent with informal own-account workers and businesses – the literature suggests mobile phones are more widespread than computers or the internet (Ilavarasan 2019; Chen 2016; Deen-Swarray, Moyo and Stork 2013) – and a variable that also informs on private use of telecommunication infrastructure; and (c) the yearly trade value of imports of robots and other machinery per the active and working population in an economy (measured in US dollars), quantifying automation.

Although the yearly trade value of imports is an imperfect measure of automation, we believe it provides important information regarding the relative adoption of new production technologies. There are few data sets that allow for a quantitative analysis of automation trends, and this is one of the few indicators that is publicly available.[17] The data about internet use and mobile cellular subscriptions we used derived from the International Telecommunication Union (ITU), the

12 Measured as the share of informal employment in total employment (indicator 8.3.1 of the Sustainable Development Goals).

13 Vulnerable employment is defined as the sum of own-account workers and contributing family workers.

14 Estimated using an indirect approach based on Multiple Indicator–Multiple Cause model. Medina and Schneider (2018) indicated that the shadow economy "includes all economic activities which are hidden from official authorities for monetary, regulatory and institutional reasons. Monetary reasons include avoiding paying taxes and all social security contributions, regulatory reasons include avoiding governmental bureaucracy or the burden of regulatory framework, while institutional reasons include corruption, the quality of political institutions and weak rule of law". Therefore, a main difference between the ILO measurement of informal employment and the shadow economy estimation is that ILO explicitly excludes illegal activities as part of the informal economy. Moreover, it is necessary to point out that according to the statistical definition from the ILO (2023), the informal economy includes not only economic units from the informal sector but also activities from the formal sector defined as "comprising economic units that are formally recognised as distinct producers of goods and services for the consumption of others and whose production is mainly intended for the market with the purpose of generating an income or profit, for a non-profit purpose, or non-market production for use by other economic units (corporations, quasi-corporations, government units, formal non-profit institutions serving households and formal household unincorporated market enterprises)" (paragraph 26(a).

15 Table 1 and figure 3 illustrate that there are fewer country-year observations. Specifically, figure 3 indicates fewer observations for informality (blue dots) and that they concentrate in certain countries – not covering the most developed economies, when compared to vulnerable employment (red dots).

16 The partial correlation between the vulnerable employment rate and the informal employment is 0.883. Both informal and vulnerable employment have a close relation to the share of the shadow economy (correlation of 0.747 and 0.691, respectively). See the scatter plots between these indicators for the data used in figure A2.

17 In contrast, data on the stock of robots, by the International Federation of Robotics, is paid access only.

official source for global ICT statistics. The trade value of imports was extracted from the United Nations Comtrade bilateral trade statistics database.

Separate analysis was conducted using the EGDI. As explained earlier, the Index represents the state of e-government development, or the digital capabilities of governance and policymaking in a country, to reflect how a country is using information technologies to promote access and inclusion of its people. The United Nations Department of Economic and Social Affairs (UN DESA) publish the data every two years on average.[18]

Covariates were defined based on the empirical literature. These variables were GDP per worker, GDP per capita, trade (imports plus exports) as proportion of GDP, proportion of rural population and population density from the World Bank's World Development Indicators; unemployment as share of the labour force, extracted from the ILOSTAT database; and the Rule of Law Index from the World Bank's World Governance Indicators.

Based on this data, we constructed an unbalanced panel of 203 unique countries for the 17-year period between 2002 and 2019. Table 2 covers the descriptive statistics.

[18] For the purposes of our study, annual values for the index and its components were assigned to the previous year of the corresponding publication year (data published in the 2020 report were considered 2019 data).

▶ Table 2. Descriptive statistics

	Count	Mean	Standard deviation	Minimum	Maximum	Countries
Informal employment rate (% of total employment)	901	40.02	29.61	1.10	99.70	132
Vulnerable employment rate (% of total employment) – from surveys	1 886	27.42	20.86	0.00	93.99	183
Size of the shadow economy (% of GDP)	2 512	29.08	12.17	5.10	69.90	157
Internet users (% of population)	3 424	34.92	29.81	0.00	99.70	203
Mobile-cellular subscriptions per 100 people	3 488	78.78	48.96	0.00	420.85	203
E-Government Development Index	1 852	0.46	0.23	0.00	0.98	186
E-Participation Index	1 852	0.31	0.30	0.00	1.00	186
Online Service Index	1 852	0.40	0.27	0.00	1.00	186
Human Capital Index	1 852	0.70	0.23	0.00	1.42	186
Telecommunication Infrastructure Index	1 852	0.29	0.26	0.00	1.00	186
Trade value of imports of robots per worker (US$)	1 519	3.42	11.36	0.00	257.36	166
GDP per 1 000 workers (constant 2017 PPP US$)	3 402	45.10	42.22	1.65	275.46	189
GDP per 1 000 people (constant 2017 PPP US$)	3 481	13.37	19.29	0.11	123.68	198
Trade as proportion of GDP (%)	3 207	90.86	59.54	1.22	863.20	190
Share of rural population (% of population)	3 574	42.24	23.57	0.00	91.32	199
Population density (1000 inhabitants per sq. km of land area)	3 527	0.33	1.50	0.00	20.21	198
Unemployment (% of total labour force)	3 366	8.15	6.19	0.10	37.25	187
Rule of Law Index	3 517	-0.07	0.99	-2.59	2.12	200
Observations	3 665					

Note: Descriptive statistics of the estimation sample consisted of 200 unique countries over the period 2002–19, except for variable size of the shadow economy, which was only available until 2017.

Source: International Telecommunication Union, United Nations Comtrade bilateral trade statistics, the EGDI database and World Bank World Development Indicators.

In our full sample, the unweighted average rate of informal employment was 40 per cent. Vulnerable employment accounted for, on average, 27.4 per cent (survey variable) of total employment. The average size of the shadow economy was 29.1 per cent of GDP. The mean rate of internet users was 34.9 per cent and of mobile cellular subscriptions it was 78.8 per cent. The average trade value of imports of robots per worker was US$3.4 (ranging from US$0 to US$257). To address the significant dispersion in magnitude, aiming at reducing the influence of outliers,

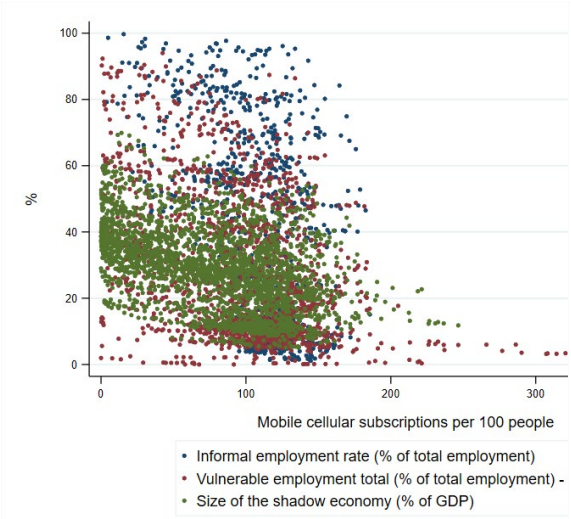
we transformed this variable using the inverse hyperbolic sine function when running regressions.[19] Lastly, the mean EGDI value was 0.46 for the period of analysis.

Figure 3 shows scatter plots that reflect the partial correlations between the measures of informal employment, vulnerable employment and the shadow economy and the different measures of technology and e-government development. They suggest that countries with higher digitalisation tend to display lower rates of informality. For a similar level of digitalisation, there is strong evidence of dispersion. For instance, in countries with a rate of internet users greater than 80 per cent, informality rates ranged from around 30 per cent to about 60 per cent. In turn, in countries displaying a rate of internet users lower than 20 per cent, informality ranged from 55 per cent to almost 100 per cent. We detected similar and even greater heterogeneity with alternative technology measures – the rate of mobile cellular subscriptions and imports of robots and other types of machinery per worker – and the informality indicators, in particular vulnerable employment and the size of the shadow economy indicators.

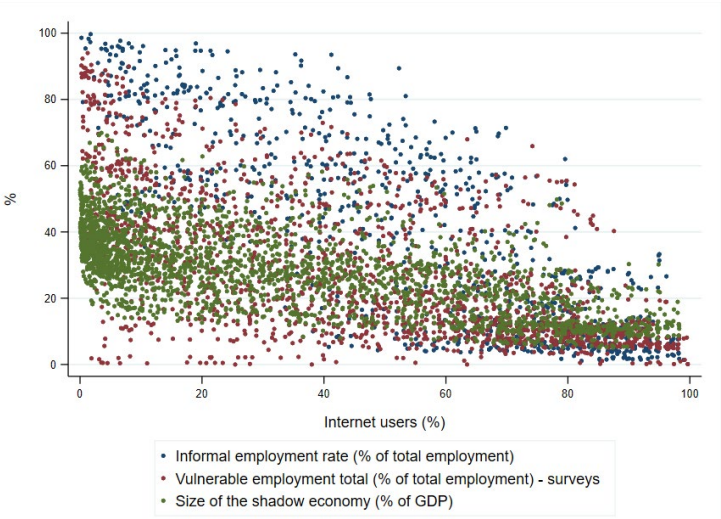
[19] The inverse hyperbolic sine function is widely used in empirical research to transform a variable because it allows for non-positive values and might reduce the influence of outliers in a right-skewed distribution. In contrast, the natural logarithm transformation is often used for skewed distributions but it is not defined when the variable is zero or negative. Except for very small values of the transformed variable, the inverse hyperbolic sine might be interpreted in the same way as a standard logarithmic variable.

▶ **Figure 4. Scatter plots, 2002–19**

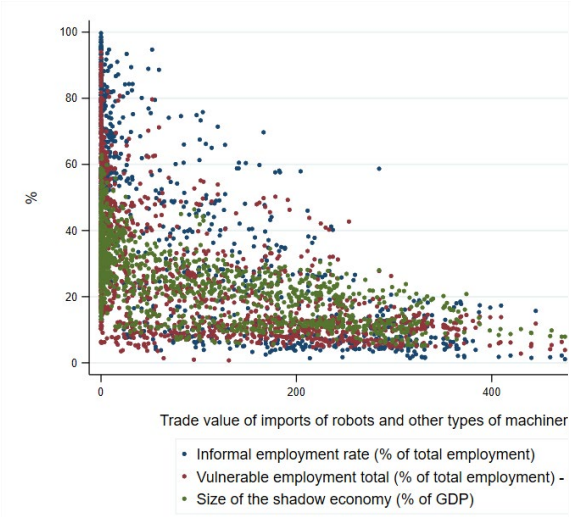
(a) Mobile cellular subscriptions



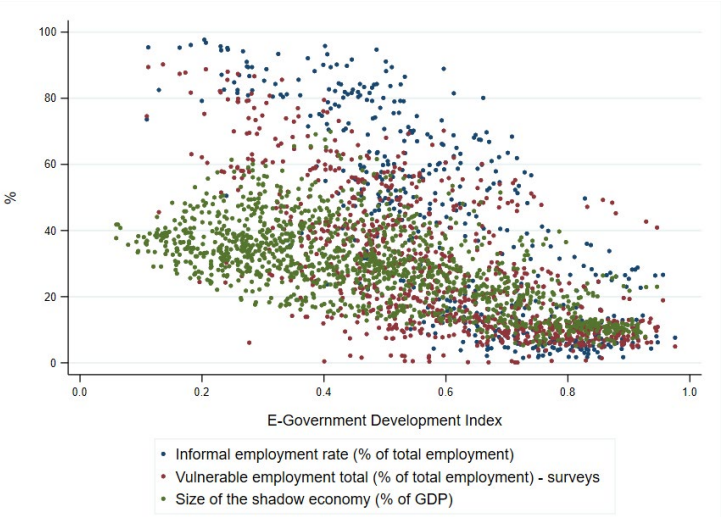
(b) Internet users



(c) Trade value of robotic imports



(d) E-Government Development Index



Source: International Telecommunication Union, United Nations Comtrade bilateral trade statistics, EGDI database, World Bank World Development Indicators; Medina and Schneider 2019.

Study method

To empirically establish the relationship between different measures of technology and informality, we ran cross-country regressions using panel data. Partial correlations and the presence of dispersion found using scatter plots constituted preliminary evidence that although digitalisation might be a determinant of formalisation, other variables affect this relationship. To address this concern, we included a series of control variables in the regressions, which, as previously discussed, were selected based on our review of literature. Our main specification related technology adoption to informality in country *c* at time (year) *t* through the following equation:

$$Y_{ct} = \beta Technology_{ct} + \Gamma X_{ct} + u_{ct}$$

Here, Y_{ct} measures informality in country *c* at time *t*, defined as, depending on the specification, (a) the rate of informal employment, (b) the share of vulnerable employment or (c) the size of the shadow economy. $Technology_{ct}$ stands for the previously outlined indicators of digital transformation – (a) the rate of internet users, (b) mobile cellular subscriptions and (c) trade value of robotic imports – or the EGDI. Finally, the vector X_{ct} included the covariates listed in the previous section. We also assumed that the error had the form $u_{ct} = u_c + \varepsilon_{ct}$, where u_c denotes unobservable country effects and ε_{ct} is the remainder stochastic term.[20] In this case, u_c were assumed to be fixed parameters. The Hausman test indicated that the fixed-effects model using the "within" estimator was an appropriate specification (Baltagi 2021).[21]

We first presented results individually for the empirical relationship of each one of the three measures of technology on the three measures of informality. We then combined the effect of all technology indicators. Next, we calculated results related to e-government. These were treated separately due to the nature of the indicator, which relates to the government's response to the digital transformation rather than to the transformation per se. Another characteristic distinguishing this indicator is the biannual nature of the data, in contrast to all other (annual) variables.

To report the goodness-of-fit (model accuracy) of the estimated models, we used the adjusted R-squared as a corrected measure for linear panel models with country fixed effects.[22] This measure identified the percentage of variance in the dependent variable that was explained by the explanatory variables. We also captured the root mean square error (RMSE), which is a frequently used general model performance measure and is the square root of the average squared difference between the regression-predicted values and the actual dependent variable values in a data set (known as "residuals"). A lower RMSE value means a better fit of the estimated model.

[20] We did not include time-specific effects that are country-invariant because they would have to be global in scale. In addition, it could also create potential multicollinearity with technological explanatory variables because their evolution strongly correlates with time. Note that our estimation period ends in 2019, before the COVID-19 pandemic.

[21] We first estimated a random effects specification (tables A1, A2 and A3 in the annex). The Hausman test (table A4 in the annex), which tests the null hypothesis that the difference in coefficients between the random effects and the fixed effects specifications is not systematic, was rejected. This implies that it was better to use the fixed-effects models to obtain consistent estimators of the parameters.

[22] The R-squared value always increases if the number of variables increases, while the adjusted R-squared only increases if the new variable improves the model more than would be expected by chance. This is particularly relevant in our case because we estimated country fixed effects.

▶ 3 Results

Partial effects

We started the empirical analysis by investigating the relationship between informality and each of the measures of technology studied. Table 3 reflects the results. Columns (1), (3) and (5) display estimates without control variables and columns (2), (4) and (6) show the covariates. The specific control variables used in the regressions were GDP per worker, trade, unemployment and the Rule of Law Index.[23] Note that simple correlations without any control variables always result in negative and significant coefficients regardless of the type of technology and the measure of informality utilized. When we introduced covariates, these patterns remained, although the size of the effects were smaller.

In the case of the rate of mobile cellular subscriptions, we first found that it negatively and significantly associates with all three informality indicators. However, the statistical significance of the relationship varies. Examining the coefficients for the regressions with controls, we found that mobile phone subscriptions negatively relate to informal employment and vulnerable employment and strongly negatively associates with the shadow economy. A 10-percentage point increase in the rate of mobile cellular subscriptions associated with a 0.53 percentage-point decline in the rate of informal employment (column 2) and to a 0.3-point decrease in vulnerable employment (column 4). The magnitude of change for the shadow economy indicator is a 0.5 percentage point contraction (column 6).

Table 3 also shows that internet use consistently associates negatively with informality. A 10-percentage point rise in the proportion of internet users led to a 1.35-point decline in informal employment as a share of total employment in a country. In the case of vulnerable employment, the coefficient indicated a 0.49 percentage-point decrease linked with a 10-point hike in the prevalence of internet users. In turn, a 10 percentage-point increase in the internet use rate linked with a 0.77-point decline in the shadow economy's share of national output. Overall, the results indicated that the association between internet use and informality is stronger (larger coefficients) than that between informality and mobile phone subscriptions.

In the case of automation, estimates from the set of regressions with and without covariates suggested that the value of robots and machinery imports per worker has a significant negative correlation with the various measures of informality.

[23] These covariates were selected to minimize the presence of multicollinearity between the regression independent variables.

▶ Table 3. Panel fixed-effects estimation on each technology, separately and informality measures

	Informal employment (1)	Informal employment, including controls (2)	Vulnerable employment (3)	Vulnerable employment, including controls (4)	Shadow economy (5)	Shadow economy, including controls (6)
Mobile cellular subscriptions per 100 people	-0.068	-0.053	-0.033	-0.030	-0.058	-0.050
	(5.564)***	(4.790)***	(9.447)***	(7.783)***	(40.536)***	(35.660)***
Rate of internet users	-0.153	-0.135	-0.060	-0.049	-0.096	-0.077
	(9.757)***	(8.884)***	(10.186)***	(8.032)***	(27.330)***	(23.799)***
Trade value of robotic and machinery imports per worker	-0.017	-0.007	-0.014	-0.007	-0.015	-0.002
	(5.412)***	(2.223)**	(6.202)***	(3.559)***	(8.847)***	(1.749)*

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. Columns (1), (3) and (5) display estimates without control variables and columns (2), (4) and (6) with covariates.

Source. Tables A5, A6 and A7 in the annex.

Combined effects

Next, we turn to a combined assessment of the three measures of technology on informality. We believe this to be useful because the technology measures could be correlated – for example, starting in 2007, internet access was possible through mobile cellular subscriptions – and the combined analysis allowed us to examine the effect of each measure in relation to the others. Table 4 shows the results.

▶ **Table 4. Panel fixed-effects estimation on combined effects of new technologies and informality measures**

	Informal employment rate (1)	**Informal employment rate, including controls (2)**	**Vulnerable employment rate (3)**	**Vulnerable employment rate, including controls (4)**	**Shadow economy share (5)**	**Shadow economy share, including controls (6)**
Mobile cellular subscriptions per 100 people	-0.036	-0.033	-0.035	-0.029	-0.042	-0.035
	(3.277)***	(3.066)***	(5.290)***	(4.271)***	(11.389)***	(9.303)***
Rate of internet users	-0.139	-0.123	-0.025	-0.017	-0.026	-0.018
	(9.792)***	(8.747)***	(2.858)***	(1.642)	(4.479)***	(3.000)***
Trade value of robotic and machinery imports per worker	-0.002	0.001	-0.004	-0.005	-0.005	-0.000
	(0.610)	(0.264)	(2.053)**	(2.470)**	(4.179)***	(0.306)
GDP per 1 000 workers		-0.127		-0.068		-0.047
		(4.766)***		(3.154)***		(4.651)***
Trade (% of GDP)		0.020		0.021		-0.026
		(1.278)		(2.587)***		(6.901)***
Rate of unemployment		0.099		-0.042		0.157
		(1.766)*		(1.279)		(8.822)***
Rule of Law Index		0.242		-3.256		-2.514
		(0.230)		(4.263)***		(7.215)***
Adjusted R-squared (within)	0.31	0.33	0.13	0.15	0.49	0.58
Observations	827	821	1 441	1 408	1 170	1 151
Countries	92	90	134	127	113	109
RMSE	3.319	3.271	3.424	3.333	1.559	1.419
F-test	52.377	30.453	45.569	23.265	246.355	204.066
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Despite the correlation between technology indicators,[24] we found statistically significant negative coefficients in equations that did not include control variables, with the exception of the coefficient for trade value of robotic and machinery imports per worker in the case of the informal employment rate. These findings are largely in line with the finding for each separate technology measure.

When control variables were added to the regressions, the negative coefficients remained for the mobile cellular subscriptions and the rate of internet users. However, in the case of the indicator of automation – the trade value of robotic and machinery imports per worker – the only statistically significant negative effect related to vulnerable employment, while the relationships between automation and informal employment or the shadow economy lost significance.

[24] Mobile cellular subscriptions and internet use had a correlation coefficient of 0.62, which could represent a potential multicollinearity problem that affects the statistic test used to determine if its effects are statically different from zero.

Results by income level

The relationship between the various technology indicators and informality could differ according to countries' income levels. To account for these potential heterogeneous effects, we ran regressions that interacted technology measures and levels of income (table 5). Due to the reduced number of observations for the informal employment variable, we ran these regressions only for vulnerable employment and the shadow economy.

Although the results confirmed the negative relationship between technology and informality in most cases, we found different patterns, or heterogeneity, depending on income level. In the case of high-income countries, a clear negative relationship emerged between cellular mobile subscriptions and internet use and all indicators of informality. In the case of automation, we did not find a significant relationship.

For upper-middle-income countries, the results suggested consistent and significant negative associations between mobile phone subscriptions, internet use and automation.

▶ **Table 5. Panel fixed-effects estimation, including interactions, by country income level**

	Mobile cellular subscriptions per 100 people		**Rate of internet users**		**Trade value of robotic and machinery imports per worker**	
	Vulnerable employment rate	**Shadow economy share**	**Vulnerable employment rate**	**Shadow economy share**	**Vulnerable employment rate**	**Shadow economy share**
High-income countries	-0.010	-0.025	-0.020	-0.035	-0.004	0.001
	(2.963)***	(11.883)***	(2.987)***	(10.118)***	(1.521)	(0.686)
Upper-middle-income countries	-0.008	-0.051	-0.023	-0.087	-0.012	-0.014
	(1.706)*	(23.345)***	(2.545)**	(15.868)***	(2.844)***	(4.802)***
Lower-middle-income countries	-0.067	-0.060	-0.140	-0.147	-0.066	-0.004
	(7.728)***	(22.714)***	(7.556)***	(12.788)***	(6.233)***	(0.459)
Low-income countries	-0.092	-0.072	-0.676	-0.284	-0.082	-0.002
	(4.492)***	(12.990)***	(4.260)***	(9.002)***	(2.533)**	(0.567)
Adjusted R-squared (within)	0.16	0.59	0.15	0.43	0.12	0.42
Observations	1 763	2 339	1 758	2 324	1 400	1 143
Countries	147	152	147	152	126	108
RMSE	3.584	1.854	3.608	2.162	3.402	1.651
F-test	21.025	286.702	21.157	182.490	22.656	76.329
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Specifications include control variables. Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

In the lower-middle-income countries, we found significant negative coefficients for mobile cellular subscriptions and the rate of internet users, both for vulnerable employment and the shadow economy. In the case of automation, the significance of the coefficient persisted for vulnerable employment but disappeared for the shadow economy. Similarly, in the case of low-income countries, significant negative coefficients were found for vulnerable employment and the shadow

economy for cellular phones and internet use. In the case of automation, significant negative coefficients were found for vulnerable employment only.

In general, while the coefficients were clearly negative for mobile subscriptions and internet access, in the case of automation, measured as trade value of robotic and machinery imports per worker, there seemed to be a less consistent link with informal employment and the shadow economy. Significant negative coefficients were found for vulnerable employment in the middle- and low-income countries, in contrast to the high-income countries, where automation appeared to positively influence this informality indicator, but the coefficients were not significant. Regarding the relationship between automation and the shadow economy, we only found a statistically significant negative relationship in the case of the upper-middle-income countries. For the high-income countries, the results suggested a positive but non-significant association.

A hypothesis for further research is that the inconsistent relationship between automation and informality across income levels could relate to the starting point or pre-existing conditions in terms of informality and robots and their relative sectoral distribution. There is more informality in the service sector than in manufacturing, where automation technologies (robots) tend to concentrate. In high-income countries, forces generating more and less informality may offset each other: A growing incidence of robots could lead to worker displacement (and informality) although there is lower initial inequality. Combined, these factors could explain the positive and non-significant coefficient sign. In contrast, in lower-income countries, despite the higher initial prevalence of informality, the increasing presence of robots could be a sign of general socio-economic progress and structural change, such that a negative link with informality could be expected.

4 E-government and informality: Does e-formalisation reduce informality?

Now, we turn to the nexus between technologies, policymaking and informality, based on what we found with the EGDI. According to UNDESA, "the EGDI is a composite measure of three important dimensions of e-government, namely: provision of online services, telecommunication connectivity and human capacity ... and it is not designed in an absolute but in a relative sense".[25] This database does not have annual information, rather data are available only for ten years: 2003, 2004, 2005, 2007, 2009, 2011, 2013, 2015, 2017 and 2019. Since 2008, the data published in a given year correspond to information from the previous year (data published for 2020 refer to 2019).

With this disclaimer in mind, we regressed the EGDI against the different measures of informality: the informal employment rate, the vulnerable employment rate and the shadow economy as a share of GDP and controlling for the same covariates used in the other regressions (GDP per worker, trade, unemployment and the Rule of Law Index). We used the same fixed-effects specification as in the previous cases. Table 6 shows the results, which confirm that the EGDI is statistically significant and negatively associated with indicators of informal employment, vulnerable employment and the shadow economy. Moreover, the significance of the relationship between e-government and informal employment holds after the introduction of control variables in this specification.[26]

[25] According to the EGDI website, "EGDI is based on a comprehensive survey of the online presence of all 193 United Nations Member States, which assesses national websites and how e-government policies and strategies are applied in general and in specific sectors for delivery of essential services. The assessment rates the e-government performance of countries relative to one another as opposed to being an absolute measurement. The results are tabulated and combined with a set of indicators embodying a country's capacity to participate in the information society, without which e-government development efforts are of limited immediate use". See https://publicadministration.un.org/egovkb/en-us/About/Overview/-E-Government-Development-Index, accessed 1 June 2023.

[26] The sign is negative and significant in the random effects specification. The smaller sample size of this variable (228 observations) and the introduction of country fixed effects may be an explanation for this.

▶ **Table 6. Panel fixed-effects estimates – E-Government Development Index**

	Informal employment rate (1)	Informal employment rate, including controls (2)	Vulnerable employment rate (3)	Vulnerable employment rate, including controls (4)	Shadow economy share (5)	Shadow economy share, including controls (6)
E-Government Development Index	-16.503	-9.123	-8.663	-5.677	-19.567	-16.645
	(4.626)***	(2.480)**	(3.652)***	(2.280)**	(19.219)***	(18.858)***
GDP per 1 000 workers		-0.183		-0.079		-0.105
		(3.498)***		(3.129)***		(8.509)***
Trade (% of GDP)		-0.031		-0.012		-0.032
		(1.132)		(1.358)		(5.984)***
Rate of unemployment		-0.025		-0.044		0.214
		(0.299)		(0.843)		(7.628)***
Rule of Law Index		-0.043		-3.799		-2.880
		(0.023)		(4.237)***		(6.262)***
Adjusted R-squared (within)	0.08	0.11	0.04	0.08	0.25	0.39
Observations	445	441	962	937	1 395	1 315
Countries	78	77	134	127	155	152
RMSE	4.414	4.342	3.844	3.748	2.585	2.291
F-test	21.396	10.927	13.339	11.625	369.386	166.005
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

The coefficient of e-government on the share of the shadow economy is larger than in the case of the informal employment and the vulnerable employment rate in all cases,[27] meaning that the sensitivity of the informal production dimension of informality is larger than the sensitivity of labour informality. Vulnerable employment appears to be less sensitive.

As in the case of individual technologies, we next investigated whether the relationship between e-government and different measures of informality differ across income groups (table 7). Again, due to the number of observations, we ran this disaggregation only for vulnerable employment and the shadow economy indicators.

In general, we found negative and statistically significant coefficients in all groups of countries in the case of the shadow economy indicator. However, in the case of vulnerable employment, we only found significant negative coefficients for high-income, lower-middle-income and low-income countries. With the upper-middle-income countries, the relationship was not significant, meaning that we could not reject the null hypothesis that these coefficients are equal to zero. Combining both results, we concluded that e-government – or e-formalisation – more strongly correlates negatively with the shadow economy, which is a proxy for informal production, and it

[27] The magnitude estimated of this effect was similar to that found by other studies. See Elbahnasawy 2021, for example.

less clearly relates to vulnerable employment, which is a proxy of labour informality, especially in high-income countries.

The direct policy implication of this finding is that e-formalisation can work more rapidly in the production or transaction dimension of informality but, in the case of labour informality in upper-middle-income countries, more needs to be done.

▶ Table 7. Panel fixed effects, by income country level and interactions with the E-Government Development Index

	Vulnerable employment rate	Shadow economy share
High-income countries	-5.080	-8.358
	(2.908)***	(8.726)***
Upper-middle-income countries	3.005	-18.166
	(0.777)	(10.162)***
Lower-middle-income countries	-24.147	-23.121
	(5.799)***	(11.638)***
Low-income countries	-30.725	-26.326
	(2.244)**	(7.271)***
Adjusted R-squared (within)	0.13	0.42
Observations	931	1 308
Countries	126	151
RMSE	3.655	2.249
F-test	12.188	117.259
Prob > F	0.000	0.000

Note: Specifications include control variables. Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$. Bolivarian Republic of Venezuela is not included due to lack of classification according to income.

Finally, to explore whether the EGDI masks heterogeneity driven by specific dimensions of the score, we disaggregated the EGDI into its three components: (a) the size and quality of online services; (b) the extent of telecommunication infrastructure and (c) human capital capacity. Table 8 presents the fixed-effects regression estimates using the e-government component and table A9 in the annex shows the random effects specification.

We first observed that online services only significantly and negatively relate to the shadow economy indicator and not to the vulnerable employment indicator. Second, the Telecommunication Infrastructure Index negatively associates with both vulnerable employment and the shadow economy indicators. Surprisingly, the Human Capital Index positively and significantly relates to vulnerable employment and the shadow economy. Although these differentiated results according to EDGI components deserve further specific research, we must emphasise that – as shown in figure A3 in the annex – in the period of analysis, the Human Capital Index showed a slight decreasing trend in a context of a slight decrease in both vulnerable employment and shadow economy.[28] The other components reflected an increasing trend.

[28] In any event, the EGDI data we collected could be a factor. In the case of the Human Capital Index, it is a relative index including "a composite of the adult literacy rate and the combined primary, secondary and tertiary gross enrolment ratio, with two thirds weight given to the adult literacy rate and one third to the gross enrolment ratio" (EGDI website). In addition, there have been some methodological changes over time in the surveys by experts.

▶ Table 8. Panel fixed effects for E-Government Development Index components

	Vulnerable employment rate	Shadow economy share
Online Service Index	0 531	-2 367
	(0 460)	(4 494)***
Human Capital Index	9 564	6 917
	(2 926)***	(5 092)***
Telecommunication Infrastructure Index	-3 799	-8 140
	(2 653)***	(10 334)***
GDP per 1 000 workers (constant 2017 PPP US$)	-0 045	-0 089
	(2 258)**	(8 006)***
Trade of goods and services (% of GDP)	-1 163	-3 138
	(1 299)	(6 510)***
Rate of unemployment	-0 020	0 203
	(0 468)	(7 400)***
Rule of Law Index	-3 909	-2 815
	(4 435)***	(6 711)***
Adjusted R-squared (within)	0 12	0 46
Observations	937	1.315
Countries	127	152
RMSE	3 670	2 153
F-test	12 757	143 489
Prob > F	0 000	0 000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

We also ran a separate regression with the E-Participation Index[29] and found a negative relationship that was consistent with the results found by Sacchi, Santolini and Schneider (2022) using a panel data set for 149 countries from 2003 to 2015 (table 9).

▶ Table 9. Panel fixed effects – E-Participation Index

	Vulnerable employment rate	Vulnerable employment rate, including controls	Shadow economy share	Shadow economy share, including controls
E-Participation Index	-3 608	-2 539	-6 456	-5 037
	(6 890)***	(4 933)***	(19 413)***	(16 231)***
GDP per 1 000 workers (constant 2017 PPP US$)		-0 070		-0 104
		(3 159)***		(8 321)***
Trade of goods and services (% of GDP)		-1 128		-3 246
		(1 262)		(6 069)***
Rate of unemployment		-0 034		0 229
		(0 627)		(7 456)***
Rule of Law Index		-3 829		-2 898
		(4 276)***		(6 224)***
Adjusted R-squared (within)	0 05	0 09	0 21	0 35
Observations	962	937	1.395	1.315
Countries	134	127	155	152
RMSE	3 818	3 733	2 642	2 372
F-test	47 475	14 778	376 873	131 346
Prob > F	0 000	0 000	0 000	0 000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

[29] Note that we did not include this variable in the previous regression because it is not a component of EGDI.

▶ 5 Robustness checks

Testing for endogeneity on e-formalisation: Generalized Method of Moments estimation

A potential problem with previous estimates is the endogeneity of the technological variables because their development in a country could have been affected by the size of its informal economy, or both variables could have been determined at the same time, influenced by similar factors not included in the estimated models.[30] In particular, we were interested in checking for possible endogeneity of the e-government variable using the Generalized Method of Moments approach based on a two-stage instrumental methodology to confront possible endogeneity. The lagged values of the explanatory variables were used as instruments. These values were not contemporaneous – and therefore were not correlated – with the dependent variable and, likewise, were not correlated with the error in the regression. Taking into account the availability of information, we used as instruments of the explanatory variables two lags for the regressions for informal employment and three lags of these variables for the vulnerable employment and the shadow economy regressions. To avoid losing degrees of freedom in the estimation, we followed Blundell and Bond's (1998) suggestion to use only the available observations of these variables for each year as instruments.

The results in table 10 show that the coefficients for e-government are negative and significant for all the dependent variables. In addition, the Hansen test – the J statistic and its p-value – indicate that this model was well specified and that the instruments used were adequate.

[30] This last possibility was controlled using a model with fixed effects (if these factors are constant over time for each country).

▶ **Table 10. Generalized Method of Moments – E-Government Development Index**

	Informal employment rate	Vulnerable employment rate	Shadow economy share
E-Government Development Index	-56.824	-33.951	-9.032
	(22.232)***	(16.648)***	(17.891)***
GDP per 1 000 workers	-0.097	-0.166	-0.077
	(5.217)***	(10.812)***	(14.277)***
Trade (% of GDP)	-0.087	-0.016	0.010
	(10.687)***	(1.514)	(3.216)***
Rate of unemployment	-1.191	-0.743	0.105
	(34.729)***	(24.454)***	(5.199)***
Rule of Law Index	-11.776	-4.086	-5.269
	(14.842)***	(7.780)***	(25.819)***
Constant	102.906	65.419	34.695
	(48.884)***	(50.615)***	(66.610)***
Observations	469	955	1 315
Countries	469	955	1315
Hansen J statistic	105	145	152
P-value (Hansen test)	77.021	120.420	137.445
RMSE	0.321	0.322	0.009

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Reverse causality: Granger Test

Endogeneity might also arise in the case that informality directly determines the adoption and use of technologies by individuals and influences a country's digital transformation over time.

We assessed the existence of simultaneity through a series of panel Granger causality tests, employing the Dumitrescu and Hurlin (2012) procedure. This exercise indicated Z-bar tildes and corresponding bootstrapped p-values for the main sample, following the estimation of equation (1) and tested the null hypothesis that the dependent variable (associated to informality) does not Granger-cause the adoption or development of the technology measures under consideration. Table 11 shows that we cannot reject this null hypothesis in all cases and hence demonstrates that neither the rate of informal employment and vulnerable employment nor the size of the shadow economy Granger-caused the mobile cellular subscriptions per 100 people, the rate of internet users or the trade value of robotic imports per worker. These test results point to unidirectional causality from the spread of the internet and automation to informality.

▶ **Table 11. Granger causality tests**

Null hypothesis	Z-bar tilde	p-value
Informality does not Granger-cause the mobile cellular subscription rate	1.132	.471
Vulnerable employment does not Granger-cause the mobile cellular subscription rate	3.432	.197
Shadow economy does not Granger-cause the mobile cellular subscription rate	1.213	.548
Informality does not Granger-cause the internet user rate	-.985	.346
Vulnerable employment does not Granger-cause the internet user rate	1.627	.458
Shadow economy does not Granger-cause the internet user rate	.958	.508
Informality does not Granger-cause the robotic import trade value	1.321	.268
Vulnerable employment does not Granger-cause the robotic import trade value	1.533	.373
Shadow economy does not Granger-the cause robotic import trade value	.006	.981

Note: The tests were run on balanced panel estimation samples following fixed-effects estimations. ***, ** and * denote rejection of the null hypothesis at 1%, 5% and 10%, respectively. The optimal number of lags is chosen based on Stata – xtgcause – BIC option. P-values were computed using 1,000 bootstrap replications.

▶ Conclusion

The world is experiencing a period of rapid digital transformation, further accelerated after the onset of the COVID-19 pandemic. Since the early 2000s, mobile cellular subscriptions have spread around the world, including in lower-income countries. This is also the case of the internet, which has become increasingly accessible around the globe. Automation technologies are also growing, but they seem to be more concentrated than other technologies, with large and widening gaps across regions of the world. And, increasingly, governments are using these technologies for policymaking through e-government initiatives.

The speed and breadth of these technological transformations are deeply and permanently transforming the way labour markets work. The impact of technological penetration on labour markets has been well documented in several previous studies, with marked emphasis on the inequalities generated, substitutions of the workforce and new forms of work. In this paper, we focus on technologies and their impact on informality to suggest that this impact can be different depending on the type of technology considered and the specific dimension of informality involved.

We built a database wherein informality is measured by the rate of informal employment and, as a proxy available for a wider range of countries, by the vulnerable employment rate and by the shadow economy share of GDP as a proxy for informal production. In the case of digital transformation, we used a range of measures: mobile phone subscription rates, the rate of internet users and automation, which was measured as the trade value of robotic and machinery imports per worker.

Using cross-country regressions, we first addressed the effect of each technology on the different indicators of informality and found that the technology–informality nexus is indeed complex. In most cases, the results indicate a majority of negative and significant relationships between technologies and informality. However, in some instances, the relationship is non-significant, meaning that it is not statistically different from zero. We suggested that the net sign of the coefficient is the result of forces that can decrease informality – enhanced productivity or more governmental capacity – and forces that can increase informality – for example, the creation of own-account work that consistently shows higher informality rates than salaried work. To further explore these associations, we disaggregated data by income level and by geographical region and found hard evidence of heterogeneity. Our results are also in line with previous literature that indicated that the relationship between technologies and informality is multidimensional and multidirectional and that the preexisting levels of both variables – informality and technology – can also have a role.

Our findings on automation do not encompass recent breakthroughs in artificial intelligence. Whereas robots are defined as automatically controlled reprogrammable machines in three or more axes for use in industrial automation,[31] artificial intelligence largely refers to automating physical tasks and relates to adaptive algorithms increasingly capable of automating complex cognitive tasks (Bordot 2022). That is to say, the expected impacts of artificial intelligence on informality are likely to differ from those of robots and merit dedicated research.

Second, because technologies also impact governance, thus creating new possibilities for policymaking, public services delivery and stronger inspection capabilities, we explored the relationship between the E-Government Development Index and different measures of informality. The results point to negative coefficients at the aggregate level. However, when we tested for heterogeneity by income level, we confirmed that the associations are mostly negative and significant

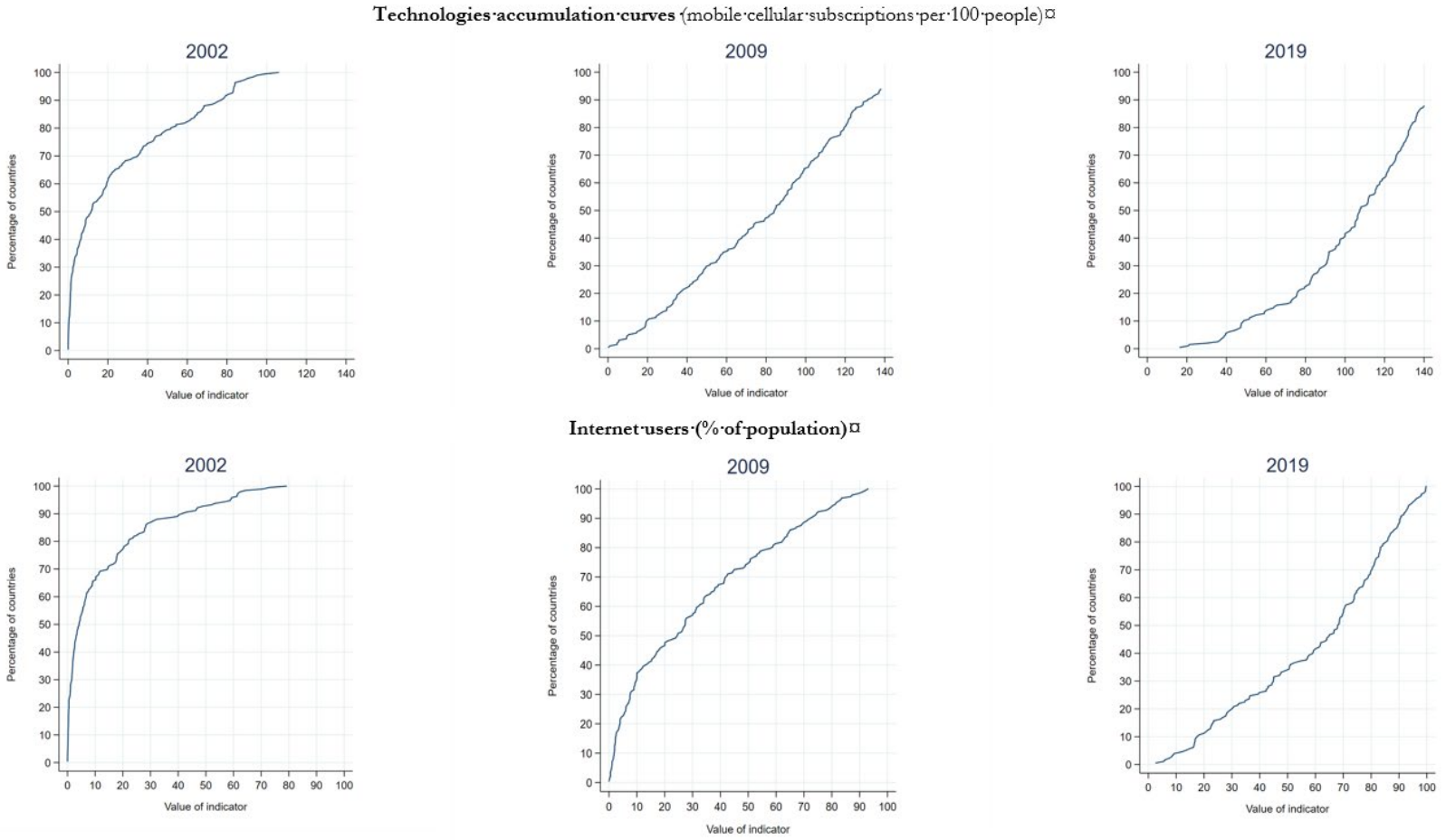
[31] Our robot data followed the definition implemented by the International Federation of Robotics. See Jurkat, Klump and Schneider 2022 for more information.

for informal production – proxied by the shadow economy indicator – across all income levels. However, in the case of informal employment– proxied by vulnerable employment, the effects are negative in high-, low- and lower-middle-income countries and non-significant in upper-middle-income countries. Considering this and the magnitude of the coefficients, we concluded that e-government initiatives can reduce informal production more easily than labour informality, where additional policy action might be required. Next, each component of the E-Government Development Index was explored separately, namely online services, human capital, telecommunication infrastructure and e-participation. We found significant negative coefficients for telecommunication infrastructure. However, we found a positive association between human capital and informality that needs further research.

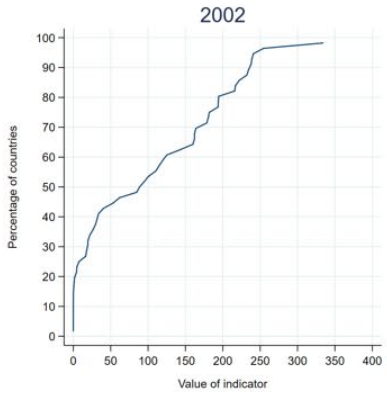
Finally, we tested for endogeneity running a Granger test to explore if there is reverse causality. The findings indicate that we can discard this possibility, especially because informality does not Granger-cause technology adoption.

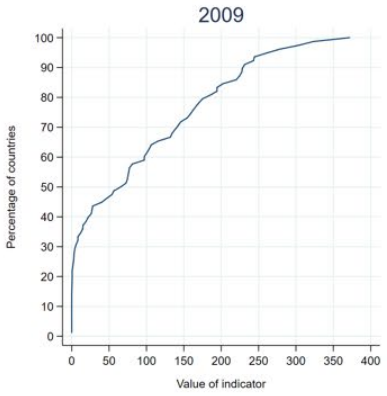
Annex

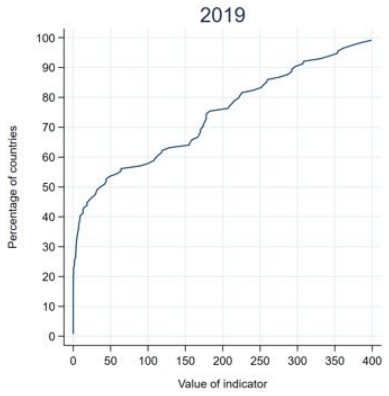
▶ **Figure A1. Technology accumulation curves in 2002, 2009 and 2019**



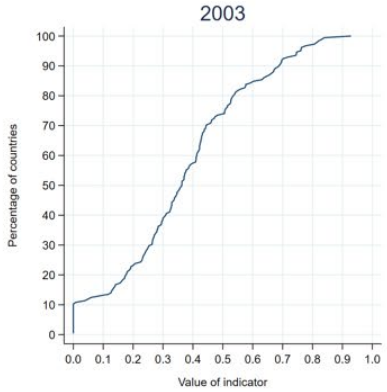
Trade value of robotic and machinery imports per worker¤

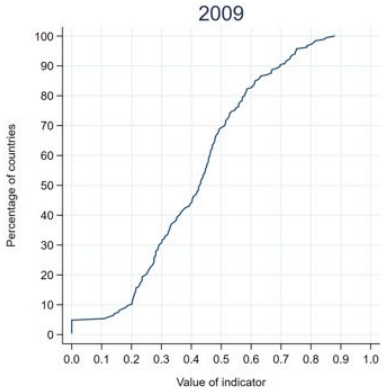


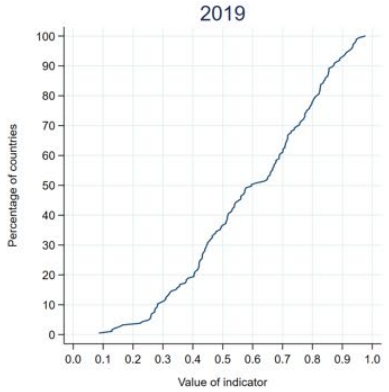




E-Government Development Index¶





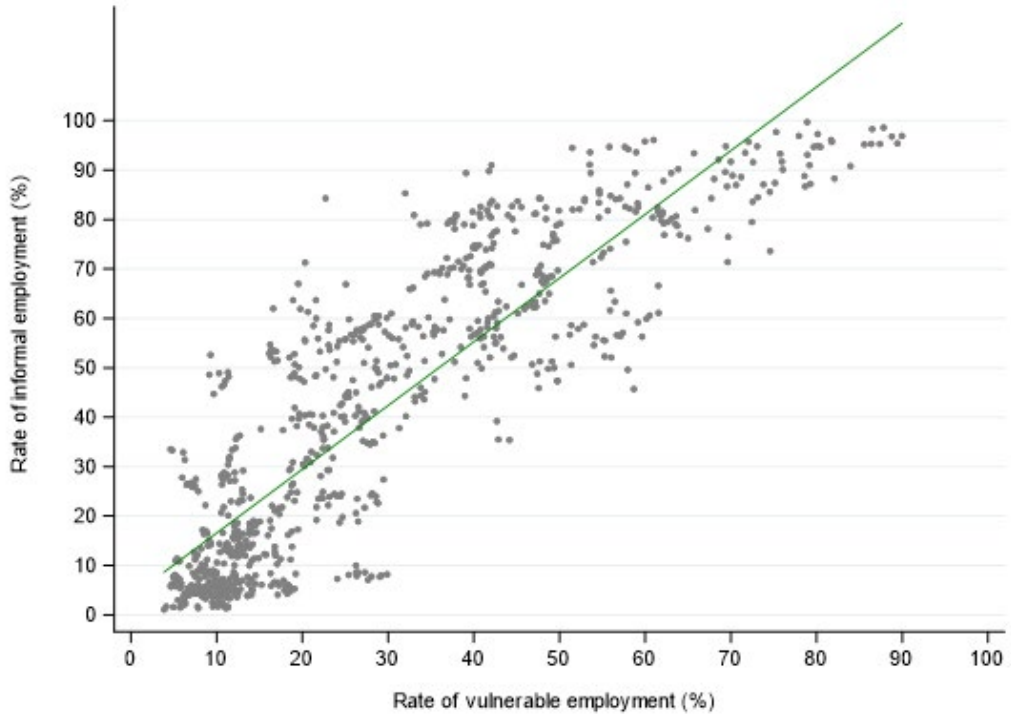


Note: In this case, we used 2003 instead of 2002 data due to data availability.

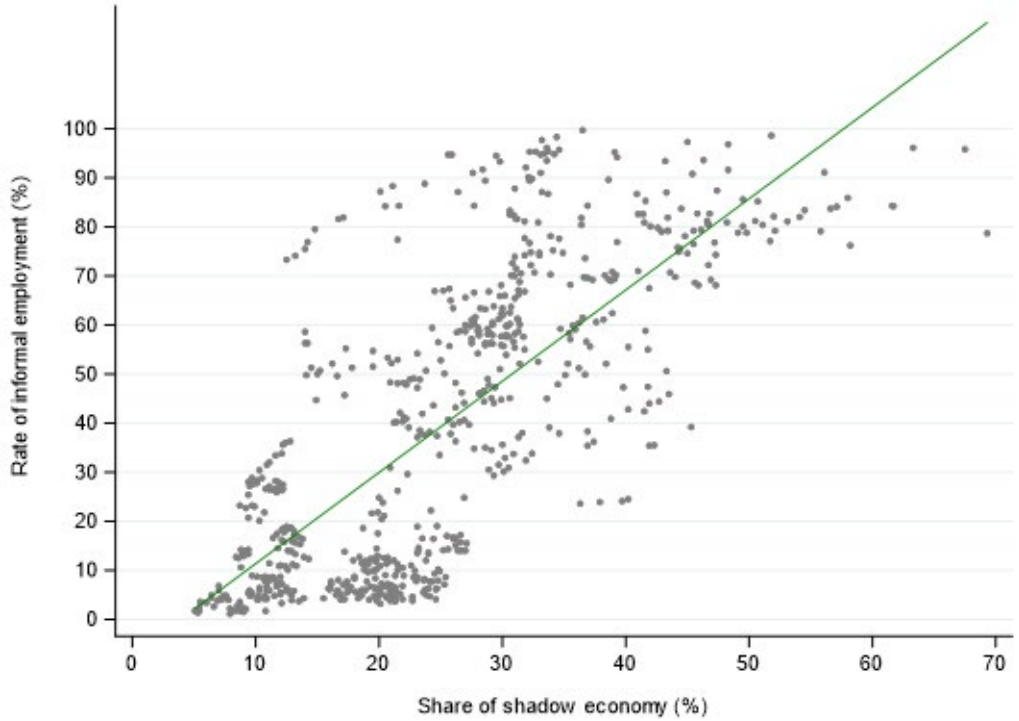
Source: International Telecommunication Union, United Nations Comtrade bilateral trade statistics and EGDI database.

▶ **Figure A2. Partial correlations scatter plots between informality-related measures**

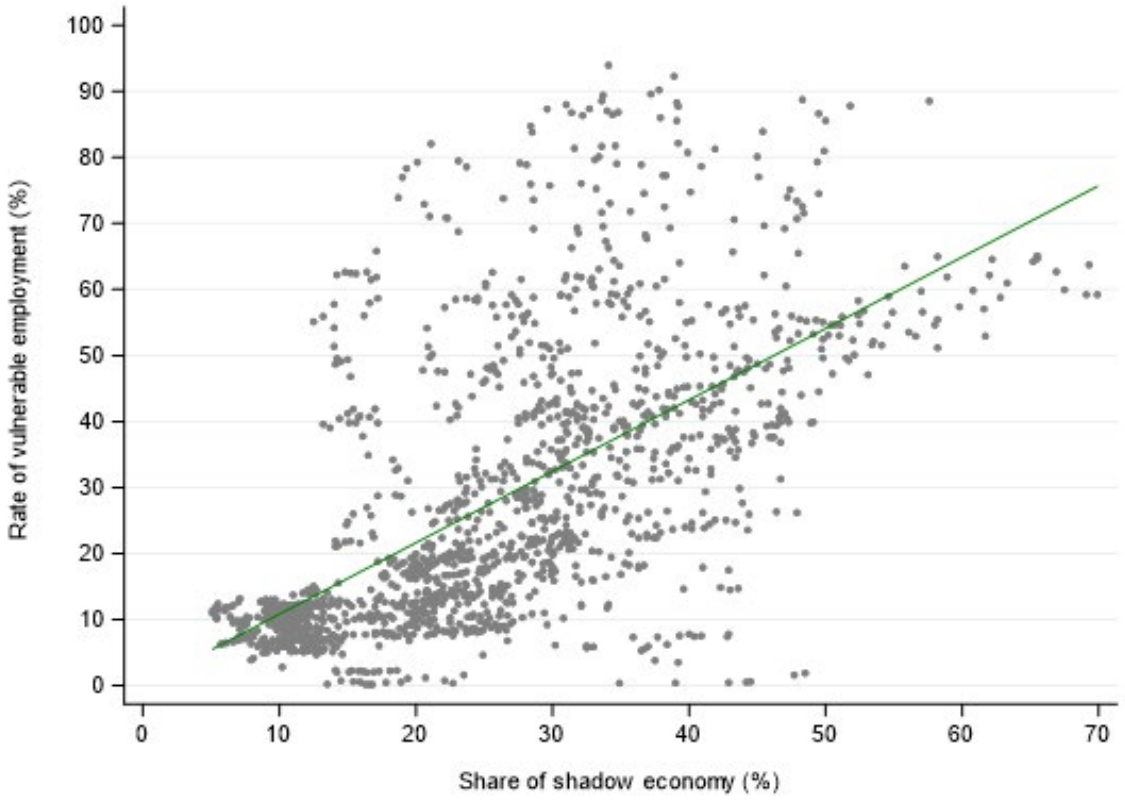
Informal employment vs. Vulnerable employment, 2002-2019



Informal employment vs. Shadow economy. 2002-2019



Vulnerable employment vs. Shadow economy, 2002-2019



Source: ILOSTAT database and Medina & Schneider (2019) database.

▶ Table A1. Panel random effects – Mobile cellular subscriptions per 100 people

	Informal employment rate	Informal employment rate, including controls	Vulnerable employment rate	Vulnerable employment rate, including controls	Shadow economy share	Shadow economy share, including controls
Mobile cellular subscriptions per 100 people	-0.072	-0.046	-0.034	-0.024	-0.058	-0.050
	(2.562)**	(1.889)*	(4.138)***	(2.805)***	(17.145)***	(16.324)***
GDP per 1 000 workers		-0.324		-0.073		-0.085
		(4.130)***		(2.279)**		(6.188)***
Trade (% of GDP)		-0.055		-0.020		-0.029
		(1.509)		(1.446)		(3.781)***
Rate of unemployment		-0.145		-0.121		0.094
		(1.749)*		(1.862)*		(2.779)***
Rule of law		-7.234		-5.392		-2.826
		(4.424)***		(5.782)***		(5.941)***
Observations	899	882	1 851	1 786	2 492	2 352
Countries	131	121	177	160	156	153
RMSE	4.093	4.095	3.955	3.840	2.139	1.922
F-test	598.139	598.139	598.139	598.139	598.139	598.139
Prob > F	0.010	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ Table A2. Panel random effects – Rate of internet users

	Informal employment rate	Informal employment rate, including controls	Vulnerable employment rate	Vulnerable employment rate, including controls	Shadow economy share	Shadow economy share, including controls
Rate of internet users	-0.188	-0.116	-0.069	-0.040	-0.100	-0.077
	(6.439)***	(4.013)***	(4.912)***	(2.702)***	(13.512)***	(12.776)***
GDP per 1 000 workers		-0.264		-0.089		-0.095
		(3.759)***		(2.957)***		(6.164)***
Trade (% of GDP)		-0.045		-0.016		-0.029
		(1.114)		(1.133)		(3.497)***
Rate of unemployment		-0.131		-0.104		0.207
		(1.816)*		(1.617)		(5.200)***
Rule of law		-7.039		-5.427		-2.867
		(4.644)***		(5.669)***		(4.415)***
Observations	889	876	1 841	1 780	2 471	2 337
Countries	128	119	175	159	156	153
RMSE	4.278	4.016	4.133	3.909	2.541	2.265
F-test	598.139	598.139	598.139	598.139	598.139	598.139
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ Table A3. Panel random effects – Trade value of robotic and machinery imports per worker

	Informal employment rate	Informal employment rate, including controls	Vulnerable employment rate	Vulnerable employment rate, including controls	Shadow economy share	Shadow economy share, including controls
Trade value of robotic and machinery imports per worker	-0.027	-0.009	-0.016	-0.006	-0.018	-0.003
	(5.167)***	(1.601)	(3.570)***	(1.616)	(6.005)***	(1.343)
GDP per 1 000 workers		-0.408		-0.211		-0.163
		(4.185)***		(3.813)***		(4.846)***
Trade (% of GDP)		0.002		0.020		-0.021
		(0.081)		(1.254)		(2.766)***
Rate of unemployment		-0.118		-0.107		0.185
		(1.355)		(1.793)*		(4.133)***
Rule of law		-6.722		-5.960		-3.637
		(3.683)***		(4.453)***		(4.592)***
Observations	874	855	1 500	1 427	1 210	1 171
Countries	132	121	161	143	132	126
RMSE	4.243	3.880	3.663	3.509	2.160	1.687
F-test	598.139	598.139	598.139	598.139	598.139	598.139
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ Table A4. Hausman test random effects versus fixed effects

	Informal employment rate (% of total employment)		Vulnerable employment total (% of total employment)		Size of the shadow economy (% of GDP)	
	Chi ^{2}	p-value	Chi ^{2}	p-value	Chi ^{2}	p-value
Mobile-cellular subscriptions (% of population)	90.14	0.00	146.92	0.00	30.53	0.00
Internet users (% of population)	127.41	0.00	172.55	0.00	17.77	0.00
Trade value of imports of robots per worker (US$)	87.17	0.00	77.36	0.00	26.40	0.00
E-government development index	72.40	0.00	115.86	0.00	20.30	0.00
E-government components and e-participation	86.62	0.00	146.52	0.00	17.06	0.03

▶ **Table A5. Panel fixed-effects estimation, mobile cellular subscriptions per 100 people**

	Informal employment rate (1)	Informal employment rate, including controls (2)	Vulnerable employment rate (5)	Vulnerable employment rate, including controls (6)	Shadow economy share (7)	Shadow economy share, including controls (8)
Mobile cellular subscriptions per 100 people	-0.068	-0.053	-0.033	-0.030	-0.058	-0.050
	(5.564)***	(4.790)***	(9.447)***	(7.783)***	(40.536)***	(35.660)***
GDP per 1 000 workers		-0.184		-0.011		-0.082
		(5.471)***		(0.912)		(10.556)***
Trade (% of GDP)		-0.041		-0.015		-0.031
		(2.432)**		(2.410)**		(7.971)***
Rate of unemployment		0.030		-0.048		0.096
		(0.483)		(1.229)		(5.277)***
Rule of law		-0.884		-3.341		-2.569
		(0.680)		(5.539)***		(9.018)***
Adjusted R-squared (within)	0.11	0.16	0.08	0.11	0.47	0.56
Observations	862	853	1 835	1 774	2 492	2 352
Countries	94	92	161	148	156	153
RMSE	4.003	3.888	3.873	3.683	2.126	1.912
F-test	30.954	23.007	89.237	25.768	1643.172	405.749
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ **Table A6. Panel fixed-effects estimation – Rate of internet users**

	Informal employment rate (1)	Informal employment rate, including controls (2)	Vulnerable employment rate (3)	Vulnerable employment rate, including controls (4)	Shadow economy share (5)	Shadow economy share, including controls (6)
Rate of internet users	-0.153	-0.135	-0.060	-0.049	-0.096	-0.077
	(9.757)***	(8.884)***	(10.186)***	(8.032)***	(27.330)***	(23.799)***
GDP per 1 000 workers		-0.080		-0.025		-0.096
		(2.928)***		(2.456)**		(11.086)***
Trade (% of GDP)		-0.025		-0.009		-0.032
		(1.397)		(1.413)		(7.779)***
Rate of unemployment		0.071		-0.014		0.215
		(1.281)		(0.368)		(10.289)***
Rule of law		0.224		-3.179		-2.664
		(0.182)		(5.063)***		(7.313)***
Adjusted R-squared (within)	0.22	0.23	0.07	0.09	0.25	0.38
Observations	855	849	1 828	1 769	2 471	2 337
Countries	94	92	162	148	156	153
RMSE	3.742	3.721	3.903	3.720	2.502	2.259
F-test	95.198	36.710	103.751	26.786	746.951	258.865
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ Table A7. Panel fixed-effects estimation – Trade value of robotic and machinery imports per worker

	Informal employment rate (1)	Informal employment rate, including controls (2)	Vulnerable employment rate (3)	Vulnerable employment rate, including controls (4)	Shadow economy share (5)	Shadow economy share, including controls (6)
Trade value of robotic and machinery imports per worker	-0.017	-0.007	-0.014	-0.007	-0.015	-0.002
	(5.412)***	(2.223)**	(6.202)***	(3.559)***	(8.847)***	(1.749)*
GDP per 1 000 workers		-0.311		-0.162		-0.180
		(6.350)***		(7.177)***		(8.936)***
Trade (% of GDP)		0.019		0.023		-0.023
		(1.098)		(2.780)***		(5.098)***
Rate of unemployment		0.044		-0.028		0.186
		(0.696)		(0.845)		(8.157)***
Rule of law		-1.160		-4.294		-3.606
		(0.932)		(5.567)***		(7.305)***
Adjusted R-squared (within)	0.03	0.15	0.02	0.11	0.08	0.41
Observations	835	824	1 477	1 411	1 192	1 154
Countries	93	90	138	127	114	109
RMSE	3.935	3.686	3.595	3.418	2.101	1.672
F-test	29.286	14.219	38.468	22.448	78.266	109.930
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ **Table A8. Panel random effects – E-Government Development Index**

	Informal employment rate	Informal employment rate, including controls	Vulnerable employment rate	Vulnerable employment rate, including controls	Shadow economy share	Shadow economy share, including controls
E-government index	-28.696	-11.315	-12.701	-5.930	-20.904	-16.442
	(4.341)***	(1.633)	(3.713)***	(1.823)*	(13.402)***	(13.408)***
GDP per 1 000 workers		-0.319		-0.163		-0.096
		(3.787)***		(3.949)***		(6.044)***
Trade (% of GDP)		-0.049		-0.016		-0.027
		(1.136)		(0.984)		(3.518)***
Rate of unemployment		-0.318		-0.183		0.205
		(3.832)***		(2.540)**		(5.418)***
Rule of law		-9.258		-5.971		-2.944
		(4.746)***		(5.443)***		(4.704)***
Observations	481	469	984	955	1 395	1 315
Countries	114	105	156	145	155	152
RMSE	5.122	4.701	4.153	3.989	2.609	2.304
F-test	598.139	598.139	598.139	598.139	598.139	598.139
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000

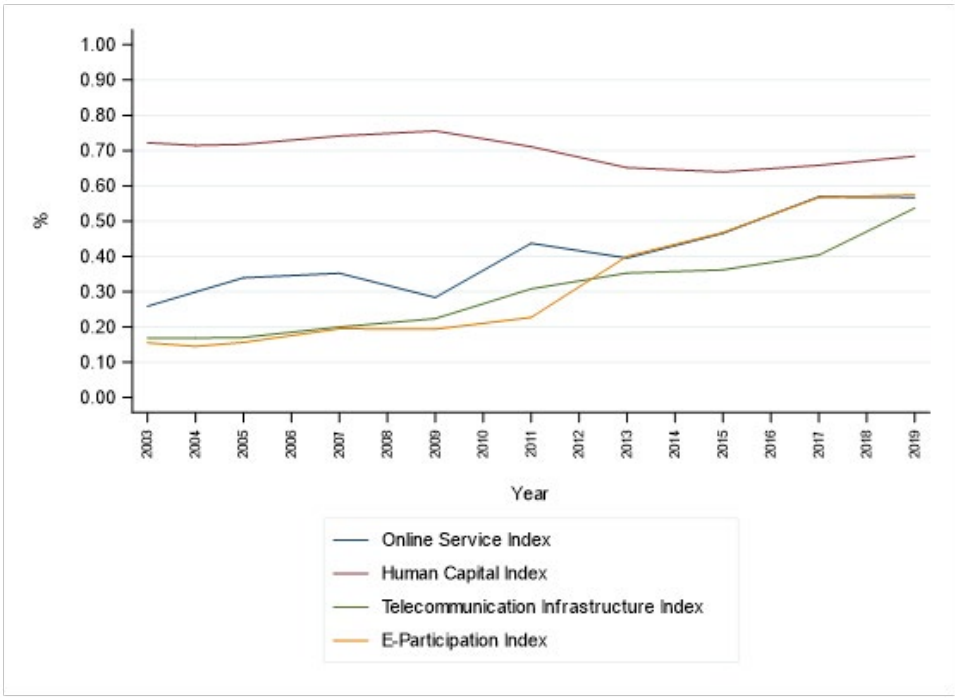
Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ **Table A9. Random effects – E-government components and e-participation**

	Vulnerable employment rate (surveys)	Shadow economy share
Online Service Index	0.272	-3.578
	(0.139)	(4.782)***
Human Capital Index	-0.366	6.805
	(0.066)	(3.644)***
Telecommunication Infrastructure Index	-4.593	-9.247
	(1.893)*	(9.028)***
E-Participation Index	0.204	1.444
	(0.160)	(2.456)**
GDP per 1 000 workers (constant 2017 PPP US$)	-0.154	-0.093
	(3.900)***	(6.117)***
Trade of goods and services (% of GDP)	-0.016	-0.028
	(1.008)	(3.902)***
Rate of unemployment	-0.190	0.183
	(2.702)***	(4.709)***
Rule of Law Index	-6.082	-3.198
	(5.400)***	(5.673)***
Constant	46.670	32.943
	(8.979)***	(19.651)***
N	955	1 315
N of countries	145	152
RMSE	3.976	2.156
F-test	128.281	128.281
Prob > F	0.000	0.000

Note: Robust standard in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

▶ **Figure A3. E-Government Development Index, by subcomponents**



Source: EDGI database.

References

Abramo, Laís. 2022. "Policies to Address the Challenges of Existing and New Forms of Informality in Latin America", Working Paper No. 240, Social Policy Series. Santiago: ECLAC.

Baltagi, Badi H. 2021. *Econometric Analysis of Panel Data*. Sixth edition. Springer Texts in Business and Economics. Springer Cham.

Berg, Andrew, Edward F. Buffie, and Luis-Felipe Zanna. 2016. "The Robot Revolution Could Have Profound Negative Implications for Equality", *Finance and Development* 53 (3): 10–13.

Berg, Janine, Uma Rani, Marianne Furrer, Ellie Harmon, and M. Six Silberman. 2018. *Digital Labour Platforms and the Future of Work*. Geneva: ILO.

Berrou, Jean-Philippe, and Kevin Mellet. 2018. "Téléphonie Mobile et Le Secteur Informel à Dakar: La Gran Polarisation Des Usages Professionnels", *The Conversation* (blog), 10 September.

Bhattacharya, Rajesh. 2019. "ICT Solutions for the Informal Sector in Developing Economies: What Can One Expect?", *Electronic Journal Of Information Systems In Developing Countries* 85 (3): 1–7.

Boitan, Iustina Alina, and Sorina Emanuela Stefoni. 2023. "Digitalization and the Shadow Economy Impact Assessment and Policy Implications for EU Countries", *Eastern European Economics* 61 (2): 152–80.

Bordot, Florent. 2022. "Artificial Intelligence, Robots and Unemployment: Evidence from OECD Countries", *Journal of Innovation Economics & Management* 37 (1): 117–38.

Brambilla, Irene, Andrés César, Guillermo Falcone, and Leonardo Gasparini. 2023. "The Impact of Robots in Latin America: Evidence from Local Labor Markets", Documentos de Trabajo del CEDLAS 312. CEDLAS-Universidad Nacional de la Plata.

Blundell, R., and S. Bond. 1998. "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models", *Journal of Econometrics* 87.

Chacaltana, Juan, Vicky Leung, and Miso Lee. 2018. "New Technologies and the Transition to Formality: The Trend towards e-Formality", Working Paper No. 247, Employment Working Paper. ILO.

Chen, Martha A. 2016. "Technology, Informal Workers and Cities: Insights from Ahmedabad (India), Durban (South Africa) and Lima (Peru)", *T EC H NO L O G Y* 28 (2): 18.

Deen-Swarray, Mariama, Mpho Moyo, and Christoph Stork. 2013. "ICT Access and Usage among Informal Businesses in Africa", *Info* 15 (5): 52–68.

Deléchat, Corinne C., and Leandro Medina (eds). 2021. *Global Informal Workforce: Priorities for Inclusive Growth.* S.l.: International Monetary Fund.

Dener, Cem, Hubert Nii-Aponsah, Love E. Ghunney, and Kimberly D. Johns. 2021. GovTech Maturity Index: The State of Public Sector Digital Transformation. Washington, DC: World Bank.

Dumitrescu, Elena I., and Christophe Hurlin. 2012. "Testing for Granger Non-Causality in Heterogeneous Panels", *Economic Modelling* 29 (4): 1450–60.

Elbahnasawy, Nasr. 2021. "Can E-Government Limit the Scope of the Informal Economy?", *World Development* 139.

Elgin, Ceyhun. 2013. "Internet Usage and the Shadow Economy: Evidence from Panel Data", *Economic Systems* 37 (1).

Fernández-Macías, Enrique, David Klenert, and José-Ignacio Antón. 2020. "Not so Disruptive yet? Characteristics, Distribution and Determinants of Robots in Europe".

Garcia-Murillo, Martha, and Jorge Andres Velez-Ospina. 2014. "The Impact of ICTs on the Informal Economy", 20th Biennial Conference of the International Telecommunications Society, Rio de Janeiro, Brazil, 30 December 2014.

—. 2017. "ICTs and the Informal Economy: Mobile and Broadband Roles", *Digital Policy, Regulation and Governance* 19 (1): 58–76.

Ghislain, Adalbert Abraham, and Melingui Bate. 2022. "Does the Diffusion of Information and Communication Technologies Affect the Shadow Economy in Africa?", *African Development Review* 34 (4): 513–26.

Haruna, Emmanuel, and Usman Alhassan. 2022. "Does Digitalization Limit the Proliferation of the Shadow Economy in African.Pdf", *African Development Review* 34: S34–62.

Ilavarasan, P. Vigneswara. 2019. "Present and Future of the Use and Impact of Information and Communication Technology in Informal Microenterprises: Insights from India". *Electronic Journal of Information Systems in Developing Countries* 85 (3): 1–9.

ILO. 2015. Recommendation No. 204 – Transition from the Informal to the Formal Economy.

—. 2018. Women and Men in the Informal Economy: A Statistical Picture.

— (ed.). 2021a. World Employment and Social Outlook 2021: The Role of Digital Labour Platforms in Transforming the World of Work.

—. (ed.). 2021b. The Role of Digital Labour Platforms in Transforming the World of Work.

—. 2022. "Reference Document for the Meeting of Experts on Decent Work in the Platform Economy".

—. 2023. Resolution concerning statistics on the informal economy.

Infante, Ricardo, and Oswaldo Sunkel. 2012. La Heterogeneidad de La Estructura Productiva Latinoamericana. Cambio Estructural Para La Igualdad: Una Visión Integrada de Desarrollo. San Salvador: CEPAL.

Jurkat, Anne, Rainer Klump, and Florian Schneider. 2022. "Tracking the Rise of Robots: The IFR Database", *Jahrbücher Für Nationalökonomie Und Statistik* 242 (5–6): 669–89.

Kelikume, Ikechukwu. 2021. "Digital Financial Inclusion, Informal Economy and Poverty Reduction in Africa", *Journal of Enterprising Communities: People and Places in the Global Economy* 15 (4): 626–40.

Kupfer, David, and Frederico Rocha. 2005. "Productividad y Heterogeneidad Estructural En La Industria Brasileña", In *Heterogeneidad Estructural, Asimetrías Tecnológicas y Crecimiento En América Latina*, 72–100. CEPAL.

Lewis, W. Arthur. 1954. "Economic Development with Unlimited Supplies of Labour". The Manchester School.

Medina, Leandro, and Friedrich Schneider. 2018. *Shadow Economies Around the World: What Did We Learn Over the Last 20 Years?* International Monetary Fund.

—. 2019. "Shedding Light on the Shadow Economy: A Global Database and the Interaction with the Official One", Working Paper No. 7981. CESifo Working Papers. Munich: Munich Society for the Promotion of Economic Research – CESifo GmbH.

Ndoya, Hermann, Donald Okere, Marie Laure Belomo, and Melissa Atangana. 2023. "Do ICTs Decrease the Spread of Informal Economy in Africa?", *Telecommunications Policy* 47 (2): 102485.

Nevzorova, Ekaterina, Anna Kireenko, and Yulia Leontyeva. 2018. "If Development of Technologies Can Win Shadow Economy." In *14th International Scientific-Technical Conference APEIE*, 422–28.

Nguyen, Canh Phuc, Binh Quang Nguyen, and Duyen Thuy Le Tran. 2023. "The Internet, Economic Uncertainty, and the Shadow Economy: "The Good, the Bad, and the Unknown?", *International Social Science Journal* 73 (247): 9–28.

O"Higgins, Niall, and Luis Pinedo Caro. 2022. "Crowdwork for Young People: Risks and Opportunities", Working Paper No. 50, ILO Working Paper.

Ohnsorge, Franziska, and Shu Yu (eds). 2021. The Long Shadow of Informality: Challenges and Policies. Washington, D.C.: World Bank Group.

Pinto, Aníbal. 1970. "Naturaleza e Implicaciones de La "Heterogeneidad Estructural" de La América Latina", *El Trimestre Económico* 37 (145): 83–100.

Rangaswamy, Nimmi. 2019. "A Note on Informal Economy and ICT", *Electronic Journal of Information Systems in Developing Countries* 85 (3): 1–5.

Remeikiene, Rita, Ligita Gaspareniene, Yilmaz Bayar, Romualdas Ginevicius, and Ieva Marija Ragaisyte. 2022. "ICT Development and Shadow Economy Empirical Evidence from the EU Transition Economies", *Economic Research-Ekonomska Istraživanja* 35 (1): 762–77.

Salazar-Xirinachs, José Manuel, and Juan Chacaltana. 2018. *Politicas de Formalizacion en America Latina*. Lima: ILO.

Sacchi, Agnese, Raffaella Santolini, and Friedrich Schneider. 2022. "On the Effects of E-participation on Shadow Economy: A Worldwide Empirical Analysis", *German Economic Review* 23 (3): 463–91.

Stefano, Valerio De, Ilda Durri, Charalampos Stylogiannis, and Mathias Wouters. 2021. "Platform Work and the Employment Relationship", Working Paper 27. ILO Working Paper.

United Nations. 2023. UN E-government Knowledge database. Accessed 1 June 2023.

UNDESA. 2020. E-Government Survey 2020: Digital Government in the Decade of Action for Sustainable Development. New York: United Nations Department of Economic and Social Affairs.

World Bank. 2023. World development indicators. Accessed 30 September 2023.

—. 2023. Worldwide governance indicators. Accessed 30 September 2023.

Williams, Colin C. 2021. *E-Formalization in Europe*. Geneva: ILO.

—. 2023. Formalization of the Informal Economy: An e-Government Approach. New York: Springer.

Zwysen, Wouter, and Agnieszka Piasna. 2023. "Juggling Online Gigs with Offline Jobs: How Local Labour Markets Are Driving the Growth in Internet and Platform Work", ETUI Research Paper No. 2.

Acknowledgements

At the time of this paper's preparation, the authors were ILO Employment Policy Specialist, Technical Officer at the Employment Policy Department and Project Manager of the Formalisation Programme in Latin America, respectively. The authors thank Clotilde Mahé for her contribution to the construction of the final database and for her many useful comments. We also benefited from valuable comments contributed by Sangheon Lee, Sher Verick, Michael Frosch, Colin Williams, Florence Bonnet, Maria Prieto, Christine Hofmann, Juan Ivan Martin and Johannes Weiss. Karen Emmons edited the initial manuscript.

Advancing social justice, promoting decent work

The International Labour Organization is the United Nations agency for the world of work. We bring together governments, employers and workers to improve the working lives of all people, driving a human-centred approach to the future of work through employment creation, rights at work, social protection and social dialogue.

Contact details

Employment Policy Department (EMPLOYMENT)

International Labour Organization
Route des Morillons 4
1211 Geneva 22
Switzerland
T +41 22 799 7861
employment@ilo.org
www.ilo.org/employment

ISBN 9789220405680