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Digitalisation, institutions and governance, and diffusion: mechanisms and evidence

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Abstract

Digitalisation can be described as a sequence of technology and supply shocks which affect the economy through employment and labour markets, productivity and output, and competition and market structure. This paper focuses on how digitalisation - the process of diffusion of digital technologies - is affected by institutions and governance. It discusses a number of theoretical mechanisms and empirical evidence for different sets of European and other countries. The results indicate that a higher quality of institutions is usually associated with both a greater speed of diffusion and a greater spread of digital technologies. The results also suggest that there are large, policy-relevant differences in the diffusion process depending on the level of development as well as the state of technological change of a country.

Keywords: technology, adoption, economy, estimates, panel
JEL codes: E02, O11, O31, O33, O57

Non-Technical Summary

For almost a century, digital technologies have spread into almost every aspect of economic activity. Robots and automation have changed how products are being made, and the internet of things electronically connects appliances. Computers and mobile phones have changed what people consume and how they communicate, and the internet serves as a source of information, a medium of exchange, and as an enabler for many types of transactions.

The increase in digital technologies - referred to in this paper as digitalisation - is on-going, and one of the most important transformations in the history of humankind, affecting economies worldwide. It has been studied in the literature to some extent, in particular when it comes to the effects it has on productivity (how much output is produced with one unit of input) and the labour market (including employment and unemployment, for example as a consequence of automation and the introduction of robots).

This paper focuses on the process of digitalisation as such, notably the question to what extent that process depends on institutions and governance, an issue that has received much less attention in the literature, but is very important, notably from a policy perspective. Institutions are often entities or bodies that are part of the public sector and perform public functions, as for example any public authority, such as the courts and ministries. Institutions can also originate outside the public sector, as for example trade unions. Governance is a set of processes determining how those entities or bodies are run, how well they perform their functions and therefore serve households and firms.

Why are institutions and governance important in the diffusion process of digitalisation? The reason is that they interact, and the diffusion depends on this interaction. The internet as a source of information, for example, is used by producers and consumers. However, how widely and how intensively they are used is likely to depend on institutions and governance, and this dependency is what is studied in this paper. The quality of institutions and governance affect how easy or how hard it is to use digital technology, for example to get access to the internet, or to use search engines, mobile phones, or robots.

The paper suggests that the diffusion of digital technologies may be faster and advance further when institutions and governance are of high quality, and this depends only to some extent on how digitalisation, institutions and governance are measured. The basis for this conclusion is an analysis for a number of country groupings (including the EU and the OECD as well as a global sample of 101 countries) for the period 1996-2019 (a maximum of 24 years).

The suggestion that the diffusion of digital technologies may be faster and go further when institutions and governance are of higher quality is also relatively robust. This is because the analysis does take into account also key factors other than institutions and governance that may play a role in the diffusion of digital technology, such as the level of development of the economy, and how much human capital (brains and ideas) it has.

1 Introduction

Since the middle of the 20th century, digital technologies have been spreading into almost every aspect of economic activity, transforming production patterns (for example via automation, industry 4.0, the internet of things, digital twins) and consumption patterns (infrastructure, software, platforms). Digital technologies are based on binary-digits (or 'bits') format for storing information, which has facilitated processing, storage and exchange of data, and has led, inter alia, to considerable savings in costs, as described in Goldfarb and Tucker (2019).[1]

The increase in digital technologies - referred to in this paper as digitalisation - is one of the most important transformations affecting microeconomic allocation (relative prices and preferences as well as the functioning of markets) and macroeconomic outcomes (trends and cycles), alongside changes in integration, demographics and climate. In line with other ongoing structural changes, digitalisation may also have broader consequences on modern economies and societies. As Milkau and Bott (2015) note: 'Digitalisation has not been changing the fundamental laws of economics, but has triggered changes in how agents interact in the market or see intermediaries facilitating this interaction.'

Some of the impacts of digitalisation have been studied in prior research, at least qualitatively.[2] This includes the effects of digitalisation on a macroeconomic level, and in particular the effects on productivity and labour markets[3]. The literature suggests that while new technologies may affect different sectors heterogeneously, they generally lead to productivity gains at the firm level, with more productive firms being, on average, more digital (and vice versa, see for example Gal et al. (2019) and OECD (2019)).

The productivity-enhancing effect derives from the general-purpose property of digital technologies (Trajtenberg, 2018) and/or those technologies being inventions in the method of inventing (Cockburn et al., 2018). While there is much support for the idea that digitalisation has productivity-enhancing effects, this idea is by no means uncontested, neither in relation to specific technologies (for example the internet (Gordon, 2016)) nor regarding digital technologies as such (given digital distraction and addiction).[4]

Nevertheless, at the aggregate level the literature emphasises the so-called productivity puzzle, whereby economy-wide productivity growth is much lower than would perhaps be expected in an era of rapid technological change, and given the firm-level evidence. This suggests that there may also be adverse effects from technology on productivity, even if they may be more

[1] As the middle of the 21st century approaches, digital technologies are in the process of being superseded by the more advanced quantum technologies. Those technologies are based on the quantum-digits ('qubits') format, which also uses zero and one as alternative states, but with the possibility that both states co-exist, so that n qubits have the ability of each storing as much information as 2^n bits. This ability makes quantum computing much more powerful than digital computing.

[2] For a broad summary and references, see for example Anderton et al. (2020) and Anderton and Cette (2021).

[3] For a survey, see for example, Degryse (2016), Hüther (2016) or OECD (2019).

[4] A related issue, which we do not cover here, is the measurement of productivity. It is discussed in some detail in Anderton and Cette (2021).

difficult to quantify, such as digital and non-digital systems being run in parallel, or distraction and/or addiction effects from digital technology.[5]

The literature on the labour market effects is also ambiguous, because digital technologies may be magnifying and enhancing human capabilities (complementing labour), as argued by Acemoglu et al. (2005), Acemoglu (2012) or Acemoglu and Restrepo (2019), or, alternatively, replacing human capabilities (substituting labour) as suggested by Trajtenberg (2018). Acemoglu and Restrepo (2019) also note that digital technologies might displace labour from routine and repetitive work, and therefore remove a number of jobs intensive in those tasks. In this way, digital technologies, like other technologies, may also lead to labour market polarisation.

Some attention has also been given to the diffusion of technologies, and comparing the diffusion of digital technologies to the diffusion of other general-purpose technologies. Comin and Hobijn (2004) consider the diffusion of 20 technologies across 23 of the world's leading industrial economies for the period 1788–2001, and find new technologies to have a common trickle-down effect. In a later study, Comin and Hobijn (2010) look at 15 technologies in 166 countries over the last two centuries, and estimate a mean adoption lag of 45 years (less for more recent technologies) after invention. Stokey (2020) contrasts within-country and cross-country adoption patterns, focusing on how costs and the relative price of capital and labour inputs affect the adoption process.

However, the interaction of the diffusion of technologies, and especially digital technologies, with the quality of institutions and governance, has not been addressed in the literature, although this interaction is potentially important, in particular, for policy-making. This paper attempts to fill this gap by describing a number of theoretical mechanisms and providing empirical evidence for the diffusion of digital technologies, and the interplay of the diffusion process with the quality of institutions and governance. The empirical evidence in this paper comes from a large cross-section of 101 countries from all around the world in order to make the assessment more robust and identify potential differences across different sets of countries.[6] Such differences could emerge, for example, for countries at different stages of development if institutions and governance are intrinsically linked to advancement.

One distinctive feature of this paper is that digital technology is measured by means of actual adoption of specific digital technologies, such as the number of devices or subscriptions, which has the advantage of better capturing the actual use of the technologies, as opposed to the potential scope for their use. This is in contrast to most of the preceding literature which relies on data on Information and Communication Technology (ICT) patents, investment or

[5] In parallel, it is still not entirely clear to what extent the measurement of productivity is impaired due to the technological change associated with digitalisation, see for example Anderton et al. (2020) and the references therein.

[6] Preliminary results based smaller data set with 24 EU countries and a shorter time sample are included in Anderton et al. (2020). In a companion paper, Labhard and Lehtimäki (2022) focus on the growth effects of digitalisation, and the possible role played by institutions and governance in that context.

consumption. While useful inter alia as a cross-check, those alternative measures do not fully capture the actual level of technology they imply (investment, for example, may be more or less efficient). Moreover, those alternative measures do not necessarily reveal sufficiently detailed information about the specific technologies as they are based on statistical categories which have originally been defined with other objectives in mind.

While measuring digitalisation via the adoption of specific technologies is a reasonable approach, it also has some limitations. They are mostly related to limited data availability, especially for the most recently adopted digital technologies, including artificial intelligence, internet of things, digital twins and quantum computing. Because of the recentness, the newest technologies are the most challenging to capture, as data is only available for short periods, and/or are not as easily comparable as in the case of more established technologies. Moreover, this paper restricts itself to traditional data provided by statistical agencies and international organisations, and not the new (and big) data sources that have become available as a result of digitalisation.

The remainder of the paper is organised as follows: Section 2 describes the mechanisms at play regarding the process of diffusion of digital technologies, and its interplay with institutions and governance. Section 3 describes the data sources and samples for digital technologies, institutions and governance as well as the variables controlling for other factors that may play a role in the diffusion process. Section 4 describes the methodology for estimating the process of technology diffusion, and how that methodology captures the interaction of the diffusion process with institutions and governance. The empirical evidence is presented and discussed in Section 5, and Section 6 concludes.

2 Theory

This section summaries some of the literature and the theory behind the diffusion process of digital technologies as well as how institutional and governance aspects might affect the process of technology change and how new technology can be adopted for use.

2.1 The Diffusion of Digital Technologies

It has long been acknowledged that technology can take time to diffuse to widespread use, and that heterogeneity of agents is one of the key reasons for that (see Young (2010) and references therein to the early models of contagion[7] and social influence and social learning[8] as the source of the heterogeneity and the resulting diffusion patterns).[9] This applies also to digital technologies - not all agents are equally exposed to digital technology (for example due

[7]See for example Bass (1969) and Mahajan and Peterson (1985).
[8]See for example Schelling (1971, 1978), Granovetter (1978) and Granovetter and Soong (1988).
[9]For a more recent reference on some of those points in a European context see Evangelista et al. (2014).

to different educational or professional backgrounds) and not all agents feel the same pressure or face the same learning curve (depending on socio-economic characteristics). The social context and personal preferences are not the same across all agents. In fact, it could be argued that because digital technologies are particular in nature, the diffusion process may simultaneously be different from other technologies as well as be more important for development.

The particularity of digital technologies derives from their general-purpose property - the fact that they do not only offer cost and/or efficiency gains but additionally have many applications, and may be combined with many other (more specific) technologies, for the benefit of further innovation (see Jovanovic and Rousseau (2005) and Lipsey et al. (2005) for an analysis and classification of general-purpose technologies). Therefore, digital technologies are potential catalysts for technological progress and far-reaching effects on the economy in the medium and long term. The potential size of the effects will depend on their diffusion to actual use and, inter alia, on their interaction with institutions and governance.

It has been argued that digital technologies (IT/ICT and the technologies that followed) are, in fact, more powerful than other more traditional technologies, and so the 'digital revolution' or 'fourth industrial revolution' is greater than the industrial revolutions preceding it[10]. Indeed, digital technologies are very general, as they have applications throughout the economy, in principle for all agents, all activities and all geographies.

While it is true that digital technologies have features which make them more powerful than other technologies, they also have features making them more difficult to fully take advantage of[11]. The first challenge arises from the fact that digital technologies are not as easily accessible as more traditional ones, and notably require more skills to operate (the power switch, for example, is sufficient to use electricity, but this is only the very first step in the use of a digital device). Taking full advantage of digital technologies may also be more difficult in decentralised economies which therefore may show 'too little, too late' innovation (Bresnahan and Trajtenberg, 1995).

In other words, the diffusion of digital technologies is very specific and is going to depend on a number of other factors that determine how well the technology is integrated into economic processes. One such element is the focus of this paper: the interaction or interplay with institutions and governance.

2.2 The Interplay with Institutions and Governance

Although the terms 'institutions' and 'governance' are sometimes used interchangeably, or as close substitutes, in most cases they refer to different concepts. Institutions, for example, are

[10] The preceding industrial revolutions have been associated with analogue technologies such as the steam engine and electricity.

[11] As noted by David (1990) for example, 'computers are not dynamos', have complexities and special attributes, including the challenges related to measurement, which distinguish digital technology from traditional technologies. See also David (1989).

sometimes considered an aspect of governance, or governance an aspect of institutions. In this paper, institutions are considered to be the structure (the skeleton, or hardware) and governance the way the structure is being run (the muscles, or software), a characterisation that may be reminiscent of Williamson (1998). In this framework, the two concepts are closely connected, intrinsically linked - one does not exist independently of the other, even if they are different aspects of the structure of an economy.

The significance of institutions has been noted in the literature since the seminal work of North (1991) who pointed out that institutions play a notable role in shaping advanced economies and are important, potentially positive or negative, drivers of real economic change, and so should be taken into account when modelling the subject.[12] Another important contribution is by Acemoglu et al. (2005) who study the role of institutions from multiple points of view, and consider evidence from history, notably on the reasons for the vast differences in institutions across countries.

The approach taken in this paper is to consider the effects from institutions and governance separately, and whether they depend on the interaction with technological change. Theoretically, this interaction arises as technological change and technology adoption generally have the potential of creating accountability to the stakeholders (e.g. by making agents and actions more traceable), and by providing equal opportunities to market participants and economic actors (for example, in terms of access to information by defining the framework for market transactions).

3 Data

This section describes the data used in this paper, starting with a summary of the data sources, samples and countries. This is followed by the descriptions of the data capturing digital technologies and those capturing institutions and governance. The section also covers other data, notably the variables used in the estimations to control for factors other than institutions and governance that are shaping the diffusion of digital technology. Listings of all the countries and country aggregates as well as all the variables used in the paper can be found in Table A.1 and Table A.2 in Appendix A.

3.1 Sources, Sample and Countries

Neither the quality of institutions and governance nor the degree of digitalisation are simple to measure. A general challenge is finding data with sufficient time and cross-section dimensions to conduct meaningful econometric analysis, given that many digital technologies are very recent technological advances.[13] Another challenge is capturing the different aspects of those technolo-

[12] A comprehensive study into growth effects, including those that might be attributed to institutions, is available in Bassanini et al. (2001).

[13] This point is also made in Stokey (2020).

gies (e.g. automation vs. communication) and of the quality of institutions and governance (e.g. accountability, transparency, etc.). A further challenge is capturing the availability as opposed to the actual use in the case of technologies, and the quality (de jure and de facto) of institutions and governance.

To address these challenges as best as possible, data from a large number of sources were considered. In the end, most data were compiled from databases of the World Bank as it is one of only a few available sources that has dedicated and comprehensive databases both for measuring the degree of digitalisation as well as the quality of institutions and governance. Another important factor was the availability of long time and wide cross-section dimensions, with series from that source extending as far back as 1960 and for as many as 253 countries, and the indicators for institutions and governance available as of 1996.

The effective sample used in this paper is 1996-2019 when digital diffusion is measured by the number of internet users, and 1998-2019 in the case of fixed broadband subscriptions. The missing values in the panel were imputed by interpolation or, in the very rare instances of occurring at the end of the sample, by assuming a constant rate of growth from the last observation available.[14]

The full panel consists of 101 countries around the World and is referred to in the study as 'All countries'.[15] Three smaller panels were also considered, with countries grouped by 'EU countries' (28), 'Non-EU OECD countries' (14) and 'Other countries' (59). For the purposes of this paper, 'EU countries' includes the United Kingdom (UK), given that the UK left the EU only after the end of the studied sample.[16]

The groupings 'EU countries' and 'Non-EU OECD countries' are relatively homogeneous, as they are tied together via common values and structures. The group 'Other countries' is more heterogeneous than 'EU countries' and 'Non-EU OECD countries', but interesting from a comparative perspective. The group consists mostly of countries located outside Europe, with the continents of Africa, America and Asia all represented. Along with others, it includes the G20 countries Argentina, Brazil, China, India, Indonesia, Russia, Saudi Arabia and South Africa.

3.2 Digital Technologies

To measure digitalisation, data were collected from the World Bank's World Development Indicators (WDI) database. Two series, in particular, were considered helpful for capturing the degree of digitalisation. The first is the series 'Individuals using the Internet (per cent of popu-

[14]The interpolation was used, for example, for the institutions and governance indicators for 1997, 1999 and 2001, as they are only available biannually until 2002.

[15]The 101 countries are those for which all series (digitalisation, institutions and governance, and controls) are available, and only have individual (as opposed to a sequence of) missing values.

[16]These specific aggregates were studied because they are often used as a reference point in the policy debate. In addition, the group of EU27 (excluding the UK) was studied, but the results were almost unchanged.

lation)', available beginning from 1996, which reflects the necessary condition during the early phases of digitalisation of being able to access and actually using the internet as a basic digital environment. The second series is 'Fixed broadband subscriptions', available for a majority of the countries in the sample from the year 1998, which captures the key precondition for the formation of advanced infrastructure and hence for the current phase of digitalisation.

The series 'Individuals using the Internet (per cent of population)' is compiled from the International Telecommunications Union and its World Telecommunication/ICT Development report and Database, and is defined as individuals who have used the internet in the past three months, via computer, mobile phone, digital television or other device. The quality of this series may vary across countries due to, for example, differences in regulations regarding the cover of data provision and availability.

The series 'Fixed broadband subscriptions' is from the same source, and covers high-speed access via TCP/IP connections at downstream speed of at least 256 kbits per second, including cable modem, DSL, fiber-to-the-building, satellite broadband and terrestrial fixed wireless broadband. The data are based on surveys carried out by National Statistical Institutes, and potentially suffer from the corresponding drawbacks. Despite best efforts, neither indicator is strictly comparable across all countries, for example, due to differences in the timing of the fiscal year. However, even with these drawbacks, they are two of the few available series with sufficient coverage to examine the effects studied by this paper.

A number of other points are worth noting in this context. First, internet use and broadband subscriptions are important digital technologies, because enabling others (e.g. no e-commerce or e-government without them). Second, while they are enabling or even precondition for other technologies, they say little about the spread of those other technologies. Third, they are capturing the number of users/installations, not how much and what for they are using/being used. The results presented in this paper have to be seen against that background.

The descriptive statistics of the digital technology variables are summarised in Table 1. They suggest that internet use has spread further but also varies more across countries than broadband subscriptions. For both internet users and broadband subscriptions, mean and standard deviation tend to be higher for the EU and OECD than the other countries. The maxima for both internet users and broadband subscriptions are highest for the non-EU OECD countries, followed closely by the EU countries. The EU and non-EU OECD contries also have the more even distribution of the digital technologies than the other countries.

Table 1: Descriptive statistics of digital technologies variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Individuals using the internet	50.4	30.8	0.1	4.1	87.5	98.1
Fixed broadband subscriptions	20.8	12.7	0.0	1.3	37.4	45.7
Non-EU OECD countries						
Individuals using the internet	54.3	31.7	0.1	4.5	91.6	100.0
Fixed broadband subscriptions	19.8	13.6	0.0	0.8	37.7	46.3
Other countries						
Individuals using the internet	21.1	23.9	0.0	0.1	60.2	95.7
Fixed broadband subscriptions	5.2	7.6	0.0	0.0	15.7	37.5
All countries						
Individuals using the internet	33.9	31.1	0.0	0.4	81.2	100.0
Fixed broadband subscriptions	11.9	12.9	0.0	0.1	32.2	46.3

Sources: World Bank, authors' calculations.
Notes: 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2019 for individuals using the internet and 1998-2019 for fixed broadband subscriptions. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

A number of other options for indicators of digitalisation were considered as well, but were not used due to (too) short samples and/or (too large-scale) changes in methodology during the sample period. They included the series 'Secure Internet servers', available from 2000, also from the World Development Indicators, the Digital Advancement Index, also published by the World Bank, for the years 2014 and 2016, the KOF Information Globalisation Index presented originally in Dreher (2006) and revisited in Gygli et al. (2019), and the European Commission's Digital Economy and Society Index (DESI) published onwards from 2014 and its international (iDESI) counterpart, published for 2018 (only). While these alternative indicators were not used in this study, they might be informative for future work when their sample and coverage are extended, or to study different aspects of the process of digital technological change.

3.3 Institutions and Governance

The data for institutions and governance were taken from the Worldwide Governance Indicators (WGI) described in Kaufmann et al. (2010) and published by the World Bank. This source was chosen due to the advantages of comprehensive databases, and the availability of long time and wide cross-section dimensions, as noted in Section 3.2. Using the World Bank as the source for the indicators on institutions and governance also has the added advantage of the homogeneity of certain data standards and principles across the two data sets.

The WGI consists of six distinct indicators. The 'control of corruption' indicator measures

the abuse of public power for private gain and the influence and interference of elites and private interests. The 'government effectiveness' indicator captures the quality of public services, civil service, its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. The 'political stability and absence of violence' indicator measures the likelihood of violence, including terrorism. The 'regulatory quality' indicator measures the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. The 'rule of law' indicator refers to the rules of a society, including contract enforcement, property rights, police and courts as well as the likelihood of crime and violence. Finally, the 'voice and accountability' indicator relates to the perceived participation in the selection of government, as well as freedom of expression, association and media.

For the approach taken by this paper, the indicators 'government effectiveness', 'political stability and absence of violence' and 'voice and accountability' were considered to capture primarily the institutional aspect (the framework or structure), while the indicators 'regulatory quality', 'rule of law' and 'control of corruption' the governance aspect (how things are run given the framework or structure).

In order to have summary measures and to assess the overall impact and the relative importance of institutional and governance aspects, indicators were created for the averages across the two sets of indicators.[17] We label them 'Institutions' and 'Governance'. It should be noted that the approach presented here attempts to select the indicators which capture institutional aspects, but say little on specific (or even genuine) institutions.[18]

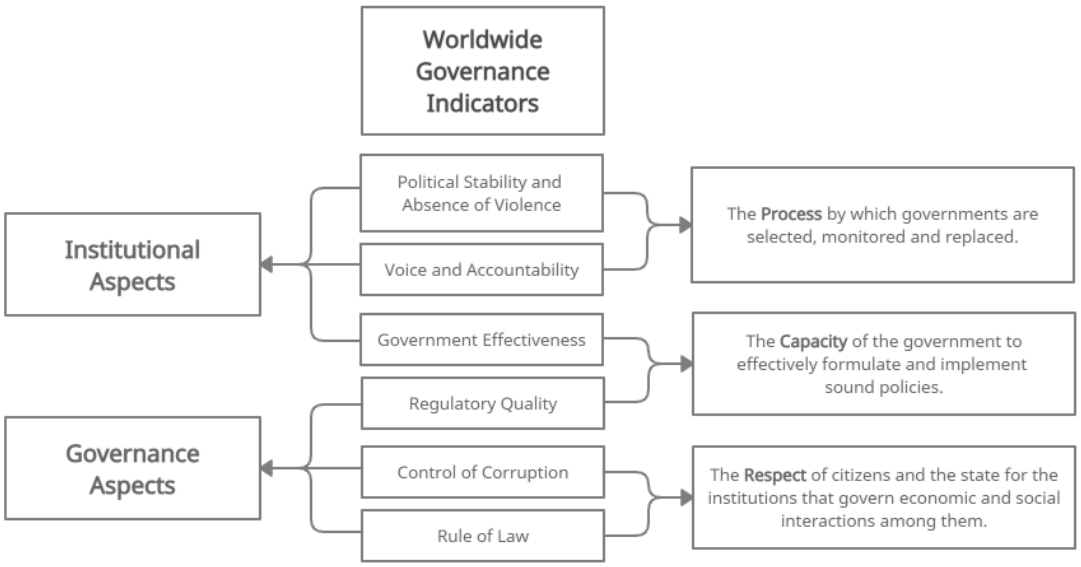
An option for alternative (three-way) summary measures is proposed in Kaufmann et al. (2010). In their three-way distinction, 'Political Stability and Absence of Violence' and 'Voice and Accountability' refer to the process by which governments are selected, monitored, and replaced (we denote this with 'Process'), 'Government Effectiveness' and 'Regulatory Quality' the capacity of the government to effectively formulate and implement sound policies ('Capacity'), and 'Rule of Law' and 'Control of Corruption' the respect of citizens and the state for the institutions that govern economic and social interactions among them ('Respect').

This implies that 'Institutions' corresponds to 'Process' and 'Government Effectiveness' from 'Capacity', while 'Governance' corresponds to 'Regulatory Quality' from 'Capacity' and 'Respect'. Figure 1 illustrates how the different Worldwide Governance Indicators are related to the summary measures used in this study, and how they compare to the alternative summary measures in Kaufmann et al. (2010).

[17] In the absence of strong priors about the relative importance of the different aspects, averages were based on equal weights for all the indicators.

[18] As noted in the literature, for example by Dellepiane-Avellaneda (2010), one of the challenges of studying the effect of institutions on economic growth, is how to differentiate between the effects of different institutions.

Figure 1: Worldwide Governance Indicators and the summary measures



Source: World Bank, Kaufmann et al. (2010), authors.

The data for the institutions and governance indicators are from surveys (of households and firms, e.g. Afrobarometer, Gallup World Poll, Global Competitiveness Report), commercial sources (Economist Intelligence Unit, Global Insight and Political Risk Services), non-governmental organisations (such as Global Integrity, Freedom House, Reporters Without Borders) and organisations from the public sector (including the World Bank and regional development banks). The multitude of sources used offers great advantages in terms of the different aspects that are in scope, but also implies that the methodology for compiling the indicators is complex and the final values are estimations, so there is at least some level of potential uncertainty involved.

As in the case of digital technologies, a number of alternative data sources were considered for institutions and governance during the study. Notable options were the Fraser Institute Economic Freedom Index (Gwartney et al. (2019)) as well as OECD Indicators of Employment Protection Legislation (EPL) and Product Market Regulation (PMR), all of which are, at least indirectly, related to institutions and governance. The other options yielded broadly similar results to the WGI indicators, but were omitted due to less comprehensive samples and other data issues.

The descriptive statistics for the data on institutions and governance are presented in Table 2.[19] For all variables, including those constructed by the authors of this paper, the maxima are recorded among the EU countries and the minima outside the EU and OECD. The mean values are much higher within EU and OECD countries than outside. The standard deviation is lowest

[19]The descriptive statistics for the WGI and summary measures can be found from Tables B.1 and B.2 in Appendix B, alongside their correlations in Tables C.1 and C.2 in Appendix C.

within the EU, highest outside EU and OECD, in between for the Non-EU OECD countries.

Table 2: Descriptive statistics of institutions and governance variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Institutions	1.022	0.419	-0.095	0.469	1.570	1.858
Governance	1.109	0.614	-0.461	0.270	1.927	2.128
Non-EU OECD countries						
Institutions	0.865	0.768	-0.985	-0.335	1.618	1.726
Governance	1.185	0.776	-0.459	-0.137	1.948	2.092
Other countries						
Institutions	-0.290	0.594	-1.912	-0.921	0.561	1.287
Governance	-0.302	0.645	-1.788	-0.940	0.542	2.066
All countries						
Institutions	0.234	0.851	-1.912	-0.806	1.440	1.858
Governance	0.295	0.966	-1.788	-0.820	1.806	2.128

Sources: World Bank, authors' calculations.
Notes: 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2019. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

3.4 Control Variables

In order to properly study the diffusion of digital technology and its interplay with institutions and governance, other factors that might impact on technology diffusion have to be controlled for. This concerns notably the broader state of development of a country and the availability of human capital facilitating the introduction and the use of new technology.

The specific control variables used for this purpose in this paper are: real GDP (per capita), as an indicator of the broader state of development; and human capital, which is proxied with the human education index. The descriptive statistics for the control data are provided in Table 3. For both of the variables, EU and Non-EU OECD countries have very similar statistics. For countries outside the EU and OECD, both variables are somewhat lower but have higher variance, in particular when it comes to human capital, and this results mostly from the longer tail at the lower end of the distribution.

Table 3: Descriptive statistics of control variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Real GDP per capita	10.4	0.5	9.2	9.8	10.9	11.7
Human Capital, Education Index	0.80	0.08	0.56	0.68	0.89	0.95
Non-EU OECD countries						
Real GDP per capita	10.4	0.5	9.1	9.6	11.0	11.1
Human Capital, Education Index	0.79	0.12	0.43	0.59	0.91	0.93
Other countries						
Real GDP per capita	8.9	0.9	6.2	7.8	9.9	11.5
Human Capital, Education Index	0.57	0.15	0.16	0.34	0.75	0.86
All countries						
Real GDP per capita	9.5	1.1	6.2	8.0	10.8	11.7
Human Capital, Education Index	0.66	0.17	0.16	0.40	0.87	0.95

Sources: World Bank, UNDP, authors' calculations.
Notes: 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2019. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Some other potential control variables were also considered, but were omitted due to lack of general significance or uncertainty over the actual effects on the technology diffusion process, as well as potential overidentification issues. Those other variables include inflation, trade openness, labour force, unemployment and investment.

4 Methodology

In order to assess the process of diffusion, this paper uses the contagion model, in other contexts sometimes called the 'epidemic' model of diffusion. As the name suggests, the other contexts are in the medical sciences, specifically epidemiology where it is used to predict contagion, endemics and pandemics given certain parameters (such as infection and recovery rates). It is the model most often used in the analysis of technology diffusion in economics (see for example Geroski (2000)).[20] The model is based on the logic that exposure or contact to technology is going to entail adoption of technology, with the speed of the process and its final point depending on past exposure and a number of other factors.

[20]The model has also been applied to other fields in economics, such as economic convergence (alpha convergence, in terms of levels). An alternative approach, incorporating technology diffusion into a neoclassical growth model, is taken by Comin and Hobijn (2010).

The model has the form:

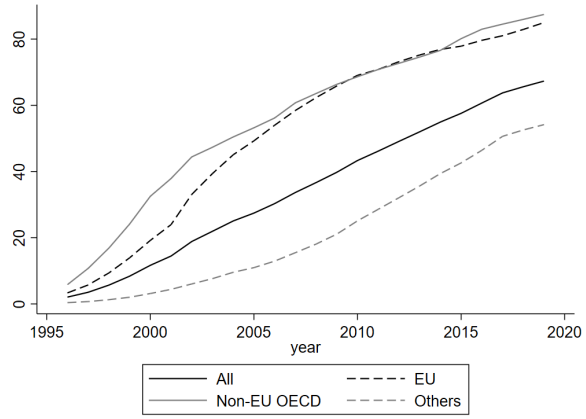
$$\Delta s_{c,t} = \beta(\tilde{X}_{c,t})[\bar{s}_{c,t}(\bar{X}_{c,t}) - s_{c,t}], \tag{1}$$

a law of motion in which $\Delta s_{c,t}$ is the change in the adoption rate in country c at time t, $\beta\tilde{X}_{c,t}$ is the speed of diffusion, $s_{c,t}$ is the saturation rate and $\bar{s}_{c,t}(\bar{X}_{c,t})$ is the long-run (saturation level of the) adoption rate, and the actual and the long-run saturation rate depend on country characteristics $\tilde{X}_{c,t}$ and $\bar{X}'_{c,t}$ respectively. Those sets of country characteristics can be different, as different sets of variables could drive the speed of convergence and the long-run saturation level.

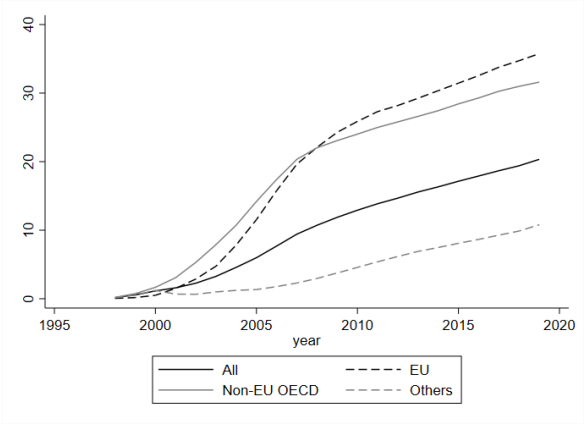
The model in equation (1) generates an S-shape of (non-linear) adoption process over time that is reflected in the data (see Figure 2).[21] The speed of adoption picks up in the early stages of adoption and in the later stages falls back as the adoption rate approaches the long-term saturation level. In the model the key role in the diffusion process is the exposure to the technology, which is initially limited, and then increases, up to the point where exposure has no further effects as the technology has already been adopted by most of the agents who are not 'immune' to it.

Figure 2: Digital Technology Adoption

(a) Individuals using the Internet



(b) Fixed broadband subscriptions



Source: World Bank, authors' calculations.

This pattern of the adoption rate is also consistent with network effects - the fact that the benefits of a technology are higher with a greater spread of that technology. These network effects do not have any obvious analogy in the other contexts in which the model is being used. However, they are important in the context of technology diffusion and support the logic of an

[21] See also Figures F.1 and F.2 in Appendix F. A technical comparison and analysis of diffusion models and the shapes they generate in the context of technology diffusion can be found in Jaakkola (1996).

S-shaped (non-linear) adoption process over time, and are another reason for the choice of this particular model for the empirical analysis in this paper.

In the empirical implementation, both the speed of technology diffusion and the steady-state adoption rate are allowed to depend on institutions and governance. Results are shown both for a specification in which institutions and governance affect only the steady-state adoption rate, i.e. $\tilde{X}_{c,t} = f(X_{c,t}^{INST})$ and $\bar{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{DIGI})$, and for a specification in which they affect both the steady-state adoption rate and the speed of diffusion, i.e. $\tilde{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{DIGI})$ and $\bar{X}_{c,t} = f(X_{c,t}^{INST}, X_{c,t}^{DIGI})$.

In the first case, the estimated equation is:

$$\Delta X_{c,t}^{DIGI} = \beta_1 X_{c,t-1}^{DIGI} + \beta_2 X_{c,t-1}^{INST} + \beta_3 X_{c,t-1}^{C}, \tag{2}$$

where $\Delta X_{c,t}^{DIGI}$ is the change in the adoption rate in country c at time t, $X_{c,t-1}^{DIGI}$ is the adoption rate at time $t-1$, $X_{c,t-1}^{INST}$ is the term capturing institutions and governance at time $t-1$ and $X_{c,t-1}^{C}$ is the set of control variables, also at time $t-1$. In the other case, the estimated equation is:

$$\Delta X_{c,t}^{DIGI} = \beta_1 X_{c,t-1}^{DIGI} + \beta_2 X_{c,t-1}^{INST} + \beta_3 X_{c,t-1}^{C} + \beta_4 (X_{c,t-1}^{DIGI} * X_{c,t-1}^{INST}) \tag{3}$$

where the terms with coefficients β_1, β_2 and β_3 are the same as in equation (2), and the added term with coefficient β_4 captures the effect of the interaction of digitalisation with institutions and governance on the speed of diffusion.

The control variables in $X_{c,t-1}^{C}$ in equations (2) and (3) are the same. Real GDP per capita is used to control for potential income effects in the diffusion process, and human capital to capture the capability of the population for adopting new technology. The two variables are intended to account for the key economic factors in the process of technological change apart from the institutional and governance aspects under focus in this study.

Turning to the expected signs, the two control variables are likely to have positive signs, suggesting a positive effect on the steady-state diffusion rate in the medium and longer term. Real GDP per capita captures the fact the better-off countries may find it easier to fund investment into digital technologies and/or to facilitate its installation. This should ultimately support their spread. Human capital is complementary to new technologies, including digital, and so should also show a positive coefficient. The more human capital is available, the more likely it is that new technologies are explored, evaluated, and, ultimately, adopted.

As for the signs on institutions and governance, the expectation is for a positive effect on the steady-state adoption rate in the medium to long run, i.e. a positive coefficient on the corresponding lagged terms $X_{c,t-1}^{INST}$, and a positive effect on the speed of adoption, i.e. a negative

coefficient on the interaction term ($X_{c,t}^{INST} * X_{c,t}^{DIGI}$).[22] This is because, as noted in Section 2.2, institutions and governance are considered key elements of the economic framework conditions that support technological advancement and innovation more generally.

5 Results

This section presents the main results, based on the series 'Individuals using the internet' and 'Fixed broadband subscriptions' from Section 3.2 to capture digital technology and the summary measures for 'Institutions' and 'Governance' introduced in Section 3.3.[23] It first presents the results for the 'EU countries' and 'Non-EU OECD countries', and continues with those for the 'Other countries' and 'All countries'. In both sections, the focus is first on the spread of digital technologies and then on the speed of diffusion.

5.1 EU and Non-EU OECD countries

The results for the EU (Table 4, columns 1-4) suggest that the spread of digital technologies (when measured by the use of the internet) is greater when institutions and governance are of higher quality, even when other factors increasing digital adoption are accounted for.[24] In the case of digitalisation measured by broadband subscriptions, the effect of institutions and governance has the opposite sign, although it is rarely significant. This could be indicative of a high level of institutions and governance potentially standing in the way of the spreading of digital technologies, for example, in the case of excessive regulation.

The measures of digital technology (internet use or broadband subscriptions) are significant, and the magnitude of the effect does not depend on the choice of measure for institutions and/or governance. The overall fit of the regression is good, and very good when digital technologies are captured by means of broadband subscriptions.

The results for the Non-EU OECD (Table 4, columns 5-8) are similar. In absolute value, the coefficients on internet use are slightly larger than for the EU, while those on broadband subscriptions are slightly smaller. Some differences also exist with respect to the other variables determining ultimate digital adoption. Human capital has larger coefficients, especially when digitalisation is measured by internet use, and is statistically significant for all four specifica-

[22] For equations (2) and (3), in the case of the lagged dependent variable and interaction terms, a negative sign means a positive effect on the rate of digital adoption; in the case of the other terms, a positive coefficient means a positive effect on the long-term level of digital adoption.

[23] For the results for the individual series of the WGI and the summary measures of Kaufmann et al. (2010) see Tables D.1 to D.4 in Appendix D (Individuals using the Internet) and Tables E.1 to E.4 in Appendix E (Fixed broadband subscriptions).

[24] The effect on the rate of adoption is captured by the coefficients on the lagged dependent variable and, where included, as in Table 5, the lagged interaction terms, while the effect on the long-run level of digital adoption is captured by the coefficient on the institutions terms and controls. For the lagged dependent variable and interaction terms, a negative sign means a positive effect on the rate of digital adoption; for the other terms, a positive coefficient means a positive effect on the long-term level of digital adoption.

tions. The overall fit of the regression is almost identical, suggesting that despite the different characteristics of countries in the Non-EU OECD group, the model works well for both groups.

Table 4: Results for EU/Non-EU OECD countries

	EU countries				Non-EU OECD countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Technology								
Internet	-0.181***	-0.184***			-0.230***	-0.229***		
	(0.009)	(0.010)			(0.012)	(0.012)		
Broadband			-0.323***	-0.322***			-0.303***	-0.295***
			(0.008)	(0.008)			(0.004)	(0.005)
Governance								
Institutions	0.111***		-0.053		0.024		-0.268***	
	(0.042)		(0.057)		(0.061)		(0.070)	
Governance		0.002		-0.077*		0.006		-0.091
		(0.034)		(0.042)		(0.056)		(0.056)
Controls								
Real GDP	0.024	0.062	0.087**	0.125**	-0.265*	-0.266**	-0.100	-0.024
	(0.060)	(0.056)	(0.039)	(0.059)	(0.137)	(0.128)	(0.261)	(0.261)
Human	0.107	0.003	0.717***	0.645**	1.297***	1.280***	1.162***	0.881**
Capital	(0.115)	(0.115)	(0.271)	(0.318)	(0.355)	(0.343)	(0.443)	(0.429)
Constant								
Constant	0.355	0.170	-0.364	-0.670	2.696**	2.735**	1.323	0.611
	(0.626)	(0.589)	(0.347)	(0.483)	(1.213)	(1.106)	(2.419)	(2.448)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
T	24	24	22	22	24	24	22	22
N	28	28	28	28	14	14	14	14
N*T	644	644	519	519	322	322	272	272
F-stat	62.7***	60.1***	292.5***	280.9***	58.1***	58.0***	285.3***	254.4***
R^2 adjusted	0.75	0.74	0.95	0.94	0.75	0.75	0.95	0.94

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. R^2 adjusted is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

The results in Table 5 suggest that for both EU and Non-EU OECD countries a model taking into account the interaction of digital adoption with institutions and governance performs just as well, and the interaction terms are highly statistically significant, at least for the Non-EU OECD countries. The other factors contributing positively to digital adoption, such as GDP per capita and human capital, see their significance reduced, suggesting that the interaction is important to account for explicitly, and their effects attributed to the control variables if they are omitted. This provides strong support for the idea that technologies and institutions are

mutually reinforcing and, more generally, for the diffusion model of technology adoption.[25] The coefficients on technology all remain significant, and some of those on institutions and governance turn significant.

[25]The same signs of the effects were reported previously in Anderton et al. (2020), on the basis of a smaller data set with 24 EU countries and a shorter time sample.

Table 5: Results for EU/Non-EU OECD countries (with interaction)

	EU countries				Non-EU OECD countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Technology								
Internet	-0.141***	-0.151***			-0.195***	-0.182***		
	(0.007)	(0.009)			(0.006)	(0.007)		
Broadband			-0.304***	-0.312***			-0.223***	-0.226***
			(0.013)	(0.007)			(0.018)	(0.017)
Governance								
Institutions	0.196***		-0.018		0.253***		-0.112*	
	(0.053)		(0.064)		(0.051)		(0.063)	
Governance		0.077*		-0.053		0.367***		0.112**
		(0.045)		(0.045)		(0.041)		(0.047)
Interaction								
Internet ×	-0.045***				-0.082***			
Institutions	(0.008)				(0.008)			
Internet ×		-0.038***				-0.080***		
Governance		(0.005)				(0.005)		
Broadband ×			-0.005				-0.059***	
Institutions			(0.013)				(0.010)	
Broadband ×				-0.007*				-0.049***
Governance				(0.004)				(0.008)
Controls								
Real GDP	0.017	0.061	0.077**	0.108*	0.019	0.089	-0.061	0.111
	(0.059)	(0.055)	(0.038)	(0.063)	(0.112)	(0.100)	(0.274)	(0.240)
Human	0.118	0.095	0.699**	0.655**	0.666**	0.595***	0.480	0.323
Capital	(0.123)	(0.130)	(0.277)	(0.320)	(0.259)	(0.227)	(0.443)	(0.443)
Constant								
Constant	0.356	0.063	-0.282	-0.531	0.215	-0.634	1.298	-0.588
	(0.617)	(0.586)	(0.338)	(0.506)	(0.985)	(0.871)	(2.601)	(2.256)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
T	24	24	22	22	24	24	22	22
N	28	28	28	28	14	14	14	14
N*T	644	644	519	519	322	322	272	272
F-stat	63.2***	63.9***	284.4***	269.7***	102.8***	96.3***	186.8***	194.1***
R^2 adjusted	0.76	0.76	0.95	0.94	0.85	0.84	0.93	0.93

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance, their interaction and controls. White cross-section robust standard errors and covariance in parentheses. R^2 adjusted is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

5.2 Other/All countries

The results for countries other than EU and Non-EU OECD (Table 6, columns 1-4) are generally comparable to those for EU and Non-EU OECD. While technology is significant, as for the EU and Non-EU OECD, the impact of technology is somewhat smaller, notably for broadband subscriptions as a measure of technology. Institutions, and notably governance, remain largely insignificant, even though they might be expected to be more informative because they are generally more variable for countries outside the EU and OECD. For the other countries, real GDP becomes significant in conjunction with internet use, but human capital is not significant. The overall fit of the regression is not quite as good for the EU and OECD countries and this might be due to the technology change process having progressed further in the EU and OECD countries.

The results for all 101 countries (Table 6, columns 5-8) are similar to those for the other countries. Interestingly, institutions are significant when the panel includes all countries, irrespective of the measure of digitalisation. This stresses their importance for technology adoption overall for the 101 countries in the full panel. Among the control variables, human capital is only significant in connection with internet use as technology. This might be due to the slightly longer sample or, more likely, due to the first phase of digitalisation having advanced more in countries outside the EU and non-EU OECD than the current phase. The overall fit of the regression is good, but closer to the (more numerous) other countries than the EU or Non-EU OECD.

Table 6: Results for other/all countries

	Other countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Technology								
Internet	-0.152***	-0.153***			-0.157***	-0.159***		
	(0.007)	(0.007)			(0.006)	(0.006)		
Broadband			-0.214***	-0.219***			-0.258***	-0.263***
			(0.014)	(0.014)			(0.009)	(0.008)
Governance								
Institutions	0.070*		-0.044		0.089***		0.124***	
	(0.038)		(0.075)		(0.024)		(0.041)	
Governance		0.006		-0.085		-0.018		-0.050
		(0.048)		(0.068)		(0.029)		(0.031)
Controls								
Real GDP	0.164***	0.184***	0.267***	0.327***	0.082**	0.114***	0.285***	0.380***
	(0.043)	(0.051)	(0.075)	(0.096)	(0.033)	(0.035)	(0.050)	(0.072)
Human	-0.031	-0.072	-0.068	-0.073	-0.176**	-0.247***	-0.052	-0.210
Capital	(0.174)	(0.171)	(0.291)	(0.298)	(0.085)	(0.080)	(0.159)	(0.192)
Constant								
Constant	-0.854**	-1.025**	-2.041***	-2.615***	-0.042	-0.271	-2.178***	-2.932***
	(0.346)	(0.420)	(0.607)	(0.797)	(0.317)	(0.336)	(0.421)	(0.590)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
T	24	24	22	22	24	24	22	22
N	59	59	59	59	101	101	101	101
N*T	1350	1350	990	990	2316	2316	1781	1781
F-stat	33.1***	32.7***	32.1***	32.1***	47.3***	46.4***	87.1***	85.0***
R^2 adjusted	0.60	0.59	0.66	0.66	0.68	0.67	0.83	0.83

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. R^2 adjusted is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

The results for the specification with interaction of technology, institutions and governance for countries countries other than EU and Non-EU OECD (Table 7) shows little change relative to the specification without those effects (Table 6). This is in analogy to the same comparison for the EU and Non-EU OECD (Table 4 vs Table 5). The interaction terms are highly significant, and suggest a faster speed of digitalisation due to the interaction. The coefficients on the other terms remain significant where significant before, also at the same level, and the changes in magnitude are relatively limited. Again, as for the EU and Non-EU OECD, the overall fit of the regression is slightly better for the specification with interaction terms. This gives strong support for the empirical model, especially across the various groups of panels, which is perhaps surprising given the other structural differences across countries.

Table 7: Results for other/all countries (with interaction term)

	Other countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Technology								
Internet	-0.173***	-0.187***			-0.171***	-0.177***		
	(0.008)	(0.008)			(0.006)	(0.006)		
Broadband			-0.230***	0.240***			-0.240***	-0.244***
			(0.015)	(0.013)			(0.007)	(0.008)
Governance								
Institutions	0.129**		0.030		0.164***		0.080*	
	(0.059)		(0.075)		(0.028)		(0.047)	
Governance		0.083		-0.078		0.114***		0.059**
		(0.069)		(0.067)		(0.044)		(0.028)
Interaction								
Internet ×	-0.039***				-0.048***			
Institutions	(0.014)				(0.004)			
Internet ×		-0.053***				-0.049***		
Governance		(0.012)				(0.003)		
Broadband ×			-0.040***				-0.057***	
Institutions			(0.008)				(0.004)	
Broadband ×				-0.050***				-0.049***
Governance				(0.007)				(0.003)
Controls								
Real GDP	0.164***	0.189***	0.339***	0.391***	0.101***	0.119***	0.205***	0.227***
	(0.038)	(0.042)	(0.085)	(0.110)	(0.035)	(0.038)	(0.041)	(0.053)
Human	0.303*	0.508**	0.101	0.311	0.336***	0.463***	0.290	0.435**
Capital	(0.182)	(0.238)	(0.383)	(0.385)	(0.101)	(0.110)	(0.185)	(0.189)
Constant								
Constant	-0.999***	-1.324***	-2.774	-3.389***	-0.484	-0.700**	-1.567***	-1.871***
	(0.304)	(0.337)	(0.689)	(0.872)	(0.333)	(0.353)	(0.376)	(0.452)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
T	24	24	22	22	24	24	22	22
N	59	59	59	59	101	101	101	101
N*T	1350	1350	990	990	2316	2316	1781	1781
F-stat	34.8***	36.9***	34.1	36.0***	55.0***	57.1***	141.6***	131.5***
R^2 adjusted	0.61	0.63	0.68	0.69	0.71	0.72	0.89	0.89

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance, their interaction and controls. White cross-section robust standard errors and covariance in parentheses. R^2 adjusted is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

6 Conclusions

This paper has discussed theoretical mechanisms and empirical evidence for the diffusion of digital technology and how it is affected by national institutions and governance.

The results point to a fundamental difference in how institutions and governance affect the introduction of technologies at a country level. Advanced institutions can positively affect the speed at which basic means of access to digital technologies are adopted, but in some cases high levels of governance might potentially slow down the process of adopting digital technology. This implies that policymakers could potentially reap higher benefits from the process of digitalisation by adjusting institutions and governance to better suit the introduction of new technologies.

The process of digitalisation tends to be faster when the quality of institutions and governance is high, and even faster by virtue of the interaction between the level of digitalisation and the quality of institutions and governance. This is a result which would lend support to calls for institutions and governance to be designed and managed in line with best international practices, at least when it comes to questions of introducing and adopting new technology.

In the results of this study the effects of the level of economic development (real GDP per capita) and human capital (education) were somewhat dependent on the studied country group and sample length. This implies that the actual process of diffusion might vary due to heterogeneous societal environments. Further research could provide a better understanding how potential country-level differences in institutions, governance and other factors might affect the process of technology adoption.

In order to understand the mechanisms and their empirical relevance better, data covering other aspects of the framework conditions would be very desirable. This suggests that traditional data providers should be encouraged to enhance their coverage, and other sources secured that could provide further information and insight, notably big data. Such sources could go some way towards more timely and more granular analysis. To make full use of them, efforts should also be made to upgrade and adapt existing empirical methodologies, and secure new ones, specifically designed for such data.

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Appendix A: Data

Table A.1: Countries and Country Aggregates

EU countries (28)
Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom
Non-EU OECD countries (14)
Australia, Canada, Chile, Colombia, Iceland, Israel, Japan, Korea, Mexico, New Zealand, Norway, Switzerland, Turkey, United States
Other countries (59)
Albania, Algeria, Argentina, Armenia, Azerbaijan, Barbados, Belarus, Benin, Bolivia, Brazil, Cambodia, Cameroon, China, Costa Rica, Côte d'Ivoire, Dominican Republic, Ecuador, Egypt, El Salvador, Gabon, Gambia, Georgia, Ghana, Hong Kong, India, Indonesia, Jamaica, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Malaysia, Mauritania, Mauritius, Moldova, Mongolia, Morocco, Mozambique, Nepal, Pakistan, Panama, Paraguay, Peru, Philippines, Russia, Saudi Arabia, Senegal, Singapore, South Africa, Sri Lanka, Sudan, Tanzania, Thailand, Togo, Tunisia, Ukraine, Uruguay, Vietnam, Zimbabwe
All countries (101)
Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Barbados, Belarus, Belgium, Benin, Bolivia, Brazil, Bulgaria, Cambodia, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Côte d'Ivoire, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea, Kyrgyz Republic, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Nepal, Netherlands, New Zealand, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Senegal, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Tanzania, Thailand, Togo, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay, Vietnam, Zimbabwe

Notes: For the purposes of this paper, 'EU countries' are the EU28, including the United Kingdom (UK), given the country was a member of the EU during the sample studied in this paper.

Table A.2: Variables

Variable/Description (and transformation)	**Code**	**Source**
Control of Corruption	CC.EST	World Bank
Government Effectiveness	GE.EST	World Bank
Political Stability	PS.EST	World Bank
Regulatory Quality	RQ.EST	World Bank
Rule of Law	RL.EST	World Bank
Voice and Accountability	VA.EST	World Bank
Respect (average of CC.EST, RL.EST)	-	Kaufmann et al. (2010)
Capacity (average of GE.EST, RQ.EST)	-	Kaufmann et al. (2010)
Process (average of PS.EST, VA.EST)	-	Kaufmann et al. (2010)
Institutions (average of GE.EST, PS.EST, VA.EST)	-	Authors
Governance (average of CC.EST, RQ.EST, RL.EST)	-	Authors
Total (average of all six indicators)	-	Authors
Fixed broadband subscriptions (per 100 people, in logs)	IT.NET.BBND	World Bank
Individuals using the Internet (% of population)	IT.NET.USER.ZS	World Bank
Real GDP per capita (log)	NY.GDP.PCAP.KD	World Bank
Human Capital, Education Index	-	UNDP

Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. 'Respect' is short for 'the respect of citizens and the state for the institutions that govern economic and social interactions among them'. 'Capacity is short for 'the capacity of the government to effectively formulate and implement sound policies'. 'Process' is short for 'the process by which governments are selected, monitored and replaced'. 'UNDP' is the United Nations Development Programme.

Appendix B: Descriptive statistics for WGI / summary measures

Table B.1: EU countries / Non-EU OECD countries

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Institutions	1.022	0.419	-0.095	0.469	1.570	1.858
Governance	1.109	0.614	-0.461	0.270	1.927	2.128
Total	1.065	0.508	-0.247	0.385	1.735	1.970
Control of Corruption	1.039	0.802	-0.615	-0.011	2.160	2.470
Government Effectiveness	1.136	0.626	-0.569	0.349	1.940	2.354
Political Stability	0.811	0.429	-0.474	0.249	1.384	1.760
Regulatory Quality	1.177	0.465	-0.184	0.580	1.799	2.098
Rule of Law	1.110	0.625	-0.634	0.201	1.882	2.100
Voice and Accountability	1.119	0.348	-0.292	0.555	1.542	1.801
Process	1.074	0.705	-0.606	0.121	2.005	2.234
Capacity	1.156	0.529	-0.241	0.485	1.831	2.140
Respect	0.965	0.348	-0.112	0.494	1.443	1.702
Non-EU OECD countries						
Institutions	0.865	0.768	-0.985	-0.335	1.618	1.726
Governance	1.185	0.776	-0.459	-0.137	1.948	2.092
Total	1.025	0.763	-0.663	-0.237	1.769	1.862
Control of Corruption	1.229	0.942	-0.928	-0.296	2.201	2.391
Government Effectiveness	1.245	0.707	-0.459	0.049	1.941	2.181
Political Stability	0.403	1.039	-2.374	-1.250	1.412	1.656
Regulatory Quality	1.173	0.578	-0.105	0.254	1.799	2.089
Rule of Law	1.154	0.854	-0.890	-0.396	1.928	2.036
Voice and Accountability	0.947	0.644	-0.831	-0.076	1.569	1.738
Process	1.191	0.890	-0.747	-0.346	2.051	2.161
Capacity	1.209	0.631	-0.282	0.179	1.808	1.970
Respect	0.675	0.822	-1.402	-0.543	1.479	1.582

Sources: World Bank, authors' calculations.

Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2019. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table B.2: Other countries / All countries

Variable	Mean	SDev	Min	10th	90th	Max
Other countries						
Institutions	-0.290	0.594	-1.912	-0.921	0.561	1.287
Governance	-0.302	0.645	-1.788	-0.940	0.542	2.066
Total	-0.296	0.598	-1.660	-0.901	0.505	1.635
Control of Corruption	-0.386	0.707	-1.531	-1.091	0.437	2.326
Government Effectiveness	-0.219	0.667	-1.622	-0.906	0.529	2.437
Political Stability	-0.324	0.776	-2.810	-1.311	0.702	1.615
Regulatory Quality	-0.171	0.668	-2.236	-0.861	0.550	2.261
Rule of Law	-0.350	0.658	-1.852	-1.076	0.520	1.879
Voice and Accountability	-0.325	0.731	-1.907	-1.302	0.590	1.343
Process	-0.368	0.666	-1.604	-1.048	0.491	2.019
Capacity	-0.195	0.647	-1.834	-0.838	0.535	2.248
Respect	-0.325	0.641	-2.195	-1.069	0.544	1.211
All countries						
Institutions	0.234	0.851	-1.912	-0.806	1.440	1.858
Governance	0.295	0.966	-1.788	-0.820	1.806	2.128
Total	0.265	0.896	-1.660	-0.799	1.608	1.970
Control of Corruption	0.233	1.065	-1.531	-0.962	1.979	2.470
Government Effectiveness	0.359	0.953	-1.622	-0.783	1.803	2.437
Political Stability	0.090	0.904	-2.810	-1.131	1.198	1.760
Regulatory Quality	0.389	0.899	-2.236	-0.695	1.669	2.261
Rule of Law	0.263	0.995	-1.852	-0.905	1.774	2.100
Voice and Accountability	0.251	0.934	-1.907	-1.075	1.435	1.801
Process	0.248	1.020	-0.923	-1.604	2.234	1.874
Capacity	0.374	0.913	-0.709	-1.834	2.248	1.728
Respect	0.171	0.849	-0.926	-2.195	1.702	1.298

Sources: World Bank, authors' calculations.

Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The sample is 1996-2019. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Appendix C: Contemporaneous correlations for WGI / summary measures

Table C.1: EU countries / Non-EU OECD countries

	Institutions	**Governance**	**Total**	**Control of Corruption**	**Government Effectiveness**	**Political Stability**	**Regulatory Quality**	**Rule of Law**	**Voice and Accountability**
EU countries									
Institutions	**1.000**	0.932	0.976	0.915	0.944	0.799	0.863	0.930	0.929
Governance	0.932	**1.000**	0.989	0.983	0.952	0.587	0.946	0.981	0.933
Total	0.976	0.989	**1.000**	0.971	0.965	0.684	0.928	0.977	0.947
Control of Corruption	0.915	0.983	0.971	**1.000**	0.945	0.563	0.889	0.950	0.912
Government Effectiveness	0.944	0.952	0.965	0.945	**1.000**	0.584	0.874	0.941	0.894
Political Stability	0.799	0.587	0.684	0.563	0.584	**1.000**	0.547	0.599	0.607
Regulatory Quality	0.863	0.946	0.928	0.889	0.874	0.547	**1.000**	0.902	0.871
Rule of Law	0.930	0.981	0.977	0.950	0.941	0.599	0.902	**1.000**	0.930
Voice and Accountability	0.929	0.933	0.947	0.912	0.894	0.607	0.871	0.930	**1.000**
Process	0.933	0.994	0.986	0.990	0.955	0.586	0.906	0.984	0.932
Capacity	0.939	0.980	0.980	0.951	0.977	0.586	0.958	0.954	0.913
Respect	0.955	0.827	0.894	0.802	0.805	0.918	0.771	0.833	0.872
Non-EU OECD countries									
Institutions	**1.000**	0.951	0.988	0.941	0.954	0.962	0.894	0.953	0.978
Governance	0.951	**1.000**	0.988	0.988	0.969	0.854	0.962	0.987	0.963
Total	0.988	0.988	**1.000**	0.976	0.973	0.919	0.940	0.982	0.983
Control of Corruption	0.941	0.988	0.976	**1.000**	0.952	0.847	0.926	0.966	0.954
Government Effectiveness	0.954	0.969	0.973	0.952	**1.000**	0.844	0.926	0.965	0.953
Political Stability	0.962	0.854	0.919	0.847	0.844	**1.000**	0.783	0.865	0.902
Regulatory Quality	0.894	0.962	0.940	0.926	0.926	0.783	**1.000**	0.927	0.917
Rule of Law	0.953	0.987	0.982	0.966	0.965	0.865	0.927	**1.000**	0.953
Voice and Accountability	0.978	0.963	0.983	0.954	0.953	0.902	0.917	0.953	**1.000**
Process	0.955	0.996	0.988	0.992	0.967	0.863	0.934	0.991	0.962
Capacity	0.944	0.984	0.976	0.958	0.985	0.832	0.977	0.966	0.954
Respect	0.992	0.917	0.966	0.909	0.907	0.986	0.854	0.920	0.962

Sources: World Bank, authors' calculations.

Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table C.2: Other countries / All countries

	Institutions	Governance	Total	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability
Other countries									
Institutions	**1.000**	0.864	0.963	0.828	0.833	0.833	0.803	0.836	0.795
Governance	0.864	**1.000**	0.968	0.956	0.934	0.632	0.934	0.964	0.586
Total	0.963	0.968	**1.000**	0.926	0.917	0.754	0.903	0.935	0.711
Control of Corruption	0.828	0.956	0.926	**1.000**	0.895	0.618	0.819	0.903	0.548
Government Effectiveness	0.833	0.934	0.917	0.895	**1.000**	0.574	0.880	0.890	0.509
Political Stability	0.833	0.632	0.754	0.6181	0.574	**1.000**	0.562	0.623	0.447
Regulatory Quality	0.803	0.934	0.903	0.819	0.880	0.562	**1.000**	0.850	0.561
Rule of Law	0.836	0.964	0.935	0.903	0.890	0.623	0.851	**1.000**	0.564
Voice and Accountability	0.795	0.586	0.711	0.548	0.509	0.447	0.561	0.564	**1.000**
Process	0.853	0.984	0.954	0.977	0.915	0.636	0.855	0.974	0.570
Capacity	0.843	0.964	0.938	0.884	0.969	0.586	0.970	0.898	0.552
Respect	0.958	0.716	0.862	0.686	0.638	0.860	0.660	0.699	0.841
All countries									
Institutions	**1.000**	0.945	0.984	0.921	0.933	0.891	0.915	0.939	0.921
Governance	0.945	**1.000**	0.988	0.981	0.973	0.769	0.968	0.987	0.849
Total	0.984	0.988	**1.000**	0.966	0.968	0.838	0.956	0.978	0.895
Control of Corruption	0.921	0.981	0.966	**1.000**	0.956	0.752	0.914	0.961	0.818
Government Effectiveness	0.933	0.973	0.968	0.956	**1.000**	0.742	0.942	0.959	0.815
Political Stability	0.891	0.769	0.838	0.752	0.742	**1.000**	0.733	0.774	0.714
Regulatory Quality	0.915	0.968	0.956	0.914	0.942	0.733	**1.000**	0.936	0.834
Rule of Law	0.939	0.987	0.978	0.961	0.959	0.774	0.936	**1.000**	0.842
Voice and Accountability	0.921	0.849	0.895	0.818	0.815	0.714	0.834	0.842	**1.000**
Process	0.939	0.994	0.982	0.991	0.967	0.770	0.933	0.990	0.838
Capacity	0.938	0.985	0.976	0.949	0.986	0.748	0.984	0.962	0.836
Respect	0.979	0.875	0.937	0.849	0.842	0.923	0.847	0.874	0.928

Sources: World Bank, authors' calculations.

Notes: 'Political Stability' is short for 'Political Stability and Absence of Violence'. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Appendix D: Results for WGI / summary measures

Table D.1: EU countries, Individuals using the Internet

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Internet	-0.184***	-0.182***	-0.180***	-0.184***	-0.186***	-0.184***	-0.184***	-0.184***	-0.181***
	(0.010)	(0.009)	(0.010)	(0.010)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)
Governance									
(column	0.022	0.073**	0.068**	0.020	-0.055	0.003	-0.011	0.074**	0.093**
header)	(0.027)	(0.030)	(0.028)	(0.028)	(0.037)	(0.036)	(0.033)	(0.037)	(0.040)
Controls									
Real GDP	0.048	0.018	0.039	0.052	0.093	0.063	0.070	0.021	0.042
	(0.060)	(0.055)	(0.067)	(0.065)	(0.059)	(0.068)	(0.055)	(0.055)	(0.065)
Human	0.048	0.104	0.105	0.025	-0.008	0.001	-0.013	0.095	0.072
Capital	(0.102)	(0.124)	(0.103)	(0.119)	(0.128)	(0.126)	(0.116)	(0.118)	(0.114)
Constant									
Constant	0.254	0.456	0.261	0.232	-0.073	0.160	0.115	0.436	0.219
	(0.623)	(0.574)	(0.666)	(0.654)	(0.597)	(0.695)	(0.584)	(0.118)	(0.665)
Sample start	1997	1997	1997	1997	1997	1997	1997	1997	1997
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	23	23	23	23	23	23	23	23	23
N	28	28	28	28	28	28	28	28	28
N*T	644	644	644	644	644	644	644	644	644
F-stat	60.5***	61.7***	62.7***	60.5***	59.8***	60.1***	59.9***	61.3***	62.5***
R^2 adjusted	0.74	0.75	0.75	0.74	0.74	0.74	0.74	0.74	0.75

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table D.2: Non-EU OECD countries, Individuals using the Internet

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Internet	-0.228***	-0.226***	-0.228***	-0.229***	-0.229***	-0.230***	-0.229***	-0.227***	-0.229***
	(0.013)	(0.014)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)
Governance)									
(column	-0.020	-0.029	0.024	-0.007	0.136*	0.033	0.019	-0.021	0.044
header)	(0.033)	(0.046)	(0.020)	(0.045)	(0.076)	(0.068)	(0.049)	(0.051)	(0.037)
Controls									
Real GDP	-0.265**	-0.269*	-0.271**	-0.256**	-0.338**	-0.252*	-0.272**	-0.258*	-0.262**
	(0.132)	(0.138)	(0.128)	(0.128)	(0.140)	(0.134)	(0.126)	(0.132)	(0.129)
Human	1.241***	1.246***	1.298***	1.250***	1.434***	1.272***	1.312***	1.246***	1.289***
Capital	(0.340)	(0.338)	(0.350)	(0.342)	(0.369)	(0.338)	(0.345)	(0.341)	(0.348)
Constant									
Constant	2.781**	2.815**	2.768**	2.660**	3.202***	2.572**	2.757**	2.701***	2.656**
	(1.162)	(1.246)	(1.107)	(1.115)	(1.161)	(1.210)	(1.085)	(1.167)	(1.125)
Sample start	1997	1997	1997	1997	1997	1997	1997	1997	1997
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	23	23	23	23	23	23	23	23	23
N	14	14	14	14	14	14	14	14	14
N*T	322	322	322	322	322	322	322	322	322
F-stat	58.8***	59.2***	58.4***	58.7***	56.8***	58.8***	57.7***	59.1***	58.8***
R^2 adjusted	0.75	0.76	0.75	0.75	0.75	0.75	0.75	0.75	0.75

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table D.3: Other countries, Individuals using the Internet

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Internet	-0.153***	-0.154***	-0.152***	-0.155***	-0.154***	-0.153***	-0.153***	-0.155***	-0.153***
	(0.006)	(0.007)	(0.006)	(0.007)	(0.007)	(0.006)	(0.007)	(0.007)	(0.006)
Governance									
(column	0.036	-0.031	-0.047**	-0.030*	0.017	0.044*	0.032	-0.041	0.068**
header)	(0.050)	(0.038)	(0.021)	(0.018)	(0.033)	(0.025)	(0.053)	(0.032)	(0.030)
Controls									
Real GDP	0.177***	0.200***	0.160***	0.204***	0.183***	0.188***	0.178***	0.207***	0.167***
	(0.047)	(0.051)	(0.040)	(0.049)	(0.048)	(0.044)	(0.050)	(0.052)	(0.041)
Human	-0.049	-0.071	0.011	-0.102	-0.034	-0.072	-0.049	-0.093	0.001
Capital	(0.172)	(0.171)	(0.166)	(0.175)	(0.180)	(0.172)	(0.174)	(0.173)	(0.165)
Constant									
Constant	-0.963**	-1.168***	-0.846***	-1.185***	-1.030***	-1.045***	-0.975**	-1.221***	-0.895***
	(0.377)	(0.423)	(0.315)	(0.381)	(0.394)	(0.343)	(0.411)	(0.416)	(0.325)
Sample start	1997	1997	1997	1997	1997	1997	1997	1997	1997
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	23	23	23	23	23	23	23	23	23
N	59	59	59	59	59	59	59	59	59
N*T	1350	1350	1350	1350	1350	1350	1350	1350	1350
F-stat	32.8***	32.8***	33.3***	32.7***	32.7***	32.9***	32.3***	32.8***	33.3***
R^2 adjusted	0.59	0.59	0.60	0.59	0.59	0.59	0.59	0.59	0.60

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table D.4: All countries, Individuals using the Internet

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Internet	-0.159***	-0.158***	-0.157***	-0.160***	-0.160***	-0.158***	-0.158***	-0.159***	-0.157***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Governance									
(column	0.018	0.014	0.059***	-0.034**	-0.023***	0.033*	0.001	-0.015	0.081***
header)	(0.021)	(0.026)	(0.016)	(0.017)	(0.027)	(0.019)	(0.030)	(0.025)	(0.023)
Controls									
Real GDP	0.101***	0.101***	0.083**	0.127***	0.117***	0.106***	0.107***	0.116***	0.090***
	(0.032)	(0.034)	(0.033)	(0.033)	(0.034)	(0.030)	(0.034)	(0.035)	(0.032)
Human	-0.211***	-0.231***	-0.159**	-0.257***	-0.228**	-0.231***	-0.235***	-0.247***	-0.180**
Capital	(0.080)	(0.084)	(0.076)	(0.083)	(0.089)	(0.089)	(0.082)	(0.082)	(0.084)
Constant									
Constant	-0.183	-0.171	-0.049	-0.379	-0.316***	-0.231	-0.222	-0.288	-0.111
	(0.308)	(0.323)	(0.315)	(0.320)	(0.335)	(0.291)	(0.329)	(0.333)	(0.309)
Sample start	1997	1997	1997	1997	1997	1997	1997	1997	1997
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	23	23	23	23	23	23	23	23	23
N	101	101	101	101	101	101	101	101	101
N*T	2316	2316	2316	2316	2316	2316	2316	2316	2316
F-stat	46.5***	46.4***	47.8***	46.3***	46.4***	46.7***	46.4***	46.3***	47.6***
R^2 adjusted	0.67	0.67	0.68	0.67	0.67	0.67	0.67	0.67	0.68

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Appendix E: Results for WGI / summary measures (ctd.)

Table E.1: EU countries, Fixed broadband subscriptions

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology)									
Broadband	-0.320***	-0.321***	-0.323***	-0.321***	-0.322***	-0.320***	-0.322***	-0.322***	-0.322***
	(0.008)	(0.007)	(0.007)	(0.008)	(0.007)	(0.007)	(0.008)	(0.007)	(0.008)
Governance									
(column	-0.013	-0.036	-0.035	-0.034	-0.105***	0.068	-0.074**	-0.057	-0.031
header)	(0.028)	(0.027)	(0.027)	(0.038)	(0.032)	(0.079)	(0.036)	(0.035)	(0.061)
Controls									
Real GDP	-0.075	0.092**	0.076**	0.084	0.149***	0.055	0.129**	0.102**	.0.073**
	(0.052)	(0.040)	(0.034)	(0.057)	(0.041)	(0.040)	(0.052)	(0.049)	(0.035)
Human	-0.732**	-0.688**	0.770***	0.739**	0.648**	0.774***	0.636**	0.672**	0.753***
Capital	(0.330)	(0.277)	(0.281)	(0.318)	(0.280)	(0.287)	(0.311)	(0.293)	(0.282)
Constant									
Constant	-0.303	-0.412	-0.322	-0.368	-0.893**	-0.216	-0.719	-0.470	-0.279
	(0.422)	(0.374)	(0.304)	(0.450)	(0.385)	(0.336)	(0.437)	(0.419)	(0.312)
Sample start	1999	1999	1999	1999	1999	1999	1999	1999	1999
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	21	21	21	21	21	21	21	21	21
N	28	28	28	28	28	28	28	28	28
N*T	519	519	519	519	519	519	519	519	519
F-stat	288.7***	292.4***	294.4***	278.2***	293.2***	285.4***	288.0***	293.0***	287.9***
R^2 adjusted	0.95	0.95	0.95	0.94	0.95	0.94	0.94	0.95	0.94

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table E.2: Non-EU OECD countries, Fixed broadband subscriptions

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Broadband	-0.296***	-0.295***	-0.305***	-0.294***	-0.299***	-0.295***	-0.298***	-0.293***	-0.303***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.005)	(0.004)	(0.004)	(0.003)
Governance									
(column	-0.075***	-0.114	-0.089***	-0.066*	0.103	-0.103	-0.052	-0.121*	-0.195***
header)	(0.025)	(0.084)	(0.028)	(0.038)	(0.088)	(0.085)	(0.052)	(0.062)	(0.054)
Controls									
Real GDP	-0.029	-0.038	0.012	-0.003	-0.053	-0.097	-0.026	-0.024	-0.062
	(0.242)	(0.253)	(0.251)	(0.246)	(0.237)	(0.287)	(0.255)	(0.253)	(0.262)
Human	0.796*	0.897**	0.948**	0.940**	0.985**	0.985**	0.890**	0.959**	1.066**
Capital	(0.407)	(0.421)	(0.435)	(0.432)	(0.417)	(0.476)	(0.410)	(0.433)	(0.454)
Constant									
Constant	0.724	0.781	0.133	0.308	0.610	1.282	0.586	0.591	0.910
	(2.248)	(2.364)	(2.300)	(2.281)	(2.234)	(2.680)	(2.400)	(2.368)	(2.409)
Sample start	1999	1999	1999	1999	1999	1999	1999	1999	1999
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	21	21	21	21	21	21	21	21	21
N	14	14	14	14	14	14	14	14	14
N*T	272	272	272	272	272	272	272	272	272
F-stat	283.4***	273.2***	266.8***	294.5***	241.9***	247.1***	248.5***	292.3***	266.6***
R^2 adjusted	0.95	0.94	0.94	0.95	0.94	0.94	0.94	0.95	0.94

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table E.3: Other countries, Fixed broadband subscriptions

	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Broadband	-0.215***	-0.215***	-0.214***	-0.216***	-0.221***	-0.217***	-0.219***	-0.215***	0.214***
	(0.014)	(0.014)	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)	(0.013)	(0.014)
Governance									
(column	0.105	0.023	0.050*	-0.003	-0.216***	-0.082**	-0.113*	0.016	0.031
header)	(0.065)	(0.064)	(0.028)	(0.048)	(0.043)	(0.039)	(0.058)	(0.068)	(0.045)
Controls									
Real GDP	0.260***	0.276***	0.256***	0.295***	0.391***	0.292***	0.320***	0.284***	0.267***
	(0.091)	(0.081)	(0.081)	(0.089)	(0.105)	(0.100)	(0.098)	(0.081)	(0.081)
Human	-0.064	-0.059	-0.025	-0.077	-0.098	0.061	-0.015	-0.077	-0.030
Capital	(0.274)	(0.296)	(0.281)	(0.309)	(0.268)	(0.307)	(0.300)	(0.300)	(0.287)
Constant									
Constant	-1.953**	-2.131***	-1.957***	-2.295***	-3.229***	-2.384***	-2.603***	-2.193***	-2.060***
	(0.767)	(0.660)	(0.672)	(0.731)	(0.893)	(0.839)	(0.822)	(0.659)	(0.677)
Sample start	1999	1999	1999	1999	1999	1999	1999	1999	1999
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	21	21	21	21	21	21	21	21	21
N	59	59	59	59	59	59	59	59	59
N*T	990	990	990	990	990	990	990	990	990
F-stat	32.5***	32.1***	32.5***	32.0***	33.4***	32.4***	32.1***	32.2***	32.0
R^2 adjusted	0.66	0.66	0.66	0.66	0.67	0.66	0.66	0.66	0.66

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

Table E.4: All countries, Fixed broadband subscriptions

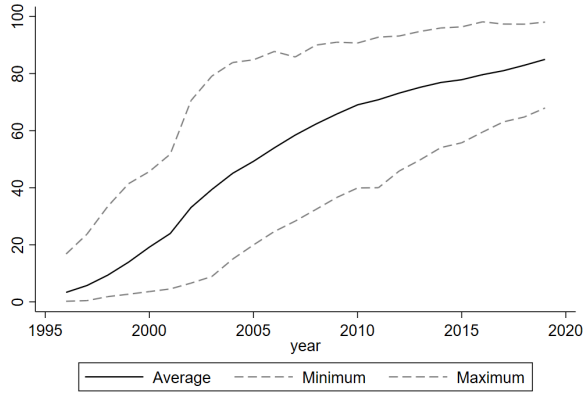
	Control of Corruption	Government Effectiveness	Political Stability	Regulatory Quality	Rule of Law	Voice and Accountability	Respect	Capacity	Process
Technology									
Broadband	-0.262***	-0.261***	-0.258***	-0.262***	-0.265***	-0.262***	-0.264***	-0.261***	-0.258***
	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)
Governance									
(column	0.050**	0.050	0.069***	-0.025	-0.150***	0.021	-0.046	0.017	0.104***
header)	(0.020)	(0.038)	(0.017)	(0.023)	(0.037)	(0.041)	(0.029)	(0.038)	(0.028)
Controls									
Real GDP	0.327***	0.0319***	0.293***	0.363***	0.442***	0.341***	0.378***	0.337***	0.296***
	(0.062)	(0.051)	(0.056)	(0.066)	(0.082)	(0.061)	(0.073)	(0.056)	(0.054)
Human	-0.043	-0.073	-0.102	-0.182	-0.241***	-0.126	-0.192	-0.125	-0.093
Capital	(0.167)	(0.154)	(0.184)	(0.184)	(0.196)	(0.164)	(0.194)	(0.165)	(0.167)
Constant									
Constant	-2.572***	-2.482***	-2.195***	-2.797***	-3.478***	-2.642***	-2.928***	-2.603***	-2.242***
	(0.524)	(0.434)	(0.459)	(0.542)	(0.684)	(0.521)	(0.597)	(0.471)	(0.459)
Sample start	1999	1999	1999	1999	1999	1999	1999	1999	1999
Sample end	2019	2019	2019	2019	2019	2019	2019	2019	2019
T	21	21	21	21	21	21	21	21	21
N	101	101	101	101	101	101	101	101	101
N*T	1781	1781	1781	1781	1781	1781	1781	1781	1781
F-stat	84.3***	85.9***	85.5***	84.8***	85.9***	84.7***	84.9***	85.3***	85.9***
R^2 adjusted	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83

Notes: Fixed Effect (cross-section weights) estimates of the change in technology (dependent variable) on past (t-1) changes in technology, governance and controls. White cross-section robust standard errors and covariance in parentheses. Adjusted R^2 is cross-section weighted. *** significant at 1% level, ** significant at 5%, * significant at 10%, T number of periods, N number of countries, N*T number of observations. The countries and country aggregates are listed in Table A.1 and the variables in Table A.2 in Appendix A.

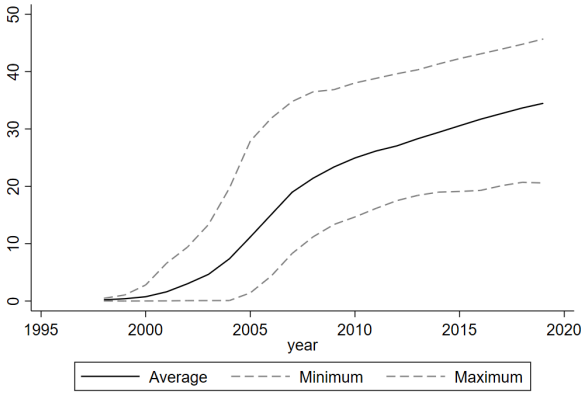
Appendix F: Figures

Figure F.1: Data for Digital Technologies,
EU countries / Non-EU OECD countries

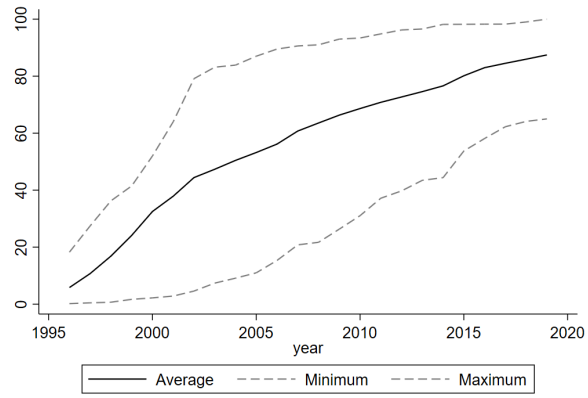
(a) Individuals using the Internet, EU countries



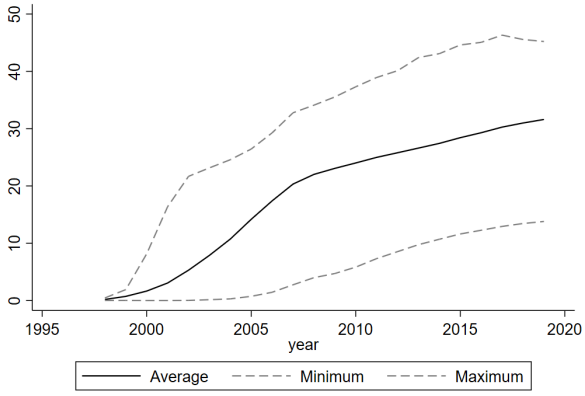
(b) Fixed broadband subscriptions, EU countries



(c) Individuals using the Internet, Non-EU OECD



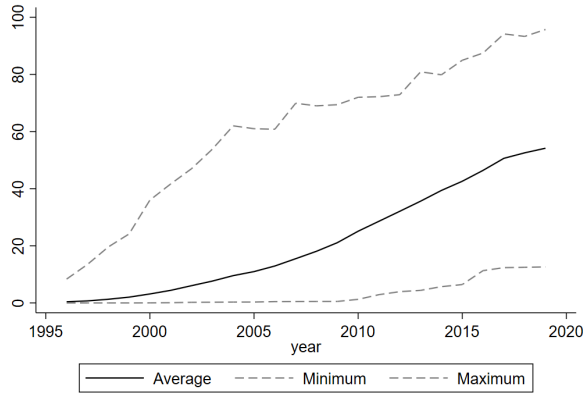
(d) Fixed broadband subscriptions, Non-EU OECD



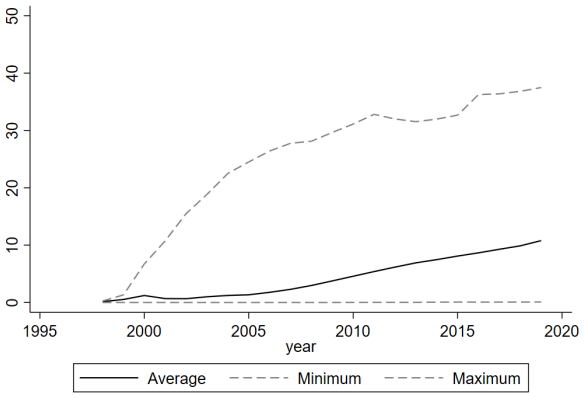
Source: World Bank, authors' calculations.
Notes: 'Non-EU OECD' is short for 'Non-EU OECD countries'.

Figure F.2: Data for Digital Technologies,
Other countries / All countries

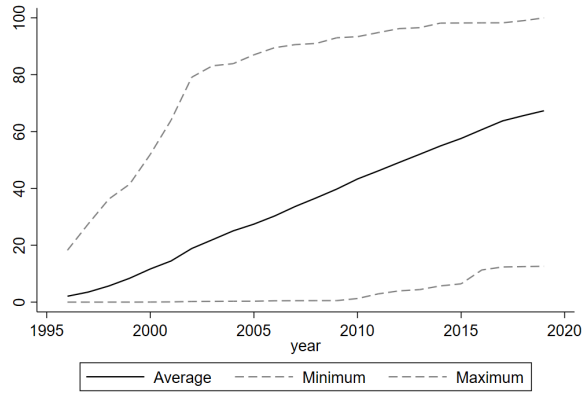
(a) Individuals using the Internet, Other countries



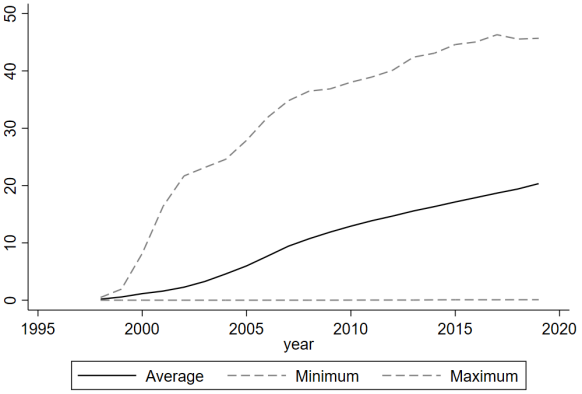
(b) Fixed broadband subscriptions, Other countries



(c) Individuals using the Internet, All countries



(d) Fixed broadband subscriptions, All countries



Source: World Bank, authors' calculations.

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