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Cybersecurity provision and online services access and usage

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Abstract: Understanding cybersecurity role in digital and online services expansion is of interest to firms, academic research, as well as public policies aiming at supporting economic development. Thus, this paper aims to assess whether improved cyber security can affect the trust needed by online services markets participants to reduce observed international differences in several dimensions of the digital economy and society. Furthermore, we explore the extent to which our results are especially relevant for countries in early stages of their mobile communications networks. We combine data, at the national level, from the 2017 SIR regional reports with broader information data from the ITU cybersecurity index for the period 2014-2021 to obtain empirical evidence on the relationship between cyber security and digital and online services expansion at the country level. We find a negative relationship between citizens, government and businesses' overall digital adoption and cyber insecurity at the country level. Furthermore, we extend this result to the relationship between cybersecurity and content access and online services diffusion. The results confirm that, in addition to other socioeconomic variables, cybersecurity is an important factor explaining the observed worldwide disparities in the studied dimensions of content access and online services access and usage. We also ascertain that cybersecurity role in content access and online services expansion may be less important to understand social media penetration in economies with lower mobile communications connectivity in comparison with more developed ones. By contrast, there seems to exist a similar negative cyber insecurity effect in apps development and availability for all countries regardless of their mobile connectivity development level.

Keywords: cybersecurity; digital divide; socioeconomic inequalities.

Introduction

Internet and overall digital security is among the current public powers main concerns. The debate on the role public institutions can play is still an open matter. Some authors have even proposed that governments should sponsor third party institutions to proactively monitor and publish organizations' security evaluation reports periodically (e.g. He et al., 2015). Additionally, they also defend that it could be necessary and beneficial for all countries that cybersecurity issues be worked on by all countries together, thus taking into account the worldwide scope of Internet insecurity and its negative externalities. Obtaining evidence on the indirect opportunity costs of cyber security can be important to inform public authorities of the magnitude of losses derived from Internet and overall digital insecurity.

Our research follows the World Bank's digital adoption index (DAI) and the European Union's digital economy and society index (European Commission, 2022) by considering simultaneously digital adoption and online services diffusion by firms, citizens and governments. Moreover, digital as well as online services access and usage is commonly viewed as expanding welfare for citizens and companies, as well as increasing the transparency and accountability of public institutions. Thus, governments worldwide put a strong emphasis on their digital and online services promotion initiatives. For example, the EU recently dedicated 127 billion euros to digital related reforms and investments (European Commission, 2022).

Cyber security is among the important factors that final users consider when assessing the value, they put in digital services, content access and online services adoption and usage. It is a crucial element to consider in this context. When these services are combined with higher levels of cybersecurity, they have a higher value and these services are more expanded than in the other cases. The expansion in the adoption of high speed broadband in recent decades created opportunities but also created the risk of vulnerabilities that could jeopardize the value firms, consumers and governments attribute to digital and online services adoption and usage. Can we determine how much of the value of these services is dependent on increased cybersecurity? The main question in this study is just whether cybersecurity may have an effect on the country-level digital and online services adoption. Economic literature has been showing the importance of several market failures in overall digital markets. Their main consequences (which could justify regulation of these markets) pointed out in previous studies are observed as suboptimal levels of investments in infrastructure; insufficient provision of digital skills; lack of use of Internet services and integration of digital technologies and in network security (Gruber, 2019), among others. Accordingly, this study's main objective is to shed some light on this last dimension by assessing how cybersecurity can be salient in explaining international differences in several dimensions of digital and online services diffusion at the country level.

In the last decade, mobile phones increasingly replaced all other Internet terminals, many services moved to the cloud and social networks expanded worldwide. This trend was closely followed by an expansion of cybercrime and overall cyber insecurity. For example, Anderson et al. (2013) estimated that spam might have cost the US industry about one billion dollars a year. Related literature postulates that cyber insecurity is partially due to underinvestment, which is commonly attributed to distorted incentives, namely incentives associated with asymmetric information, network externalities or moral hazard issues (Anderson 2002; Bauer and van Eeten, 2009). Moreover, a substantial fraction of cybercrime's overall costs to society may be viewed as indirect opportunity costs, resulting from unused digital and online services. Thus, the importance we give to the topic in this paper.

In this paper, our first research objective is to test whether cybersecurity can have a role in explaining observed international differences in digital and online services expansion and additionally we want to contribute to the literature that explores the digital divide across countries. Aiming at obtaining results for this last objective, we test if the above-mentioned cybersecurity role is similar across countries exhibiting different levels of mobile communications networks development.

We start by using linear regression models and a data set of 97 countries for the period 2016–2019, in which cybersecurity levels, at the country level, are based on the Microsoft SIR regional

reports available. This first part of our analysis tests the impact that cyber insecurity can have on digital adoption at the country level for three main dimensions considered in the World Bank's DAI: people, business and government. In the remaining parts of the paper, we use the publicly available 2014-2021 BSMA Intelligence Mobile Connectivity Index (MCI)'s database to answer questions such as: Can cyber insecurity affect citizen's use of virtual social networks such as Facebook, Twitter or LinkedIn? Is cyber insecurity important to explain Mobile Social Media penetration? Do countries exhibiting higher scores in cybersecurity also perform better in apps availability and development? Is cybersecurity important to explain new digital businesses such as new apps and, especially, apps developed in national languages? Overall, our aim is to add new empirical evidence to the study of the observed international differences in several dimensions of digital and online services diffusion. Furthermore, we explore the extent to which our results depend on countries' mobile communications networks development levels.

The remainder of this paper is organized as follows: The next section gives an overview of the related literature and the evidence available for this topic. Subsequently, we describe our data and present some descriptive evidence for our sample. The fourth section presents our regression estimation results concerning the determinants of several dimensions of the digital and online services adoption and the causal relation between these services and cybersecurity. Finally, the last section concludes.

2. Literature Review and Hypotheses to be tested

Recent literature has dedicated much effort to finding which are the main factors that determine digital and online access, usage, and related outcomes in general (a summary can be found in Lythreitis et al., 2022), including the assessment of public and private initiatives that help understand that many less developed countries are lagging behind in digital inclusion (Cariolle, 2021). Simultaneously, the importance of this topic is also growing because big firms as well as small and medium sized enterprises (SMEs) are increasingly taking advantage of digital globalization and increasingly using digital platforms such as eBay, Amazon, Facebook or Alibaba to connect with foreign clients and suppliers. Moreover, even small start-ups are now more often than ever seen as global firms more quickly as they can exploit digital platforms in order to accelerate their globalization processes (Etemad, 2022). Eventually, also e-participation by its iterative nature for both enterprises and citizens may contribute to a more collaborative environment between public authorities and their stakeholders, reducing informal economic activities and thus stimulating economic development (Sacchi et al., 2022). Thus, studying the digital divide between developed countries and the others has been receiving careful attention from economic literature (e.g.; Vimalkumar et al., 2021; Sawadogo, 2021; Bastianin et al., 2018; Hübler and Hartje, 2016; Paunov and Rollo, 2016; Howard and Mazaheri, 2009, among others).

However, the topic of the potential convergence of higher cybersecurity with higher digital and online services adoption by citizens, firms and government has received relatively less attention. Cybersecurity emerges as a crucial element to consider, for example, when it becomes decisive to protect data from cybercrime and this in turn may require more governments' international coordination to deal with it. In recent decades, economics literature has been studying the cybersecurity markets and their overall impact on the economy. In line with these broad objectives,

this paper aims to examine especially the relationship between cybersecurity and digital and online services expansion at the country level. Despite the existence of an already vast literature on the digital divide across countries, further evidence on the impact that cyber insecurity can have on digital and online services diffusion can be important to inform public policies aiming at reducing the digital divide across countries.

The World Bank (World Bank, 2016a; 2016b) emphasizes that the benefits of new digital technologies present considerable disparities among countries with less developed economies and regions lagging behind in high-speed internet. Academic literature has analyzed the digital divide at micro, regional, and macro levels, studying issues such as the definition and measurement of the digital divide or the study of the determinants of digital platforms penetration and diffusion. Our approach aims at extending the understanding of digital divides at the country level with a particular focus on digital and online services distribution across countries.

In general, economic literature usually explained technology diffusion disparities as the result of supply and demand forces that reflect the economic and social structure and countries' development levels (Mubarak et al., 2020; Drouard, 2011, Chinn and Fairlie, 2006; Antonelli, 2003). Among the studied above mentioned forces and their links to digital adoption at the country level, a country's income and education system have been playing a crucial role in the analysis.

This literature has demonstrated the importance of several socioeconomic variables for attenuating the different levels of the digital divide, with an important focus on the level of education and digital and non-digital skills both in absolute terms and as inequalities (Billon et al., 2021). Theoretical models from the economics literature have demonstrated the importance of human capital to adopt and use new technologies. The educational level has been traditionally considered as a significant determinant of digital and online services adoption (Scheerder et al., 2017; Robles et al., 2015 and Bonfadelli, 2002).

Furthermore, when analyzing Internet diffusion, several authors (among them Hargittai, 1999 or Kiiski and Pohjola, 2002) analyzed the diffusion of the Internet, finding that GDP per capita, education levels, English proficiency, and university education are crucial to Internet expansion. Most previous studies consider income level measured by gross domestic product (GDP), or gross national income (GNI) per capita, as an Internet diffusion factor, and except for studies such as Garcia-Murillo (2005) or Lee and Brown (2008), past literature has shown that GDP/GNI per capita has an effect on Internet diffusion. The first studies, published before the mid two-thousands measured the number of Internet hosts as a proxy for broadband or Internet diffusion. After that, analysis tended to use broadband subscribers or penetration as a proxy for Internet diffusion and the number of Internet hosts as a proxy for digital content instead (Garcia-Murillo, 2005; Lee and Brown, 2008). In a similar vein, in this paper, we consider digital and online services diffusion as dependent variables. Thus, we conjecture that,

H1: Education level measured as tertiary education enrolment rate (%) is likely to have a positive impact on digital and online services expansion at the country level.

H2: GDP (or GNI per capita) is likely to have a positive impact on digital and online services expansion at the country level.

H3: Income inequality (Gini index) in a country is likely to have a positive impact on digital and online services expansion at the country level.

More closely related to our analysis, Riek et al. (2015) obtained evidence of a negative impact of cyber insecurity (when measured by the perceived risk of cybercrime) on the usage of three categories of online services, namely online banking, online shopping and online social networking. These authors also studied the role of cybercrime experience as an antecedent of perceived risk of cybercrime. They found evidence for a negative impact of perceived risk of cybercrime on the usage of online services and showed that the biggest impact is on the avoidance of online shopping.

In our study we consider a slightly different perspective more in line with the segmentation used in the worldwide index developed by the World Bank, the DAI index, originally constructed as part of the World Development Report 2016 (World Bank, 2016a; 2016b), that measures countries' digital adoption across three dimensions of the economy: people, government, and business.

Taken the above arguments into account, we conjecture that

H4: The level of cybersecurity at the country level is likely to have a positive impact on digital and online services expansion at the country level.

Related literature's results indicate that consumer perceptions, evaluations and adoption intentions may differ depending on perceptions of inherent usage risks. Increased levels of perceived risk tend to lead to information search and reliance on trusted others for assistance in consumers' choices (Kharlamov and Pogrebna, 2021; Ferreira, 2018; Dinev et al., 2009 or Featherman and Fuller, 2003). In a world where some countries are still in the very early stages in digitizing, this aspect can be particularly important to consider.

Internet access costs and telecoms markets competition_(Hargittai, 1999 or Kiiski and Pohjola, 2002) have been pointed out as crucial factors to explain overall Internet access and usage. Related evidence showed that broadband is more likely to be available in high-income countries and population size and market competition may have a considerable impact. The studies using digital content as an independent variable indicate that digital content has a positive effect on broadband diffusion. Lee and Brown (2008) also pointed out that high levels of platform competition can be associated with high levels of fixed-broadband penetration for developed countries, but the effects of platform competition are not overall statistically significant in OECD countries. This result means that the effects of platform competition are decreasing when the broadband market size is sufficiently large or the broadband market is mature.

Furthermore, Andrés et al. (2010) have shown that the internet diffusion has a different curve in each income country group. Their results suggest a lack of long-term convergence in Internet diffusion between low-and high-income countries. We consider these results by testing in our analysis the existence of different main effects between countries with more developed communications networks and the other countries. Another important finding of the above-mentioned work is that the degree of competition in the provision of the Internet contributes positively to its diffusion. Consequently, in our models we test the validity of this relationship between the degree of market competition and the digital and online services expansion at the country level. Generally, competition in network service industries has been identified as an important factor for promoting broadband diffusion by many previous studies, such as, Ovington

et al. (2017), Yates et al. (2015), Lin and Wu (2013) or Lee et al. (2011). Accordingly, based on this evidence, we conjecture that,

H5: Internet access costs (e.g. fixed and mobile broadband prices) are likely to have a negative impact on digital and online services expansion at the country level.

H6: The degree of markets competition is likely to have a positive effect on digital and online services expansion at the country level.

In the reviewed literature a gender gap in communications networks' participation is also tested as having an impact in digital and online services adoption. For example, Efobi et al. (2018) stated that as women's participation in labor markets increases their interest in mobile broadband services also improves. Moreover, female spouses are commonly considered as having a leading role in household communications networks' subscription decisions (Dwivedi and Lal, 2007 and Choudrie and Lee, 2004). Furthermore, the gender gap ratio for social media use (female/male ratio) has been traditionally associated with an increase in mobile communications networks expansion (GSMA, 2022b). Summing up, we hypothesized that as more women in a country participate in social media networks, digital and online services adoption and usage increases in that country.

H7: A reduction in the gender gap ratio for social media is likely to have a positive effect on digital and online services expansion at the country level.

Another dimension of digital adoption usually explored in the literature is service quality. Based on a sample of OECD member states analyzed in the period from 2008 to 2010, Rohman and Bohlin (2012) estimated that doubling the internet download speed can contribute on average to a 0.3 percent increase in annual income at the country level. Moreover, Savage and Waldman (2005) studied United States household Internet use based on survey data and find that speed and reliability of broadband connections were key determining factors for willingness to pay for better Internet service.

Thus, we conjecture that:

H8: Mobile download/upload speed is likely to have a positive effect on digital and online services expansion at the country level.

Previous studies often found evidence that low population density and lower proportion of urban areas can contribute to explaining regional disparities in broadband diffusion. Telecommunications firms tend to focus their operations on urban areas due to low rollout cost and high profit potential. Rural areas are usually associated with lower profits for these companies due to the higher costs of rural connections (Grubestic (2012) or Hill et al., 2014). Furthermore, several authors (e.g. Viard and Economides, 2015) showed that urbanization played a positive role in broadband adoption. In addition, Silva et al. (2018) showed that as urban areas are usually viewed as having more consumers who are more educated and richer than those in rural areas, urbanization ratios can be positively correlated with broadband adoption rates.

Accordingly, we conjecture that:

H9: Population density in a country is likely to have a positive impact on digital and online services expansion at the country level.

H10: The percentage of urban areas in a country is likely to have a positive impact on digital and online services expansion at the country level.

Dobson et al. (2013), Prieger (2013) as well as Teklemariam and Kwon (2022) emphasized the importance of mobile broadband coverage as a supply constraint that limits the percentage of the population who can get access to this service. A country's mobile broadband subscription rate tends to increase as mobile broadband coverage expands. Even in developed economies, there may be some coverage (supply) gaps.

Simultaneously, spectrum is also an indispensable resource for mobile broadband service provision as connection speed is limited by bandwidth (Lundborg et al., 2012; Kwon et al., 2017). Thus, this study hypothesizes that spectrum per operator in MHz is likely to have a positive impact in digital adoption.

Therefore, we conjecture that

H11: Mobile communications networks' 4G coverage is likely to have a positive impact on digital and online services expansion at the country level.

H12: Spectrum per operator in MHz is likely to have a positive impact on digital and online services expansion at the country level.

Governmental policies aiming at digital and online services promotion based on communicating and persuading the citizens of the merits of internet adoption and usage are also among the factors recent literature has been testing as having a positive effect on digital and online services adoption (Gulati and Yates, 2012; Yates et al., 2013 and Teklemariam and Kwon, 2022). Kyriakidou et al., (2013) found that also e-government online availability can help promoting broadband diffusion. Moreover, Teklemariam and Kwon (2020) when analyzing the importance of e-government services quality for mobile broadband adoption found that it has strong and moderate positive effects respectively in the fast diffusion and saturated stage of mobile broadband adoption

Therefore, we conjecture that

H13: Higher quality in e-government services is likely to have a positive impact on digital and online services expansion at the country level.

After running several regressions and testing the importance of the above-mentioned digital adoption and online services determiners for digital adoption and online services adoption and use, we excluded market concentration, urban population and population density from our main reference models due to persistent violations of the regressions assumptions or to lack of significance for several of the models in use. Thus, income and income inequality, fixed and mobile broadband prices, 4G coverage, broadband speed, spectrum in 1-3GHz bands (MHz per operator), tertiary enrolment rate, gender gap in social media usage, e-government quality of service, are used here as control variables to explain digital adoption and online services expansion. Regarding our model's dependent variables, we split digital adoption into three main categories: people, business and government following the categories presented in the World Bank's DAI index. For

the online services regressions we used MCI index's indicators for apps (development and availability) and social media penetration as proxies for online services adoption and usage. As stated before, for our independent variable of interest, cybersecurity, we start with data from the Microsoft SIR regional reports in the first part of the study followed by a broader cybersecurity measure published in ITU global cybersecurity index' reports (which are publicly available in <https://www.itu.int/en/publications/ITU-D/pages/publications.aspx?parent=D-STR-GCI.01-2021&media=electronic>).

3. Data and Methods

In order to analyze whether cybersecurity can have a role in explaining international differences in digital adoption and online services expansion at the country level, this paper uses a sample consisting of more than 170 countries observed in the period 2014-2021. The World Bank's DAI index scores (World Bank, 2016) in its three subcategories: people, business and government as well as the number of apps in a national language, apps developed per person and social media penetration (from the Mobile Connectivity Index reports (GSMA, 2022)) are used here as dependent variables in order to capture countries' digital adoption and online services' expansion.

Moreover, our approach considers several alternative measures for cyber insecurity. Among them malicious and unwanted software as well as security software usage data are extracted from the regional database published in Microsoft SIR Reports (which are available online at <https://www.microsoft.com/en-us/security/business/security-intelligence-report>). For the majority of the countries, *trojans* and *worms* are the most common malicious software encountered in observed computers. The percentage of computers where this malicious software was encountered was considered here as giving us information on the severity of cyber insecurity in the observed country. Similarly, unwanted software categories such as *browser modifiers*, *software bundlers* and *adware*, are also included in our analysis as the percentage of computers where it was found aiming at giving us information on the severity of cyber insecurity in the observed country. In addition, secure software use was considered and gives us information on the percentage of computers that the MSRT found to be running up-to-date real-time security software.

Additionally, our study also uses the ITU global cybersecurity index as a measure for cyber security in our panel data regression models (results presented in Tables 7 and 8) as more recent SIR reports are not publicly available at the regional level. Moreover, to complete the models, data is collected on all the factors mentioned in the hypotheses described in the previous section 2 as having an impact on countries' digital adoption and online services' expansion. All the variables used in the analysis and corresponding data sources are listed in Table 1. There, it can be seen that our empirical methodology exploits information on several economic factors such as the GDP and GNI per capita (H2), Gini index (H3), Internet access costs (ITU Fixed and mobile-broadband sub-baskets as % of GNI p.c) (H5) and the degree of markets competition (HH Market concentration index) (H6). The state of the country's infrastructures relevant for mobile connectivity is also considered here and it is measured by 4G mobile broadband coverage (H11), mobile broadband upload speeds) (H8), as well as the spectrum in 1-3GHz bands per operator (H12). Society's characteristics such as the population education (measured as tertiary enrollment rates – H1), gender gap in social media participation (H7), population density (H9), the percentage of urban

areas (H10) are tested as significant factors important to explain variations in our dependent variables. Finally, e-government quality performance (H13) is among our models' independent variables.

Table 1: Data sources and Variables description

	Variable	Description	Source
Online services:	AppFlag	Percentage of population with access to apps in national language	GSMA Intelligence
	Apps	Percentage of population with access to apps	GSMA Intelligence
	Socialmedia	Percentage of population using Mobile Social Media	GSMA Intelligence
Digital Adoption	Digital Adoption (DAI)	Digital adoption index and its 3 subcategories: DAI (Businesses); DAI (People); DAI (Governments).	World Bank DAI index
Cyber security variables	(MS) Trojans	% computers encountered with Malicious software (MS) Trojans	Microsoft SIR Regional Report
	(MS) Worms	% computers encountered with Malicious software (MS) Worms	Microsoft SIR Regional Report
	(US) BModifiers	% computers encountered with Unwanted software (US) Browser Modifiers	Microsoft SIR Regional Report
	(US) Bundlers	% computers encountered with Unwanted software (US) Software Bundlers	Microsoft SIR Regional Report
	(US) Adware	% computers encountered with Unwanted software (US) Adware	Microsoft SIR Regional Report
	SecSoftUse	% computers MSRT found to be running up-to-date real-time security	Microsoft SIR Regional Report
	CyberSec	ITU Global Cybersecurity Index (H4)	GSMA Intelligence
Control variables	Skills	Education level Tertiary education enrollment rate (%) (H1)	GSMA Intelligence
	Income	Logarithmic transf. of GDP or GNI per capita (in \$PPP) (H2)	World Bank Indicators **
	Inequality	Gini index (H3)	World Development Indicators
	FixBBPrices in PPP	Fixed broadband price in PPP dollars (H5)	ITU statistics database
	Entrybasket100MB	Cost of a basket with a 100MB monthly allowance (as a % of monthly GDP per capita) (H5)	GSMA Intelligence
	Mediumbasket500MB	Cost of a basket with a 500MB monthly allowance (as a % of monthly GDP per capita) (H5)	GSMA Intelligence
	Premiumbasket5GB	Cost of a basket with a 5GB monthly allowance (as a % of monthly GDP per capita) (H5)	GSMA Intelligence
	HHI	the degree of markets competition (HH Market concentration index HHI (0= not concentrated, 1= highly concentrated) (H6)	WITS: https://wits.worldbank.org
	Female	Gender gap in social media participation (H7)	GSMA Intelligence
	Mobspeed	Internet upload speed Mobile broadband (Megabits per second, Mbps) (H8)	GSMA Intelligence
	PopDens	Population density The number of people per land area of the country (H9)	IMF: https://data.imf.org
	Urban	Percentage of people residing in the urban areas to the total population (H10)	World Bank https://data.worldbank.org/indicator
	4Gcoverage	Mobile broadband 4G technology coverage % of total population covered (H11)	GSMA Intelligence
	Spectrum	Spectrum allocation in bands 1 to 3 GHz per operator (MHz) (H12)	GSMA Intelligence
	E-government	UN Online Service Index score for E-Government (H13)	GSMA Intelligence

* World Bank, the DAI index. Long form DAI data available in <https://www.worldbank.org/en/publication/wdr2016/Digital-Adoption-Index>. **Gross Domestic Product and Gross National Income are extracted from World Bank website in <https://data.worldbank.org/indicator>. ITU statistics database available in <https://www.itu.int/en/ITU-D/Statistics>

We use cluster analysis for assessing the similarities and differences of cybersecurity provision in the observed countries located across the globe. The k-means clustering method is used to split observations in groups and obtain a ranking of countries in terms of cyber security provision's performance. Thus, this approach gives us information on which countries share similar levels of cybersecurity on their communications networks and allows for the assessment of the main

disparities across countries, when SIR reports data are used as a proxy for cyber security at the country level. The corresponding results are shown in Tables 3 and 4.

Furthermore, in order to test the importance of cybersecurity for the diffusion of overall digital technologies across countries (when measured by the Digital Adoption Index) we use ordinary least squares and generalized least squares regressions (results are in Table 5). The variables *Rank i group of countries* are dichotomous variables indicating whether the country belongs to the rank i group of countries or not. If cyber security is among the significant factors to consider when explaining digital adoption at the country level, these coefficient estimates should be statistically significant at the relevant significance levels.

In addition, we apply panel data (fixed and random effects) regressions to test whether benefits from increased cyber security provision at the country level can further develop online services adoption and usage (results in Tables 7). We use this framework to validate or not our hypotheses (H1-H13) regarding the importance of cyber security to citizens' use of virtual social networks such as Facebook, Twitter or LinkedIn (mobile social media in our analysis) as well as to promoting new digital businesses such as new apps and especially apps developed in a national language. Overall, our aim here is to add new empirical evidence to the study of the observed international differences in several dimensions of digital and online services expansion.

Furthermore, we explore the extent to which our results may depend on countries' mobile networks development levels. In this section we classified as a Mobile Connectivity Advanced (MC Advanced) country the countries listed in GSMA (2022a) reports as Leaders and Advanced countries, the remaining countries are classified as MCI Other countries (results in Table 8).

Table 2 shows that countries on average performed better in terms of business and government digital adoption than in the cluster of citizens. The sample mean for the overall DAI is 0.64 (on the 0-1 scale) which is higher than the 0.58 exhibited by people's DAI subcategory. The average score for apps available in the country's own language is 61.84 (on the 0-100 scale), the best performing country is the United States of America with a score of 100 for all the eight years analyzed and the lowest scores are exhibited by Afghanistan, Gambia, South Sudan and Timor-Leste whose score is below 2. Similarly, the apps developed score (in percentage of the population) sample mean is 64.65 (on the 0-100 scale), the best performing country is Singapore with a score of 100 for five of the eight years analyzed and the lowest scores are exhibited by Malawi and Sierra Leone whose score is below 2. In the period 2014-2021, the social media penetration scores sample mean is also lower than the previous apps related indicators. Accordingly, it seems that, globally, citizens' participation in the Internet is lower than businesses and governments.

Table 2 shows that, in 2018, a fixed broadband basket with a monthly data usage of (a minimum of) 5GB costs on average 37.72 dollars (in PPP) for the sampled countries but a wide range of values is observed. There are important disparities in prices observed in our sample with the lowest prices observed for China (7.87 PPP dollars) and Nepal (5.38 PPP dollars) and the highest prices for Nigeria (81.63 PPP dollars), Pakistan (82.65 PPP dollars) and Qatar (108.09 PPP dollars).

Table 2: Sample's descriptive statistics

Variable	N	Mean	Std.Dev.	Min	Max
DAI	93	0.64	0.14	0.26	0.87
DAI Business	94	0.68	0.15	0.28	0.97
DAI People	94	0.58	0.19	0.16	0.91
DAI Government	93	0.65	0.15	0.23	0.98
MSTrojans	97	9.13	5.00	1.86	22.28
MSWorms	97	2.38	2.85	0.01	14.05
USBModifiers	97	2.60	1.89	0.32	10.26
USBundlers	97	1.56	1.14	0.15	8.06
USAdware	97	0.20	0.09	0.01	0.44
SecSoftUse	97	85.23	4.04	73	92
FixBBPrices in PPP	92	37.72	17.59	5.38	108.09
logGDP percapita	94	10.04	0.81	8.15	11.52

Variable	N	Mean	Std.Dev	Min	Max
AppFlag	1360	61.84	25.00	2.69	100
Apps	1326	64.65	21.96	0.57	100
Social media	1360	41.37	26.20	0.82	100
Cybersec	1352	44.18	29.37	0.23	100
Skills	1360	40.25	27.30	0.59	100
log GNI percapita	1308	9.35	1.17	6.52	11.83
Inequality	1297	56.54	19.59	0.50	100
Entrybasket100MB	1287	45.34	22.53	0.05	100
Mediumbasket500MB	1272	50.86	24.25	0.31	100
Premiumbasket5GB	1239	52.26	25.13	0.12	100
Female	1308	71.49	31.30	0.00	100
Mobspeed	1355	33.12	25.06	1.88	100
4Gcoverage	1186	71.25	30.96	1.00	100
Spectrum	1360	53.26	25.45	3.75	100
Egovernment	1356	54.51	26.15	0.79	100

Results and Discussion

Aiming at obtaining evidence of international differences in citizens access to cybersecurity at the country level, we explore a rich data set published by Microsoft (regional reports are available online in <https://www.microsoft.com/en-us/security/business/security-intelligence-report>), which is based on data collected by Microsoft (known as SIR reports) from users of its security products. Rates of computers' malware infections, unwanted software and the percentage of computers found to be running up-to-date real-time security software are collected from this source. We start this section by exploring these cybersecurity data.

These variables are chosen to perform our cluster analysis because they reflect the level of cybersecurity provision and they are comparable for countries and regions of different size and population. Cluster analysis can be a useful exploratory data analysis tool as it enables us to arrange observations into groups that can be further analyzed; it is a common process of finding out unknown group profiles. Our aim is to use cluster analysis for supporting a discussion of the similarities and differences of cybersecurity provision in countries across the globe. The k-means clustering is used to split observations in groups and this help us testing what the main characteristics of these groups are. Thus, this approach gives us information on which countries share similar levels of cybersecurity on their communications networks and allows for the assessment of the main disparities across countries.

The results of cluster analysis are presented in Table 3 and the corresponding descriptive statistics are shown in Table 2. Following these results, cluster 1 has the lowest rates of malicious and unwanted software and the highest rates of computers found to be running up-to-date real-time security software and consequently we can infer that this group includes the countries with better performing communications networks in terms of cybersecurity provision.

This cluster is also the largest of our sample and includes 55 countries. Cluster 2 can be viewed as consisting of countries with moderate levels of cybersecurity because, on average, countries in this cluster have higher rates of malicious software and unwanted software present in computers and lower defense rates than cluster 1, but still have a better performance than the one observed for cluster 3. This last cluster includes the 27 countries with the worst performance in terms of the considered cybersecurity indicators.

Table 3: Countries ranked by Cybersecurity Cluster Analysis' results

Cluster Analysis* Ranking based on SIR's data (2017)	Countries (n=97)
<i>Rank 1</i> group of countries (n=55)	Argentina; Australia; Austria; Belgium; Bulgaria; Canada; Chile; China; Colombia; Costa Rica; Croatia; Cyprus; Czech Republic; Denmark; Dominican Republic; El Salvador; Estonia; Finland; France; Germany; Greece; Hong Kong; Hungary; Iceland; Ireland; Israel; Italy; Jamaica; Japan; Korea; Kuwait; Latvia; Lithuania; Malaysia; Mexico; Netherlands; New Zealand; Norway; Panama; Poland; Portugal; Puerto Rico; Singapore; Slovakia; Slovenia; South Africa; Spain; Sweden; Switzerland; Taiwan; Trinidad and Tobago; United Arab Emirates; United Kingdom; United States and Uruguay.
<i>Rank 2</i> group of countries (n=18)	Brazil; Ecuador; Georgia; Guatemala; Honduras; India; Kenya; Lebanon; Oman; Paraguay; Peru; Qatar; Romania; Russia; Saudi Arabia; Serbia; Thailand and Turkey.
<i>Rank 3</i> group of countries (n=24)	Albania; Algeria; Bangladesh; Belarus; Bolivia; Egypt; Indonesia; Iraq; Jordan; Kazakhstan; Moldova; Morocco; Myanmar; Nepal; Nigeria; Pakistan; Palestinian Authority; Philippines; Senegal; Sri Lanka; Tunisia; Ukraine; Venezuela and Vietnam.

* clusters obtained using the k-means cluster analysis with Euclidean distance as similarity/dissimilarity measure. Data come from Microsoft Intelligence SIR regional 2017 reports (vol22: January through June 2017 (Microsoft.com, 2017a) and vol23: July through December 2017 (Microsoft.com, 2017b)).

It is worth noting that in cluster 1, from the 55 countries included, 45 are classified as high-income countries (in the 2017 World Bank's list corresponding to economies whose gross national income (GNI) per capita, calculated using the World Bank Atlas method, was 12,056 US dollars (\$) or more¹). By contrast, there are only two low-income economies (in this context, a low-income country has (GNI) per capita of \$995 or less) in our data set, namely Nepal and Senegal.

Table 4 shows the descriptive statistics with means, standard deviations, maximum and minimum values for the SIR's cybersecurity data present in our sample. According to the results presented in Table 4, there are important differences in software security among the observed countries. For example, the percentage of computers with *Trojans* malicious software encountered for cluster 1 is very close to the minimum value attained for cluster 2. Cluster 1 countries perform better than all other countries in terms of the dimensions of security analyzed here. The mean percentage of computers found to be running up-to-date real-time security software in cluster 1 is above the maximum value found in cluster 2 countries. Countries in cluster 3, for all indicators, register minimum values of malicious and unwanted software that are worse than the mean values for

¹ Information published online, e.g. in https://www.esicm.org/wp-content/uploads/2018/11/CountriesClassment_WBC.pdf

cluster 1 (for example, on average, 4.53% computers were found with *Trojans* in ranking group 1 of countries but for cluster rank 3 the minimum registered percentage is as high as 10.14%).

Table 4: Descriptive statistics for SIR data presented by Clusters

	% of computers encountered with						SecSoftUse ^a
		Malicious software (MS) category:		Unwanted software (US) category:			
Ranking Group		Trojans	Worms	Browser Modifiers	Bundlers	Adware	
Rank 1 group of countries (n=49)	Min	1.43	0.01	0.44	0.09	0.01	86
	Mean	4.53	0.25	1.65	0.69	0.12	89.27
	(Std.Dev)	(1.82)	(0.27)	(0.90)	(0.41)	(0.07)	(1.56)
	Max	9.11	1.07	7.47	2.09	0.38	94.2
Rank 2 group of countries (n=21)	Min	4.43	0.04	0.32	0.28	0.01	78.7
	Mean	9.50	1.79	2.74	1.38	0.16	84.01
	(Std.Dev)	(2.46)	(1.31)	(1.10)	(0.76)	(0.08)	(2.52)
	Max	14.79	5.70	7.02	5.01	0.44	89
Rank 3 group of countries (n=27)	Min	10.14	0.20	2.2	1.38	0.07	73
	Mean	15.83	5.00	4.60	2.78	0.22	81.6
	(Std.Dev)	(3.12)	(3.21)	(2.06)	(1.22)	(0.96)	(3.34)
	Max	22.28	14.05	10.26	8.06	0.4	87
Total	Min	1.43	0.01	0.32	0.09	0.01	73
	Mean	8.06	1.55	2.50	1.26	0.15	86.24
	(Std.Dev)	(4.71)	(2.26)	(1.61)	(1.04)	(0.09)	(3.87)
	Max	22.28	14.05	10.26	8.06	0.44	94.2

^a SecSoftUse is the percentage of computers found to be running up-to-date real-time security software

Summing up the results presented in Tables 3 and 4, there are important disparities in cybersecurity provision across countries worldwide and consequently there are significant disparities in citizens, governments and firms' access to cybersecurity. In order to analyze the consequences of these inequalities on the degree of online services adoption and usage, we next consider the information provided by the World Bank's digital adoption index (DAI). Combining these data with our findings on cybersecurity provision's disparities across the world, we can explore the possible positive relationship between cybersecurity and digital adoption at the country level.

The DAI was constructed as part of the World Development Report 2016: Digital Dividends to measure the diffusion of digital technologies across countries. The Digital Adoption Index (DAI) is a composite index measuring the extent of spread of digital technologies within and across countries. The importance of this index to our analysis lies in the fact that it includes several dimensions of network communications activities which are relevant for studying online services adoption and usage such as: mobile and Internet access, secure Internet servers, download speed, business' websites, 3G coverage, online public services and the digital identification. Thus, knowing the impact of cyber insecurity on the DAI at the country level can be informative when public authorities want to clarify if cybersecurity is among their countries' barriers to innovation or not.

The DAI holds two advantages over existing indices: it reflects the extent to which digital technologies are available and adopted by all the key agents in an economy: people, businesses (firms), and governments, and uses data on coverage and usage, often coming from the World Bank's internal databases rather than being affected by citizen's subjective perceptions.

The World Bank's DAI index covers 180 countries classified on a zero to one scale, and emphasizes the "supply-side" of digital adoption. The overall DAI is based on three sectoral sub-indexes covering businesses, people, and governments, with each sub-index assigned an equal weight: DAI (Economy) = DAI (Businesses) + DAI (People) + DAI (Governments). Each sub-index is the simple average of several normalized indicators measuring the adoption rate for the relevant groups (World Bank, 2020). Thus, the DAI (Business) is the simple average of four normalized indicators: the percentage of businesses with websites, the number of secure servers, the download speed, and mobile network's 3G (third-generation) coverage in the country.

Moreover, the DAI (People) is the simple average of two normalized indicators from the Gallup World Poll: mobile access at home and internet access at home. Finally, the DAI (Governments) is the simple average of three normalized sub-indexes: core administrative systems, online public services, and digital identification. Data for online public services come from the UN's Online Service Index; the World Bank compiled data for core administrative systems and for digital identification (for the World Bank's Digital Dividend Report).

An important limitation of our study lies in the limited data availability (digital adoption index only available for 2014 and 2016). Accordingly, in Table 5 regressions we assume that DAI is stable in the short run and thus remains invariable between 2016 and 2018, the year for which the remaining data was collected. Moreover, in order to mitigate the endogeneity issue between the digital adoption rates and cyber security, the cyber security data was lagged by one year in our analysis. Accordingly, data for cyber security is relative to year 2017 and the other variables in Table 5 are for 2018.

Table 5: Relationship between CS provision and the Digital Adoption Index

VARIABLES	(1) Digital Adoption Index	(2) DAI Business • Subindex	(3) DAI People • Subindex	(4) DAI Government • Subindex
Fix BB Prices in PPP	-0.0008** (0.0004)	-0.0005 (0.0004)	-0.0011** (0.0004)	-0.0008 (0.0008)
logGDP percapita	0.1313*** (0.0114)	0.1296*** (0.0117)	0.2078*** (0.0131)	0.0578** (0.0252)
Rank 2 group of countries	-0.0489** (0.0189)	-0.0753*** (0.0182)	-0.0590*** (0.0219)	-0.0132 (0.0419)
Rank 3 group of countries	-0.0533** (0.0217)	-0.0853*** (0.0241)	-0.0212 (0.0252)	-0.0534 (0.0480)
Constant	-0.6228*** (0.1210)	-0.5596*** (0.1220)	-1.440*** (0.1400)	0.1222 (0.2680)
Observations	90	91	91	90
R-squared	0.808	0.793	0.866	0.189

a DAI (Business) is the simple average of four normalized indicators: the percentage of businesses with websites, the number of secure servers, the download speed, and mobile network's 3G (third-generation) coverage in the country.

b DAI (People) is the simple average of two normalized indicators from the Gallup World Poll: mobile access at home and internet access at home.

c DAI (Governments) is the simple average of three normalized sub-indexes: core administrative systems, online public services, and digital identification.

Note: Fixed BB Prices in \$PPP collected from the ITU database for 2018 and log GDP per capita extracted from World Bank's World Development Indicators for 2018. CS rankings based on 2017 data from SIR report, thus CS variable is lagged one year, assuming that DAI₂₀₁₈=DAI₂₀₁₆ for all countries in the sample.

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Identifying the relevant determinants of Digital Adoption appears to be an important way for governments to stimulate economic activity. Digital transformation has been identified as having effects on both innovation and entrepreneurship (e.g. Nambisan et al., 2019). Simple models explaining Digital Adoption based on prices, income and the countries' clusters results are shown in Table 5. Prices are the fixed broadband prices in PPP dollars published in ITU databases and GDP per capita PPP dollars extracted from the World Bank Indicators.

The estimation results in Table 5 show the importance of cybersecurity to the diffusion of digital technologies across countries as measured by the Digital Adoption Index. The importance of Internet security seems to be higher for the business and people's dimension as the coefficient estimates for cybersecurity are statistically significant at 5% significance level in the first three columns of Table 5. Better security performing countries tend to exhibit higher levels of the overall DAI and firms and citizen's digital adoption seem to increase with increases in countries cybersecurity ranking level (based on the negative signs of the coefficient estimates for rank 2 and 3 groups of countries in models 2 and 3's estimation results).

In table 5, model 1's coefficient's estimates indicate that there is evidence that rank 3 group of countries and rank 2 group of countries differ from group 1 (cluster rank 1) by -0.064 in terms of overall digital adoption, and that this difference is significant at the 1% level. Thus, countries with higher levels of cybersecurity tend to, on average, exhibit more digitization of their economies and societies than the other countries. As the reported coefficients for CS measure the differences from group 1 (Cluster rank #1) we can state that there is evidence that group 2 (cluster rank 2) differs from group 1 (cluster rank 1) by -0.075 and -0.059 for firms and citizen's digital adoption respectively, and that differences are significant at the 1% level. Regarding group 3, it is important to separate firms and people's digital adoption. In peoples' digital adoption, group 3 is not significantly different from group 1 but this difference is relevant and equal to -0.085 for firms' digital adoption and this difference is significant at the 1% level. Considering these results, cybersecurity impacts on digital adoption may differ when we analyze e.g. social media or social networking (examples of people's dimension of digital adoption) or when we instead analyze firms' digital adoption (business digital adoption in Table 5' column 2).

In the rest of the paper, we give more emphasis to the citizens and firms above-mentioned dimensions of digital adoption. Based on publicly available MCI database (GSMA, 2022b) we further run several regressions in which we test the validity of the hypothesis that cybersecurity is among the relevant determinants of firms and citizen's participation in online activities. From the myriad of current online services provision, we select mobile apps development (lines 1-2 in Table 6) and mobile social networking (line 3 in Table 6) to measure online services access and usage.

The MCI measures the enablers of mobile Internet connectivity, giving us information on the current and future online services access and usage. GSMA Intelligence considers four key enablers, namely infrastructure, affordability, content and consumer readiness. In our study we use the following content and services enablers' indicators: number of active mobile apps developed per person (Apps); number of mobile apps available in a national language (AppFlag), percentage of population using mobile social media (Social media) and Index value (0-1) of the ITU global cybersecurity index (Cybersec) as well as the e-Government services indicator (E-government). From the Infrastructure enabler indicators, we use the following in our models: mobile upload speeds (Mobspeed), 4G network coverage (4Gcoverage) and spectrum in bands 1-3GHz

(Spectrum). In terms of communications affordability we selected mobile tariffs indicators (Entry basket with monthly allowance of 100MB, Medium basket with monthly allowance of 500MB, Premium basket with monthly allowance of 5GB) and Gini inequality indicators. Finally, we use the following data for consumer readiness: tertiary enrollment rates and gender gap ratio indicators. The variable GNI per capita is extracted directly from the World Development Indicators database. The sample descriptive statistics for these data is in Table 6.

In order to analyze whether cybersecurity can affect online services access and usage at the country we use the above-mentioned data consisting of more than 170 countries observed in the period 2014-2021 (results in Table 7). Additionally, we also explore the extent to which our results are especially relevant for countries exhibiting early stages of mobile communications networks (results in Table 8).

Results shown in Table 7 allow us to validate if the effects of cybersecurity provision on apps development and availability as well as on online social media participation are similar to those obtained in Table 5 for overall digital adoption, where we concluded that among the socioeconomic variables to consider cyber security is one of the most relevant. Are countries with lower levels of cyber security provision also underperforming the other countries in terms of their citizens, firms and governments participation in online services access and usage? In Table 7, we can find the estimates for the impact of cybersecurity on each of the dependent variables here being considered (apps development and online social media participation) when ITU cybersecurity index is used as a proxy for cybersecurity provision at the country level.

Moreover, models 1-2's coefficients estimates presented in Table 7 show that better positions in the cybersecurity index (higher cybersecurity provision) positively affects the number of apps developed at the country level. A unitary increase in the ITU cybersecurity index promotes, on average, an increase in the indicator of apps developed per person of approximately +0.03 units and the effect is statistically significant at 1% level. These results seem to indicate that countries' cybersecurity provision may have a role in explaining international disparities in businesses and citizens' adoption and use of online services when we consider apps as a proxy for these services.

Additionally, income, prices, network quality, social media usage, income inequality, skills, gender gap and e-government variables exhibit coefficient estimates statistically significant at least at the 5% level, meaning that these are important factors to consider when analyzing online services expansion at the country level. According to Table 7 results, Internet upload speed (network quality of mobile services) is positively correlated with apps in a national language and mobile social media development dependent variables. These coefficients estimates are positive and statistically significant at the 1% level (results presented in models 3-6). Thus, mobile network quality of service is among the important determiners of apps developed in national languages and in social media penetration. Moreover, the network coverage coefficients estimates are all positive and significant at the 1% level of significance.

The importance of skills development for social media usage (assessed by tertiary enrolment rates) is validated in Table 7's results. Column 5 shows that the skills coefficient's estimate is positive and significant for all relevant significance levels. It is worth noting that, according to the Hausman's specification test, column 5 model (fixed effects) is preferred to the random effects approach in column 6. Under the current specification, the hypothesis that the individual-level effects are

adequately modeled by a random-effects model is rejected ($p\text{-value}=0.000$). Consequently, we infer that countries with more educated citizens tend to perform better in social media penetration.

Based on our models estimates we also find evidence that countries with lower prices for the premium 5GB monthly allowances seem to perform better in terms of apps developed per person. As expected a cheaper access to more allowed data transmission contributes to increased apps development and possibly to innovation performance at the country level. Moreover, this indicate that countries with lower prices in this segment are, on average, in a better position to witness more business efforts to create and develop apps.

For the social media penetration, we cannot reject that the coefficient estimate for the cyber security variable is zero for all relevant levels of significance. Thus, income, network quality and education at the country level seem to be more important than cyber security provision to explain international differences in social media usage.

The reduction in the gender gap in social media exhibits a positive and significant coefficient estimate in models 1-4 of Table 7, indicating that female participation in social media can have an important role to play in online services expansion, namely in apps development and availability. Literature has been pointing out this role, for example Choudrie and Lee, 2004; Dwivedi; Lal, 2007) found that female spouses play a leading role in household broadband subscription decisions. Thus, female participation may eventually influence positively apps development at the country level.

Table 7 also shows that e-government quality when measured by the United Nations' online service index of e-government is important in apps development and availability (models 1-4 of Table 7). Countries performing better in their e-government initiatives tend to perform better in apps development and availability, confirming our expectation that public authorities can create a more positive environment for digital transformation and online services expansion by offering high-quality e-services.

Unsurprisingly, the estimated coefficients, in Table 7, for social media penetration, as an independent variable, are all positive and statistically significant enabling us to infer that the higher expansion of social media networks, the better the country performance is in terms of apps development and availability.

We next consider if the communications networks' development stage is also a significant determiner of apps development and social media expansions (results in Table 8). Benefiting from MCI data classification of countries' mobile connectivity performance, we explore the possibility that cybersecurity effects differ by stage of mobile networks development. In Table 8 we show the estimation results obtained when we split the sample into two main groups of countries. For the more advanced mobile communications group (MC Advanced) we choose countries classified in the last MCI report publicly available (GSMA, 2022b) as Leaders or as Advanced countries. The MCI report classifies as Leaders countries scoring above 75, which generally perform very well across all enablers and have very high levels of mobile internet penetration. Advanced countries are those scoring above 65, which perform well on three enablers and usually have high penetration rates. The remaining countries are included in the MC Other countries group.

Table 6 shows descriptive statistics for both the advanced and the remaining countries groups, classified according to their stages of mobile connectivity. The first columns show statistics for Advanced countries and the second part of the Table shows statistics for the other group of countries. These statistics and the corresponding t test for the difference in means (middle column in Table 6) allow us to understand how different the two groups are across different dimensions of mobile connectivity and other variables present in our study.

Table 6: descriptive statistics for advanced and non-advanced stages of mobile connectivity

Advanced	N	Mean	Std Dev	Min	Max	t test*	Other countries	N	Mean	Std Dev	Min	Max
AppFlag	503	79.00	10.02	49.87	100	22.79***	AppFlag	857	51.77	25.67	2.69	100
Apps	503	84.71	9.51	56.15	100	37.15***	Apps	823	52.39	18.04	0.57	100
Socialmedia	503	63.38	16.49	16.54	100	31.72***	Socialmedia	857	28.44	21.87	0.82	100
Cybersec	503	70.43	20.99	9.80	100	35.06***	Cybersec	849	28.63	21.51	0.23	97.5
Skills	503	66.29	18.98	13.58	100	39.19***	Skills	857	24.96	18.42	0.59	100
log GNI percapita	497	10.45	0.52	9.08	11.54	39.04***	log GNI percapita	811	8.68	0.93	6.52	11.83
Inequality	503	63.90	16.97	10	96.75	11.29***	Inequality	794	51.87	19.72	0.50	100
Entry basket100MB	503	62.27	16.34	12.06	100	27.04***	Entry basket100MB	784	34.47	18.97	0.05	93.87
Medium basket500MB	503	71.26	15.02	29.87	100	33.10***	Medium basket500MB	769	37.52	19.36	0.31	100
Premium basket5GB	503	73.63	15.01	20.22	100	34.79***	Premium basket5GB	736	37.66	19.58	0.12	92.86
Female	501	89.21	21.15	1.24	100	18.01***	Female	807	60.50	31.55	0	100
Mobspeed	503	55.21	23.01	8.56	100	33.87***	Mobspeed	852	20.09	15.11	1.88	88.57
4Gcoverage	503	94.45	8.80	41.21	100	28.91***	4Gcoverage	683	54.17	30.32	1	100
Spectrum	503	73.19	20.64	11.46	100	27.49***	Spectrum	857	41.56	20.21	3.75	100
Egovernment	503	78.82	13.41	35.88	100	37.52***	Egovernment	853	40.18	20.67	0.79	95.14

Data extracted from GSMA Intelligence MCI database (GSMA, 2022b). This data is normalized to adjust for different units of measurement, using the min-max method to transform all indicators. Accordingly, higher values correspond to better performance for each of the variables.

* Based on means' differences t tests we get evidence of significant differences between the two groups' means. For all variables, the means for the advanced and the non-advanced groups of countries are statistically different at the 1% level of significance. For all variables except Spectrum, Skills and Cybersec the equal variance t test was applied supported on the results for the robust tests for equality variances (the Levene, Brown and Forsythe tests).

Based on means' differences t tests we get evidence of significant differences between the two groups of countries' means. For all variables, the means for the advanced and the less advanced groups of countries are statistically different at the 1% level of significance. The Advanced group of countries performed better for all dimensions of mobile connectivity considered here. The advanced group of countries includes almost 80 countries observed in a period of eight years comprised between 2014 and 2021. Countries at different stages of mobile connectivity have indeed different means for all indicators studied. The two groups of countries' means differences seem to be larger (larger t statistic) for apps development ($t=37.15$), cyber security ($t=35.06$), skills ($t=39.19$), income ($t=39.04$) and e-government ($t=37.52$).

Table 7: Regression estimates overall sample

VARIABLES	(1) Apps developed per person (FE)	(2) Apps developed per person (RE)	(3) Number of apps in national lang (FE)	(4) Number of apps in national lang (RE)	(5) Social media penetration (FE)	(6) Social media penetration (RE)
IGNIpc	-1.577 (2.450)	5.206*** (1.031)	4.885** (2.023)	6.411*** (1.391)	19.511*** (5.838)	9.834*** (1.520)
Entrybasket100MB	-0.032 (0.027)	-0.020 (0.028)	-0.040 (0.026)	-0.041 (0.026)	0.068 (0.076)	0.023 (0.064)
Mediumbasket500MB	-0.023 (0.034)	-0.026 (0.034)	0.006 (0.028)	0.006 (0.028)	-0.096 (0.080)	-0.111 (0.074)
Premiumbasket5GB	0.055** (0.021)	0.047*** (0.021)	0.016 (0.017)	0.015 (0.017)	0.071* (0.043)	0.120*** (0.043)
CyberSec (lag1)*	0.029*** (0.010)	0.025*** (0.008)	0.010 (0.007)	0.008 (0.007)	0.018 (0.021)	0.019 (0.022)
4G Coverage	0.114*** (0.012)	0.110*** (0.011)	0.036*** (0.010)	0.033*** (0.010)	0.104*** (0.027)	0.133*** (0.025)
Mobspeed	-0.004 (0.014)	-0.014 (0.011)	0.076*** (0.015)	0.072*** (0.014)	0.401*** (0.037)	0.446*** (0.032)
Spectrum	-0.029 (0.021)	-0.028** (0.018)	-0.013 (0.019)	-0.015 (0.019)	-0.037 (0.053)	-0.095** (0.042)
Inequality	0.020 (0.021)	0.051*** (0.020)	-0.014 (0.019)	-0.017 (0.018)	0.055 (0.051)	-0.055 (0.035)
Skills	0.038 (0.046)	0.066*** (0.031)	0.033 (0.035)	0.044** (0.034)	0.404*** (0.133)	0.104 (0.066)
Female	0.221*** (0.032)	0.194*** (0.024)	0.031 (0.030)	0.044*** (0.028)	0.012 (0.061)	0.006 (0.035)
E-Government	0.046** (0.021)	0.049*** (0.021)	0.025 (0.020)	0.026** (0.019)	-0.014 (0.048)	-0.040 (0.046)
Mobile Social media	0.147*** (0.026)	0.128*** (0.023)	0.173*** (0.021)	0.174*** (0.020)		
Constant	47.615** (23.19)	-17.765*** (8.483)	3.075 (18.990)	-13.042* (12.274)	-186*** (55.616)	-70.7*** (11.550)
Observations	1,005	1,005	1,005	1,005	1,005	1,005
F-statistics (p-value)	152.75 (0.000)		290.89 (0.000)		176 (0.000)	
Wald-statistic (p-value)		2,636 (0.000)		3,909.25 (0.000)		2,268 (0.000)
Adjusted R-squared	0.70	0.69	0.82	0.82	0.7157	0.699
Hausman test chi2 (p-value)	45.62 (0.000)		24.08 (0.003)		75.5 (0.000)	

*in order to mitigate the endogeneity issue between the digital adoption rate and cyber security, the cyber security data was lagged by one year in our analysis. Robust standard errors are in parenthesis.

Based on Table 8 results, improving cybersecurity, augmenting 4G network coverage (% of population covered), reducing the gender gap ratio for social media use (female/male ratio) and overall social media expansion are simultaneously important for both the advanced and the non-advanced mobile connectivity countries when these want to further strengthen apps development at the country level. The importance of skills development (tertiary education enrolment rate) for apps availability seem to be more significant in more developed mobile networks (column 1 in Table 8) than in the others. By contrast, prices of premium baskets (cost of a basket with 5GB as monthly allowance) seem to be more relevant for apps development in less developed mobile networks (column 2 in Table 8).

In a similar vein, augmenting mobile broadband speed, 4G coverage and social media expansion are also among the significant factors to consider when defining public authorities' strategies to

improve apps available in national languages for all countries, regardless of their networks' development stage. Cyber security provision (more secure mobile broadband networks) seem to be particularly relevant for apps in national languages availability in more advanced mobile networks.

Moreover, social media penetration is mainly affected by income (GNI per capita) and quality of mobile broadband networks (mobile upload speed as well as 4G coverage). Thus, improving the purchasing power of the consumers by improving GNI per capita and increasing the quality of mobile communications networks are important factors to take into account when aiming at further strengthening social media penetration rates thus promoting more citizens' participation online. The importance of skills development (tertiary education enrolment rate) for social media diffusion rates seems to be more significant in more developed mobile networks (column 5 in Table 8) than in the others.

Table 8: Regression estimates by countries' Mobile Connectivity development stage

VARIABLES	(1) Apps per person MC Advanced	(2) Apps per person MC Other countries	(3) Apps in national language MC Advanced	(4) Apps in national language MC Other countries	(5) Mobile Socialmedia Penetration MC Advanced	(6) Mobile Socialmedia Penetration MC Other countries
IGNIpc	-1.010 (3.128)	-0.148 (3.718)	8.345*** (2.583)	1.441 (2.681)	36.584*** (9.815)	12.390* (6.403)
Entrybasket100MB	-0.033 (0.030)	-0.031 (0.050)	-0.020 (0.019)	-0.097** (0.043)	0.099 (0.101)	0.099 (0.074)
Mediumbasket500MB	-0.003 (0.040)	-0.046 (0.051)	-0.021 (0.028)	0.079** (0.036)	-0.106 (0.134)	-0.124* (0.075)
Premiumbasket5GB	0.011 (0.024)	0.064** (0.031)	0.004 (0.021)	0.042 (0.026)	0.064 (0.067)	0.063 (0.045)
CyberSec (lag1)*	0.050*** (0.011)	0.040** (0.015)	0.027*** (0.009)	-0.010 (0.010)	0.085*** (0.032)	-0.033 (0.021)
4G Coverage	0.079** (0.031)	0.091*** (0.016)	0.079*** (0.023)	0.030** (0.015)	0.130** (0.083)	0.066** (0.032)
Mobspeed	0.024** (0.016)	0.020 (0.040)	0.054*** (0.013)	0.062* (0.033)	0.279*** (0.043)	0.519*** (0.069)
Spectrum	-0.004 (0.022)	-0.012 (0.046)	-0.017 (0.016)	0.0130 (0.050)	-0.069 (0.065)	0.044 (0.069)
Inequality	0.031 (0.020)	0.024 (0.034)	0.003 (0.021)	-0.043* (0.026)	0.121* (0.075)	0.040 (0.057)
Skills	0.088** (0.036)	0.087 (0.091)	0.030 (0.034)	0.019 (0.073)	0.325** (0.132)	0.109 (0.171)
Female	0.086** (0.035)	0.247*** (0.037)	0.085*** (0.028)	0.018 (0.035)	0.163 (0.115)	-0.040 (0.061)
E-Government	0.012 (0.035)	0.044 (0.029)	0.012 (0.028)	0.029 (0.029)	-0.067 (0.073)	0.071* (0.058)
Mobile Social media Penetration _cons	0.100*** (0.026) 62.188** (30.657)	0.218*** (0.058) 23.311 (32.245)	0.156*** (0.019) -37.311 (25.389)	0.190*** (0.045) 32.591 (22.569)	-389.333*** (95.177)	-100.723* (57.534)
Observations	495	510	495	510	495	510
F-statistics	59.1	76.1	230.5	83.1	82.8	87.5
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R-squared	0.66	0.72	0.88	0.739	0.70	0.73

*in order to mitigate the endogeneity issue between the digital adoption rate and cyber security, the cyber security data was lagged by one year in our analysis. Robust standard errors are in parenthesis.

Conclusions

In this paper, we started from the relationship between cyber security and digital adoption at the country level and we find evidence that cyber insecurity can be an important factor for public authorities to take into account when aiming at increasing digital adoption in all its dimensions: industry, governments and people digital adoption. Our results indicate that the level of cyber security at the country level has a positive significant impact on citizens, government and businesses' overall digital adoption.

Moreover, despite the progress observed worldwide in online services adoption and usage, there remains a persistent disparity in Internet expansion among countries, and between countries with advanced electronic communications networks and the others. Accordingly, this study also provides an international comparative analysis of online services access and usage at the country level by extending previous results on the relationship between cybersecurity and online services and usage, especially for apps and social media expansion.

Our findings confirm that, in addition to other socioeconomic variables, cybersecurity is an important factor explaining the observed worldwide disparities in online services access and usage. We also ascertain that the distribution of cybersecurity across countries may affect social media penetration and apps developed in national language(s) to a lower extent in economies with lower mobile communications connectivity in comparison with more developed ones. By contrast, there seems to exist a similar positive cyber security effect in apps development and availability for all countries regardless of their mobile connectivity development level.

Taken together, these findings suggest a role for cyber security to explain the international digital divide. Thus, effective policies against the digital divide should fight against cyber insecurity on a global scale.

It is left to future research to explore more detailed reasons behind the international differences observed in cyberspace. Yet, it appears that cyber security is an important determinant of the heterogeneity for online services access and usage across the globe, which should not be overlooked.

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