EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

Vincent Labhard, Jonne Lehtimäki

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

No 2735 / September 2022

Abstract

Digitalisation may be viewed as a sequence of supply and technology shocks affecting the economy through productivity and output, employment and labour markets, competition and market structure. This paper focuses on the effects of digitalisation on economic growth, and how those effects may be impacted by institutions and governance. It discusses a number of theoretical mechanisms and empirical evidence for different sets of European and other countries. The results suggest that better institutions and governance tend to be associated with greater growth-enhancing effects from digital technologies.

JEL codes: E22, O33, O43, O52, O57
Keywords: technology, adoption, estimates, pooled mean group estimation (PMGE), panel

Non-Technical Summary

Digital technologies have spread into almost every aspect of economic activity. Robots and the process of 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 an ever-present source of information, a medium of exchange, and an enabler for various types of different transactions. New digital technologies are introduced at a rapid pace, and existing ones are continuously improved.

The increase and adoption of digital technologies - commonly referred to as digitalisation - is one of the most important technological transformations in the history, affecting economies worldwide at a previously unseen scale. It has been studied in the literature to some extent, in particular its effects 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 effects of digitalisation on economic growth and how they may be impacted by institutions and governance. Institutions are entities or bodies that are part of the public sector and perform public functions, as for example any public authority, such as courts and ministries. 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 for the growth effects of digitalisation to be realised? The reason is that institutions and governance interact with digitalisation, and that the growth effects depend on this interaction. For example, the internet, as a source of information, is used by producers and consumers, and so supports economic growth. The effect is likely to be greater when institutions and governance are of high quality (and as a result, for example the internet is widely available), and less if they are not (and it is not).

The paper suggests that the growth effects of digitalisation may be greater 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 (the EU and the OECD as well as the total sample in the study which consists of 101 countries around the globe), for the period 1996-2019 (a maximum of 24 years).

The suggestion that the growth effects of digitalisation are greater when institutions and governance are of high quality is also relatively robust. The paper takes into account a number of other factors that may play a role in economic growth, such as the size of the economy, whether it is growing or contracting, how much human capital (brains and ideas) it has, or how much is invested, traded, or spent by the public sector.

1 Introduction

From their origins in the middle of the 20th century, digital technologies have spread 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). The essence of digital technology is the binary-digits (or 'bits') format for storing information, which has facilitated processing, storage and exchange of data, and has led, inter alia, to notable savings in costs, as described in Goldfarb and Tucker (2019).[1]

The increase in digital technologies - commonly referred to 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 fallout effects 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 facets of the effects of digitalisation have been studied in prior research, at least qualitatively.[2] This includes the effects of digitalisation on the macroeconomy, 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). At the aggregate level the literature emphasises the so-called productivity puzzle, whereby economy-wide productivity growth is much lower than expected in an era of rapid technological change, which seems to be at odds with the firm-level evidence. This suggests that there may also be adverse effects from technology on productivity, as noted for example by Gordon (2016), even if they may be more difficult to quantify, such as digital and non-digital systems being run in parallel, or effects from distraction and/or addiction.[4]

The literature on the labour market effects is also ambiguous, because digital technologies

[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 summary and references, see for example Anderton and Cette (2021) and Anderton et al. (2020). For recent work on the process of digitalisation see Baccianti et al. (2022) and Hoffreumon and Labhard (2022).

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

[4] 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.

may be magnifying and enhancing human capabilities (complementing labour), as argued by Acemoglu and Restrepo (2019), Acemoglu (2012) or Acemoglu et al. (2005), 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.

Apart from productivity and labour markets, some attention has also been given to the growth effects of digital technologies, notably comparing those growth effects to the growth effects of other general-purpose technologies such as electricity (see for example Jovanovic and Rousseau (2005), or the contributions in Helpman (2003) or Lipsey et al. (2005)). Some papers have also investigated the growth impact of specific technologies, for example the internet, finding both growth-enhancing (Choi and Yi, 2009) and growth-reducing (Maurseth, 2018) effects.

In order to extend the existing literature, and because they are both important, in particular for policy-making, this paper considers (i) the growth effects of digital technologies and (ii) the growth effects of the interaction of those technologies with institutions and governance, for the macroeconomy. The paper describes a number of theoretical mechanisms and provides empirical evidence using two complementary estimation techniques.

The empirical evidence comes from a large cross-section of data, comprising in total 101 countries. The data set consists of countries from all around the world in order to make the assessment more robust as well as to identify potential differences across different sets of countries.[5] Such differences could emerge, for example, in countries at different stages of development if institutions and governance are intrinsically linked to advancement.

One distinctive feature of this paper is that digitalisation 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 a difference to most of the preceding literature which relies on data on Information and Communication Technology (ICT) patents, investment or consumption.[6] While useful inter alia as an alternative measure, those other data might not fully capture the actual level of technology (investment, for example, may be more or less efficient), and might not reveal sufficient information about the specific technologies as they are based on statistical categories which have been defined with other objectives in mind.

While measuring digitalisation via the adoption of specific technologies is a reasonable approach, it also has its limitations. They mostly stem from limited data availability, especially for the most recent digital technologies, including artificial intelligence, internet of things, digital twins, edge and quantum computing. Data (if any) for the most recent digital technologies are

[5] A companion paper, Baccianti et al. (2022), focuses on the diffusion of digital technologies, and the potential role played by institutions and governance in that context

[6] For studies summarising the work focussing on the role of ICT, see Bloom et al. (2010), Cardona et al. (2013) and, more recently, Vu et al. (2020).

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 (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 behind the growth effects of digital technologies, and their interplay with institutions and governance. Section 3 describes the data sources and samples as well as the data used in this paper for digital technologies, institutions and governance as well as for other factors that may play a role for economic growth and need to be taken into account. Section 4 describes the methodology for estimating the growth effects, and how that methodology captures the interaction of technology with institutions and governance. The empirical evidence is presented and discussed in Section 5, and Section 6 concludes.

2 Theory

This section summaries the background and theoretical mechanism behind the potential growth effects of digital technologies as well as the potential interplay of technology change with institutions and governance. It argues that while technology has historically had a growth-enhancing effect, the absence or presence of established and high quality societal environment can help in amplifying the potential growth effects.

2.1 The Growth Effects of Digital Technologies

Technology, at least implicitly, has been considered to be a key ingredient of models of economic growth ever since the conceptualisation of neoclassical growth theory with the hallmark Solow (1957a) and Solow (1957b) papers. Technological (or technical, in the terminology of Solow (1957b)) progress, by virtue of pushing the production boundary of an economy further, provides the scope for enabling the economy to grow more than it would have in the absence of the technological improvement.

Half a century after his seminal work, Solow (2005)[7] noted that the main effort and accomplishment of growth theory in subsequent decades went into 'the endogenization of changes in technology (or more broadly total factor productivity (TFP), though usually with technology in mind) and changes in the stock of human capital' which, as discussed in more detail in Section 2.2, 'have led to a welcome emphasis on social norms and institutions as enabling or limiting factors or even as actual sources of growth'.

[7] In the introduction of one of the most comprehensive handbooks on economic growth to date, which also includes many relevant references to technology in Aghion and Durlauf (2005a) (Part 4), alongside those on theories (Part 1) and empirics (Part 2) in Aghion and Durlauf (2005b).

There is a wide array of literature which analyses the growth effects of technology from a historical perspective. Mokyr (2005) is one prominent example, focusing on the role of technology (including in relation to institutions) during the industrial revolution, and noting in particular the view 'that useful knowledge and its application to production' and that 'as far as future technological progress and economic growth are concerned, not even the sky is the limit'. Among the papers making explicit reference to digital technologies is Jorgensen (2005), who considers 'information technology (IT)', a term that has been superseded somewhat by the slightly more general term 'digital technologies' which spans both communication (as in the term 'information and communication technologies (ICT)' used in the interim) and production technologies (encompassing automation and robotics). As he points out with reference to Schreyer (2000), changes in the (relative) price of those technologies have been instrumental in initiating the corresponding investment and spread of those technologies, and the entailed growth effects, notably in the 1990s and 2000s in the United States, including relative to the countries in Europe.

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 growth (and other effects on the economy) in the medium to long term[8].

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[9]. Indeed, digital technologies are very general, as they have applications throughout the economy, in principle for all agents, activities and 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[10]. 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 (for example, operating a power switch is sufficient for using electricity, but it 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 may show 'too little, too late' innovation (Bresnahan and Trajtenberg, 1995). In other words, the extent of the growth effects of digitalisation is going

[8] A collection which stresses the importance of general-purpose technologies for growth is available in Helpman (2003).

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

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

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 interplay of digital technologies with institutions and governance.

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

The importance of institutions for economic growth has been emphasised ever since the seminal work by North (1991) who pointed out that institutions play a substantial role in shaping modern economies and are important (positive or negative) drivers of growth, and therefore should be taken into account when modelling growth[11], even if they may be considered 'background forces' supporting the basic neoclassical model rather than core elements[12].

In fact, North (1991) also made an early reference to the interaction of institutions and technology in noting that 'an institutional framework [...] permits [...] to capture the potential economic benefits of modern technology'. The relevance of institutions for economic growth (or more generally, as he labels it, development) is also documented in Acemoglu et al. (2005), who examine the role of institutions from multiple points of view, and study historical evidence on the reasons for the differences in institutions across countries.

The necessity of considering institutions alongside industrial structure, when analysing economic growth driven by technological change, was first noted by Nelson (2005), who also pointed out that institutions display a great diversity that would have to be taken into account when trying to make sense of economic growth. In parallel, several authors began examining the growth effects of governance, even if defined more narrowly than in this paper. For example Gradstein (2004) provides some evidence on a positive growth effect of property rights, and Méndez-Picazo et al. (2012) point to a significant indirect effect of governance on growth via effects on entrepreneurship.

The approach taken in this paper is to consider the growth effects of (digital) technologies, institutions and governance, as well as the growth effects stemming from their interaction. This is a novelty in the literature and worth exploring, because the interaction might potentially have

[11] Also see Barro (1996). A comprehensive empirical study into growth effects, including those that might be attributed to institutions, is available in Bassanini et al. (2001) for the OECD countries.

[12] See Solow (2005).

higher growth effects if compared to those from technology or institutions and governance on their own.

Digitalisation, institutions and governance provide opportunities to economic agents, for example in terms of access to information access, by defining a framework for market transactions, by establishing accountability for the stakeholders (e.g. by increasing the traceability of agents and actions) and by enabling enforcement. This implies that they can be mutually reinforcing in their growth effects or, alternatively, that growth effects may be subdued if only one of them is in force.

A few examples may help to illustrate some of the mechanisms at play. Take an economy that has high quality institutions and governance and very little digital technology, for example, none of the digital communication tools and platforms, or none of the complementary human capital that may be required to take advantage of such tools or platforms. This will lead to investment and growth likely being lower because information on investment opportunities is going to be costly, or not up-to-date, and investment, therefore, very risky. Alternatively, consider an economy that is very digital, and has poor quality institutions or governance. While information is not an issue, the economy is also unlikely to generate high levels of investment as it is unclear what the potential return is going to be. This economy is also missing the interaction of technology and institutions and governance and, as a result, is not going to grow as fast as an economy with both in force.

In addition, there are two scenarios in which the interaction is particularly pertinent. The first is the digitalisation of institutions and governance. Through the adoption of digital technology, institutions are becoming more likely to fulfil their mandates and achieve their objectives, and thus contribute to an environment that is more conducive to growth. The second area is the institutions and governance of digitalisation - how the process of digitalisation is carried out, both the organisations and the checks and balances that are in place to accompany that process, in contrast to pure self-governance that is not uncommon in the context of new technologies. A proper policy of digitalisation is going to increase the chances that the process is inclusive and conducive to higher growth rates.

The remainder of the paper provides empirical evidence on whether digital technology and institutions and governance have growth-enhancing effects beyond the growth effects associated to either on its own (or other factors). It should be noted that a few of the caveats of the existing empirical work linking technology and/or institutions to growth apply to the approach taken in this paper: varying definitions, the complexity of institutions and governance, other factors impacting growth performance, as well as the appropriate measurement of institutions and governance. Some of the issues regarding the measurement of technology, institutions and governance raised in that and other papers are addressed in Section 3. This includes, for example, the suggestion by Glaeser et al. (2004) that some of the indicators of institutional quality may be conceptually unsuitable to address questions of institutions.

3 Data

This section describes the data used in this paper. It covers the data sources and samples, describes the data capturing digital technologies as well as capturing institutions and governance. It also discusses other data, notably the variables used in the estimations to control for factors contributing to growth that are independent of digital technologies, institutions and governance. Series codes and series transformations for all the data used in this paper as well as the countries and country aggregates in the panel can be found in Appendix A.

3.1 Sources and Sample

Neither the quality of institutions and governance or the degree of digitalisation are easy 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 advances[13]. Another challenge is capturing the different aspects of those technologies (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 sources with dedicated and comprehensive databases both for measuring the degree of digitalisation and the quality of institutions and governance. Another important factor was the availability of long time and cross-section dimensions, with series extending back to 1960 and for as many as 253 countries, even if not all observations are available for all series.

The effective sample extends from 1996 to 2019 when technological change is measured by the number of internet users, and 1998 to 2019 in the case of fixed broadband subscriptions. Any missing values in the effective sample were imputed by interpolation (in the middle of the sample) or (on the very rare instances of occurring at the end of the sample) by assuming a constant rate of growth from the last observation.[14]

The full cross-section, 'All countries', consists of 101 countries for which sufficient data was available to address the questions of the study.[15] Three smaller cross-sections were also considered, with countries grouped by 'EU countries' (27), 'Non-EU OECD countries' (16) and

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

[14] The interpolation was used, for example, for the institutions and governance indicators in 1997, 1999 and 2001 as they were published on a biennial basis until 2002).

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

'Other countries' (58).[16]

The groupings 'EU countries' and 'Non-EU OECD countries' are (or becoming) 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 still 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 population)', 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 as they enable the use of digital goods and

[16]These specific aggregates were studied because they are often used as a reference point in the policy debate. The estimates are similar for the groupings prior to Brexit in 2020 and the accession of Colombia and Costa Rica to the OECD, with 28 in the 'EU countries', 13 'Non-EU OECD countries' and 60 in the 'Other countries', as used in an earlier version of this paper.

services, e.g. no e-commerce or e-government without digital connections. Second, while they are enabling, or even a precondition for other technologies, they say little about the spread of those other technologies. Third, they are capturing the number of users or installations - the extensive margin - rather than how much or for what purpose they are 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. For both internet users and broadband subscriptions, the maximum can be found among the 'Non-EU OECD countries', and the minimum among the 'Other countries'. The means and standard deviations tend to be higher for EU and OECD countries, with the standard deviations a little more similar across the groupings.

Table 1: Descriptive statistics of technology variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Individuals using the internet	49.9	30.6	0.1	4.0	87.0	98.1
Fixed Broadband subscriptions	20.6	12.7	0.0	1.3	36.8	46.0
Non-EU OECD countries						
Individuals using the internet	53.5	31.8	0.1	4.4	91.2	99.0
Fixed Broadband subscriptions	19.5	13.7	0.0	0.8	37.7	46.8
Other countries						
Individuals using the internet	21.1	23.9	0.0	0.1	60.8	95.7
Fixed Broadband subscriptions	5.1	7.7	0.0	0.0	15.7	37.7
All countries						
Individuals using the internet	34.3	31.1	0.0	0.5	81.2	98.1
Fixed Broadband subscriptions	11.8	12.7	0.0	0.1	31.5	46.8

Notes: The sample is 1996-2019 for individuals using the internet and 1998-2019 for fixed broadband subscriptions. 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The 'EU countries', 'Non-EU OECD countries', 'Other countries' and 'All countries' are listed 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 shorter samples or changes in methodology during the sample period. They included:

- the series 'Secure Internet servers', available from 2000 and the Digital Advancement Index, both published by the World Bank,
- the European Commission's Digital Economy and Society Index (DESI) published onwards from 2014 and its international (iDESI) counterpart,
- the KOF Information Globalisation Index (total as well as de-facto and de-jure sub-

indicators) presented originally in Dreher (2006) and revisited in Gygli et al. (2019), which begins from 1970 and is a composite index and therefore a potentially useful measure to study concepts of broad technological changes in economies, and

- the 'Digitalisation Index' introduced by Katz et al. (2014), starting in 2004, which is another composite index (and thus also providing a more holistic measure of digitalisation), made up of 24 single indicators for six categories; the categories are affordability, reliability, access, capacity, usage and human capital; the indicators include price series and series capturing technical features and types of technology, from a large number of sources (see Sabbagh et al. (2012)) and also include the number of individuals using the internet (from the World Bank) mentioned before.

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 compiled from the Worldwide Governance Indicators (WGI) described in Kaufmann et al. (2010), and published by the World Bank beginning from 1996. This source was chosen due to the advantages of comprehensive databases, and the availability of long time series and cross-section dimensions mentioned in connection with the indicators on digitalisation. 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 main sets of data.

The WGI consists of six distinct indicators, each focusing on a specific aspect of institutions and governance. For the approach taken by this paper, the indicators 'voice and accountability', 'political stability and absence of violence' and 'government effectiveness' were considered to capture primarily institutional aspect (the framework or structure), 'regulatory quality', 'rule of law' and 'control of corruption' the governance aspect (how the institutions are run).

The 'voice and accountability' indicator relates to the perceived participation in the selection of government, as well as freedom of expression, association and media. The 'political stability and absence of violence' indicator measures the likelihood of violence, including terrorism. 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. Those three indicators are considered to refer to institutions.

The other three indicators are taken to relate to governance. 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 'control of corruption' indicator measures the abuse of public power for private gain and the influence and interference of elites and private interests.

In order to have summary measures, indicators were created for the averages across the three indicators associated to institutions or governance respectively.[17] This helps to assess the overall impact and the relative importance of institutions and governance. However, it should be noted that institutions and governance are codependent to a large degree and that the approach presented here provides evidence on the role institutions and governance across a country while saying very little on the contribution of individual institutions operating in an economy. 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.

The data for all 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.

The descriptive statistics for the data on institutions and governance are presented in Table 2. For all variables, including those constructed by the authors of this paper, the maxima tend to be recorded for the EU countries and the minima for other than EU and OECD. The mean values tend to be higher among EU and OECD countries than elsewhere, with the noticeable distance for example for the indicator 'Political Stability and Absence of Violence'. The standard deviation is generally lowest within the EU. In terms of standard deviation, the indicator 'Control of Corruption' is the one that stands out most.

[17] The analysis was also done for the total average and each of the six indicators individually. The results are available upon request. In all cases, in the absence of strong priors about the relative importance of the different aspects, averages were based on equal weight for each of the components considered.

Table 2: Descriptive statistics of institutional variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Control of Corruption	1.008	0.799	-0.615	-0.016	2.165	2.470
Government Effectiveness	1.115	0.627	-0.569	0.339	1.943	2.354
Political Stability and Absence of Violence	0.822	0.429	-0.474	0.270	1.393	1.760
Regulatory Quality	1.155	0.457	-0.184	0.576	1.781	2.098
Rule of Law	1.088	0.625	-0.634	0.198	1.884	2.100
Voice and Accountability	1.109	0.350	-0.292	0.551	1.541	1.801
Quality of Governance	1.084	0.610	-0.461	0.258	1.926	2.128
Institutional Environment	1.015	0.424	-0.095	0.443	1.573	1.858
Non-EU OECD countries						
Control of Corruption	1.234	0.906	-0.928	-0.268	2.181	2.391
Government Effectiveness	1.215	0.709	-0.459	0.071	1.926	2.181
Political Stability and Absence of Violence	0.429	0.978	-2.375	-1.186	1.372	1.656
Regulatory Quality	1.170	0.586	-0.106	0.280	1.811	2.089
Rule of Law	1.151	0.824	-0.890	-0.352	1.922	2.036
Voice and Accountability	0.975	0.609	-0.851	-0.059	1.559	1.738
Quality of Governance	1.185	0.757	-0.459	-0.125	1.936	2.092
Institutional Environment	0.873	0.724	-0.986	-0.264	1.605	1.726
Other countries						
Control of Corruption	-0.404	0.699	-1.532	-1.096	0.335	2.326
Government Effectiveness	-0.228	0.668	-1.622	-0.908	0.532	2.437
Political Stability and Absence of Violence	-0.342	0.771	-2.810	-1.323	0.666	1.615
Regulatory Quality	-0.183	0.668	-2.236	-0.863	0.528	2.261
Rule of Law	-0.366	0.652	-1.852	-1.079	0.450	1.879
Voice and Accountability	-0.351	0.713	-1.907	-1.312	0.537	1.343
Quality of Governance	-0.318	0.639	-1.788	-0.942	0.436	2.066
Institutional Environment	-0.307	0.585	-1.912	-0.927	0.381	1.287
All countries						
Control of Corruption	0.245	1.048	-1.531	-0.979	2.044	2.391
Government Effectiveness	0.384	0.945	-1.622	-0.786	1.804	2.437
Political Stability and Absence of Violence	0.078	0.946	-2.810	-1.174	1.253	1.760
Regulatory Quality	0.416	0.876	-2.236	-0.618	1.680	2.261
Rule of Law	0.301	0.969	-1.852	-0.871	1.768	2.038
Voice and Accountability	0.244	0.934	-1.907	-1.055	1.459	1.739
Quality of Governance	0.321	0.944	-1.788	-0.781	1.834	2.092
Institutional Environment	0.236	0.858	-1.912	-0.782	1.447	1.791

Notes: The sample is 1996-2019. 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The 'EU countries', 'Non-EU OECD countries', 'Other countries' and 'All countries' are listed in Table A.2 in Appendix A.

As in the case of digital technologies, a number of alternative data sources were considered for institutions and governance during the study. They yielded broadly similar results to the WGI indicators, but were omitted owing to, inter alia, less extensive samples. Notable options were:

- the Fraser Institute Economic Freedom Index (Gwartney et al. (2019)),
- the OECD indicators of Employment Protection Legislation (EPL) and Product Market Regulation (PMR), and
- the World Economic Forum's Global Competitiveness Index.

3.4 Other Data

In order to capture the actual effects of digitalisation and its interplay with institutions and governance on economic growth, other potential factors affecting growth should be controlled for. In this paper, those factors include elements identified in classical and neoclassical growth theory and relate to the accumulation of physical capital, human capital and other factors, identified inter alia in connection with endogenous growth theory, such as fiscal policy (and public sector policies more generally), the labour market and international trade.

The specific control variables used for this purpose in this paper are: (i) investment, measured with gross fixed capital formation, as an indicator of the capital stock; (ii) labour force, in millions of people, (iii) unemployment, (iv) human capital, measured by the human education index, (v) government expenditure (as per cent of GDP), as an indicator for fiscal policy and (vi) trade (as per cent of GDP). The descriptive statistics for the control data are provided in Table 3. For most of the variables, EU and Non-EU OECD countries have similar statistics, with trade being the notable exception with higher numbers for the EU.

Table 3: Descriptive statistics of control variables

Variable	Mean	SDev	Min	10th	90th	Max
EU countries						
Real GDP per capita, log	10.4	0.5	9.2	9.8	10.9	11.7
Investment, % of GDP	22.2	4.1	4.5	17.8	27.1	43.4
Human Capital	0.79	0.08	0.56	0.68	0.89	0.95
Unemployment	8.9	4.4	1.8	4.4	15.0	27.9
Labour Force, mn, log	1.2	1.4	-1.9	-0.5	3.2	3.8
Government Expenditure, % of GDP	19.7	2.9	11.7	16.1	24.1	27.9
Trade, % of GDP	114.2	60.5	37.5	56.1	177.4	380.1
Non-EU OECD countries						
Real GDP per capita, log	10.4	0.5	9.1	9.6	11.0	11.2
Investment, % of GDP	22.9	3.9	13.2	18.2	28.4	37.5
Human Capital	0.79	0.12	0.43	0.59	0.91	0.93
Unemployment	6.2	2.8	1.9	3.2	10.2	20.5
Labour Force, mn, log	2.3	1.6	-1.9	0.7	4.2	5.1
Government Expenditure, % of GDP	16.8	4.3	8.1	11.3	22.7	26.8
Trade, % of GDP	60.4	22.0	18.1	31.1	88.3	131.0
Other countries						
Real GDP per capita, log	8.9	0.9	6.2	7.8	9.9	11.5
Investment, % of GDP	22.8	7.1	2.0	15.4	32.6	57.7
Human Capital	0.57	0.15	0.16	0.34	0.76	0.86
Unemployment	7.6	5.5	0.1	2.3	15.2	33.3
Labour Force, mn, log	1.9	1.6	-1.9	0.1	4.0	6.7
Government Expenditure, % of GDP	13.1	4.5	2.0	8.2	18.9	30.0
Trade, % of GDP	84.0	61.0	1.2	37.9	130.8	442.6
All countries						
Real GDP per capita, log	9.5	1.1	6.2	8.0	10.8	11.7
Investment, % of GDP	22.7	5.9	2.0	16.3	30.0	53.6
Human Capital	0.66	0.18	0.16	0.38	0.87	0.92
Unemployment	7.4	5.0	0.3	2.8	14.0	33.3
Labour Force, mn, log	1.8	1.6	-1.9	-0.1	3.7	6.7
Government Expenditure, % of GDP	15.7	4.7	2.0	9.9	21.2	30.0
Trade, % of GDP	93.4	63.4	1.2	42.3	154.9	437.3

Notes: The sample is 1996-2019. 'Mean' is the arithmetic mean, 'SDev' the standard deviation, 'Min' the minimum, '10th' the 10th, '90th' the 90th percentile, 'Max' the maximum. The 'EU countries', 'Non-EU OECD countries', 'Other countries' and 'All countries' are listed in Table A.2 in Appendix A.

The control variables attempt to capture effects beyond technological change, institutions and governance. They shape growth and the economy more generally, contribute to a level playing field for all economic actors, ensure that extraction of rents and waste of resources are limited, and whether sound economic incentives are in place for encouraging investment, innovation, saving, solving problems related to collective actions and providing public goods. Several other control variables suggested by different sources were also considered during the study, such as inflation and the domestic credit to private sector, but were found to be largely insignificant for the sample and therefore left out of the reported results. Most of the control variables were taken from the World Bank databases.

4 Methodology

In order to estimate growth effects, this paper combines elements of the classical, neoclassical and endogenous growth literature[18] with elements from existing empirical work assessing the link between institutions and growth. The paper presents results from two different approaches. The first approach is the pooled mean group (PMG) estimator presented by Pesaran et al. (1999), which is appealing as it allows short-run coefficients, the speed of adjustment and error variances to differ across studied countries, while assuming cross-country homogeneity on the long-run coefficients. This approach is similar to that of Bouis et al. (2011) and Compton and Giedeman (2011).

The model specification of the PMGE is the following function:

$$\begin{aligned}\Delta Y_{c,t} = -\phi_c(\beta_1 Y_{c,t-1} + \beta_2 X^{INST}_{c,t-1} + \beta_3 X^{DIGI}_{c,t-1} + \beta_4 X^{C}_{c,t-1} + \beta_{0,c}) \\ +\alpha_{1,c}\Delta X^{INST}_{c,t} + \alpha_{2,c}\Delta X^{DIGI}_{c,t} + \alpha_{3,c}\Delta X^{C}_{c,t} + \epsilon_{c,t}\end{aligned} \tag{1}$$

where $Y_{c,t}$ is the log of real GDP per capita at time t for country c, X^{INST} is the variable for institutions, X^{DIGI} the variable for the level of technology and X^{C} is the set of control variables consisting of investment, human capital, unemployment, labour force, government expenditure and trade while ϵ is the error term.

The second approach is based on fixed-effect (FE) estimates, and included given their use in the related literature. An impotant example are Masuch et al. (2017) who study whether the quality of institutions is an important determinant of long-term growth in European countries, and whether cross-country differences in the quality of institutions can explain the relative long-term GDP performance of European countries. Their findings lend support to the call for structural policies aimed at enhancing the efficiency of public administration and regulation, and the rule of law. Another closely related paper is Maurseth (2020) who also studies the potential effects of technological change and institutions as well as their interaction on economic growth.

[18] For example Acemoglu (2012).

The fixed-effects estimation uses a panel with country and year fixed effects, and has the following form:

$$\Delta Y_{c,t} = \alpha + \beta_1 Y_{c,t-1} + \beta_2 \Delta X_{c,t}^{INST} + \beta_3 \Delta X_{c,t}^{DIGI} + \beta_4 \Delta X_{c,t}^{C} + \epsilon_{c,t} \quad (2)$$

where all variables are as in equation (1). In order to study the possible interaction between digitalisation and institutions and governance, the fixed-effects specification becomes:

$$\Delta Y_{c,t} = \alpha + \beta_1 Y_{c,t-1} + \beta_2 \Delta X_{c,t}^{INST} + \beta_3 \Delta X_{c,t}^{DIGI} + \beta_4 \Delta (X_{c,t}^{INST} \times X_{c,t}^{DIGI}) + \beta_5 \Delta X_{c,t}^{C} + \epsilon_{c,t} \quad (3)$$

where all variables are as in equations (1) and (2), but the interaction between the quality of institutions and governance and the level of technological change replaces the individual variables.

The expected growth-enhancing effect of digital technologies, on their own or in conjunction with high quality institutions and governance, would be documented by significant positive coefficients of the $X_{c,t}^{DIGI}$ and $(X_{c,t}^{INST} \times X_{c,t}^{DIGI})$ variables. However, as noted in Section 1, it cannot be excluded that digital technologies could also have negative effects, at least in the short run, in which case the coefficients would be negative. The same holds for institutions and governance as, while more developed frameworks would be expected to have positive effects on the functioning economies, it could also be that institutional structures might slow down the implementation of new forms of technology, and therefore hinder economic growth.

The control variables could have positive or negative signs. The labour force, human capital and investment would be expected to contribute positively to growth whereas unemployment is expected to have a negative coefficient. The same goes for government expenditure which is expected to have a negative effect as it crowds out investment from technology. Trade would be expected to have a positive impact, not least because it may imply a push to productivity, but in some cases the effect might be negative if, for example, a large share of raw materials is exported instead of being used in production.

5 Results

This section presents the main results, based on the series 'Individuals using the internet' and 'Fixed broadband subscriptions' to capture digital technology (the caveats associated to these series and alternatives were discussed in Section 3). It starts with the results for the 'EU countries' and 'Non-EU OECD countries' in Section 5.1, and continues with those for the 'Other countries' and 'All countries' in Section 5.2.

5.1 EU and Non-EU OECD Countries

As noted in section 3.1, the EU and non-EU OECD may be viewed as consisting of relatively homogeneous countries that are tied together also via common structures (and values). Moreover, they are generally more advanced economically although there is still some variation within and between the EU and non-EU OECD. The results for those countries from the PMG estimation are shown in Table 4 (for the EU in columns (1)-(4) and the non-EU OECD in columns (5)-(8)). They turn out to be relatively similar, consistent with the similarity in economic structures alluded to above.

The digital technology variables have highly significant growth effects in the long run whereas in the short run the effects are more insignificant. Institutions have a significant effect for long-term as well as short-term growth whereas the effects of governance are only significant in the long run for the EU, while having a statistically significant negative effect when internet use is used as the variable for technological development in Non-EU OECD countries in column (6).

Table 4: Pooled mean group estimates for EU and Non-EU OECD countries

	EU countries				Non-EU OECD countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Long run								
Internet	0.490**	0.293**			0.364***	0.354***		
	(0.201)	(0.120)			(0.048)	(0.040)		
Broadband			0.466*	0.350***			0.496***	0.871***
			(0.250)	(0.112)			(0.099)	(0.173)
Institutions	0.245**		0.569***		0.101**		0.134**	
	(0.124)		(0.144)		(0.050)		(0.063)	
Governance		1.014***		0.963***		-0.257***		-0.115
		(0.124)		(0.082)		(0.059)		(0.075)
Capital	0.658**	0.879***	0.365***	0.482***	0.453***	0.696***	0.488***	0.944***
	(0.258)	(0.173)	(0.098)	(0.064)	(0.086)	(0.071)	(0.099)	(0.088)
Human Capital	0.328***	0.401***	0.452***	0.138***	0.053	0.153***	0.321***	0.053***
	(0.100)	(0.063)	(0.757)	(0.255)	(0.033)	(0.019)	(0.061)	(0.020)
Unemployment	-0.303***	-0.349	0.747	-1.139***	-1.714***	-0.495	0.238	-1.385***
	(0.097)	(0.502)	(0.532)	(0.151)	(0.639)	(0.429)	(0.716)	(0.335)
Labour Force	0.428***	0.207***	0.745*	1.168***	-0.121	-0.170	0.141	0.110***
	(0.110)	(0.428)	(0.389)	(0.154)	(0.155)	(0.120)	(0.176)	(0.013)
Government	0.995***	0.353***	-0.209	-0.154**	-0.201***	-0.207***	0.206	0.522***
	(0.275)	(0.124)	(1.140)	(0.062)	(0.057)	(0.531)	(0.407)	(0.080)
Trade	0.099	0.151**	0.252*	0.265***	0.216*	-0.109	-0.105***	0.005
	(0.127)	(0.062)	(0.148)	(0.071)	(0.120)	(0.103)	(0.021)	(0.056)
Convergence								
Real GDP(-1)	-0.039**	-0.029**	-0.082**	-0.126***	0.016	0.002***	-0.116**	-0.101**
	(0.016)	(0.013)	(0.039)	(0.028)	(0.025)	(0.001)	(0.046)	(0.040)
Short run								
Internet	0.046	0.044			0.023	0.051***		
	(0.044)	(0.052)			(0.018)	(0.016)		
Broadband			0.159	0.275*			0.291	-0.066
			(0.117)	(0.166)			(0.266)	(0.264)
Institutions	0.024*		0.030**		0.032**		0.030***	
	(0.014)		(0.015)		(0.012)		(0.009)	
Governance		0.031		0.039		0.050**		0.039**
		(0.018)		(0.030)		(0.020)		(0.015)
Capital	0.102***	0.099***	0.063***	0.067***	0.049*	0.035	0.036	0.035
	(0.024)	(0.026)	(0.018)	(0.022)	(0.028)	(0.023)	(0.033)	(0.049)
Human Capital	0.109	0.085	0.111	0.130	0.001	0.008	-0.012	-0.003
	(0.173)	(0.159)	(0.116)	(0.120)	(0.017)	(0.017)	(0.014)	(0.017)
Unemployment	-0.641***	-0.722***	-0.955***	-0.965***	-0.712***	-0.710***	-0.830***	-0.737***
	(0.130)	(0.150)	(0.131)	(0.174)	(0.208)	(0.203)	(0.185)	(0.205)
Labour Force	0.175***	0.279***	0.177	0.162	0.002	0.002	0.095	-0.056
	(0.094)	(0.096)	(0.161)	(0.206)	(0.131)	(0.150)	(0.112)	(0.129)
Government	-1.281***	-1.254***	-1.185***	-1.208***	-1.621***	-1.441***	-1.510***	-1.773***
	(0.230)	(0.245)	(0.242)	(0.273)	(0.319)	(0.295)	(0.390)	(0.376)
Trade	0.055***	0.052**	0.074**	0.086**	0.060*	0.078***	0.070**	0.010
	(0.020)	(0.021)	(0.035)	(0.041)	(0.030)	(0.028)	(0.030)	(0.028)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
Countries	27	27	27	27	16	16	16	16
N	621	621	500	500	368	368	308	308
F-stat	7.8***	7.6***	14.8***	14.1***	9.5***	9.9***	17.0***	17.6***
adj. R^2	0.83	0.83	0.92	0.91	0.85	0.86	0.93	0.93

Notes: Pooled mean group estimates of the relationship of real GDP per capita growth (dependant variable) and technology, institutions, governance and control variables. *** significant at 1% level, ** significant at 5%, * significant at 10%, N number of observations.

The FE estimates for the EU are presented in Table 5 columns (1)-(4). They suggest that the growth effect of digital technology has been significant when measured by internet use, even if institutions are taken into account and other factors are controlled for. Digital technology is significant for internet use at least the 1% level. The measures of institutions and governance are significant for the longer sample at the 10 % level, but turn are insignificant for the shorter sample. Most of the control variables are significant as well, including notably investment, human capital, unemployment, government expenditure and labour force.

The FE results for the non-EU OECD, columns (5)-(8), are similar to those for the EU. The coefficients of internet use are slightly higher for the non-EU OECD. The coefficients on institutions are insignificant, whereas governance aspects are significant. Some differences between the EU and non-EU OECD groupings also exist with respect to the control variables. This is generally not surprising as the non-EU OECD economies may be different in some respects, including their economic dynamics. However, the insignificance of human capital is notable, and could be related to the particular cross-section being slightly more heterogeneous when it comes to structures of production and the stage of development.

Table 5: Fixed-effects estimates for EU and Non-EU OECD countries

	EU countries				Non-EU OECD countries			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lagged dep.								
Real GDP(-1)	-0.018*	-0.018*	-0.029**	-0.030**	-0.009	-0.007	-0.041***	-0.040***
	(0.010)	(0.008)	(0.012)	(0.012)	(0.015)	(0.015)	(0.013)	(0.013)
ΔTechnology								
Internet	0.047**	0.051***			0.086***	0.089***		
	(0.023)	(0.022)			(0.024)	(0.024)		
Broadband			0.019	0.023			0.036	0.039
			(0.071)	(0.070)			(0.058)	(0.058)
ΔInstitutions								
Institutions	0.026*		0.019		0.003		0.003	
	(0.014)		(0.012)		(0.012)		(0.011)	
Governance		0.030*		0.017		0.028**		0.020*
		(0.016)		(0.012)		(0.011)		(0.011)
ΔControls								
Capital	0.206**	0.206**	0.186**	0.186**	0.459***	0.444***	0.321***	0.313***
	(0.095)	(0.094)	(0.075)	(0.074)	(0.101)	(0.100)	(0.089)	(0.089)
Human Capital	0.020**	0.021**	0.019**	0.019**	0.005	0.005	0.002	0.002
	(0.010)	(0.010)	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)
Unemployment	-0.872***	-0.870***	-0.875***	-0.876***	-0.610***	-0.594***	-0.272	-0.263
	(0.111)	(0.111)	(0.116)	(0.113)	(0.190)	(0.189)	(0.202)	(0.203)
Government	-0.892***	-0.913***	-1.202***	-1.214***	-0.510*	-0.538**	-0.681***	-0.696***
	(0.260)	(0.254)	(0.341)	(0.334)	(0.263)	(0.264)	(0.198)	(0.197)
Labour Force	0.182**	0.174*	0.164**	0.162*	0.121*	0.119*	0.116	0.114
	(0.088)	(0.090)	(0.082)	(0.083)	(0.067)	(0.067)	(0.077)	(0.077)
Trade	0.014	0.011	-0.011	-0.013	-0.041	-0.032	-0.048**	-0.041*
	(0.019)	(0.019)	(0.018)	(0.018)	(0.028)	(0.028)	(0.022)	(0.023)
Constant	0.206**	0.205**	0.319**	0.331***	0.108	0.091	0.447***	0.435***
	(0.100)	(0.100)	(0.018)	(0.126)	(0.154)	(0.154)	(0.140)	(0.140)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	
Countries	27	27	27	27	16	16	16	16
N	621	621	500	500	368	368	308	308
F-stat	21.8***	21.8***	30.2***	30.1***	17.0***	17.4***	18.7***	18.9***
adj. R^2	0.66	0.66	0.76	0.76	0.67	0.67	0.72	0.72

Notes: Fixed-effect (country and time) estimates of the relationship of real GDP per capita growth (dependant variable) and changes in technology, institutions and governance and control variables. White diagonal standard errors and covariance (corrected for degrees of freedom) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%.

Table 6 presents the results with interaction terms for the EU and Non-EU OECD countries. The interaction between fixed broadband users and institutions and governance have a statistically significant positive growth-enhancing effect in the case of the EU. For the non-EU OECD countries, the interactions between digitalisation variables and institutions are positive, whereas

Table 6: Fixed-effects estimates for EU and Non-EU OECD countries (ctd.)

	EU countries				Non-EU OECD countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Lagged dep.								
Real GDP(-1)	-0.020*	-0.021*	-0.026**	-0.027**	-0.016	-0.012	-0.068***	-0.064***
	(0.010)	(0.011)	(0.012)	(0.013)	(0.015)	(0.015)	(0.015)	(0.015)
ΔTechnology								
Internet	0.047**	0.051**			0.061***	0.068***		
	(0.023)	(0.022)			(0.023)	(0.023)		
Broadband			0.067	0.082			-0.044	-0.038
			(0.076)	(0.078)			(0.058)	(0.060)
ΔInstitutions								
Institutions	0.021		0.022*		0.001		0.001	
	(0.015)		(0.012)		(0.012)		(0.010)	
Governance		0.028*		0.020*		0.026**		0.019*
		(0.016)		(0.012)		(0.011)		(0.010)
ΔInteractions								
Internet ×	-0.015				0.011*			
Institutions	(0.013)				(0.006)			
Internet ×		-0.009				-0.008*		
Governance		(0.008)				(0.005)		
Broadband ×			0.026*				0.042***	
Institutions			(0.015)				(0.011)	
Broadband ×				0.020*				-0.031***
Governance				(0.011)				(0.009)
ΔControls								
Capital	0.218**	0.216**	0.181**	0.181**	0.458***	0.445***	0.315***	0.305***
	(0.091)	(0.090)	(0.076)	(0.074)	(0.100)	(0.100)	(0.094)	(0.094)
Human Capital	0.019**	0.021**	0.018**	0.018**	0.005	0.005	0.001	0.002
	(0.010)	(0.010)	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)
Unemployment	-0.869***	-0.855***	-0.869***	-0.878***	-0.592***	-0.581***	-0.275	-0.264
	(0.109)	(0.107)	(0.116)	(0.114)	(0.187)	(0.186)	(0.178)	(0.181)
Government	-0.856***	-0.883***	-1.121***	-1.222***	-0.500**	-0.518**	-0.688***	-0.706***
	(0.277)	(0.270)	(0.341)	(0.333)	(0.253)	(0.256)	(0.190)	(0.192)
Labour Force	0.183**	0.176*	0.159**	0.156*	0.115*	0.123*	0.103	0.107
	(0.090)	(0.091)	(0.080)	(0.082)	(0.068)	(0.066)	(0.077)	(0.077)
Trade	0.012	0.010	-0.010	-0.012	-0.046*	-0.037	-0.039*	-0.035
	(0.019)	(0.019)	(0.017)	(0.018)	(0.027)	(0.027)	(0.021)	(0.022)
Constant	0.235**	0.242**	0.280**	0.289**	0.190	0.149	0.737***	0.689***
	(0.108)	(0.113)	(0.130)	(0.132)	(0.162)	(0.160)	(0.154)	(0.156)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
Countries	27	27	27	27	16	16	16	16
N	621	621	500	500	368	368	308	308
F-stat	21.6***	21.6***	29.8***	29.7***	17.0***	17.2***	19.8***	19.7***
adj. R^2	0.66	0.66	0.76	0.76	0.67	0.67	0.73	0.73

Notes: Fixed-effect (country and time) estimates of the relationship of real GDP per capita growth (dependant variable) and changes in technology, institutions and governance and control variables. White diagonal standard errors and covariance (corrected for degrees of freedom) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%.

the interactions with governance are negative. The results for the control variables, in terms of coefficients and their significance, the variations across measures of technology, and between EU and non-EU OECD countries, are similar to those results in Table 5, an indication that the effect of interaction between technology and institutions is independent from other economic activity.

In most cases for EU and non-EU OECD countries, the change in digital technologies is a significant factor explaining growth when internet use is used as the variable for technology. When it comes to institutions, they seem more important in EU countries whereas governance aspects are significant for both aggregates, but more in non-EU OECD countries. The interaction between digital technologies and institutions and governance are significant in several cases. A positive effect from the interaction is observed for broadband use in the EU countries and for institutions for non-EU OECD countries. The interactions between digitalisation variables and governance aspects get a negative sign for the non-EU OECD countries. When it comes to control variables, the coefficients all get expected signs when significant. Some interesting differences arise between the two sets of countries, especially when it comes to the effects of human capital, but the model performance is quite stable across groups. Generally, in terms of the adjusted R^2, the defined econometric model explains a very similar share of economic growth for both groupings.

5.2 Other/All Countries

The set of 'Other countries' is more heterogeneous than 'EU countries' and 'Non-EU OECD countries'. Based on the data presented in Sections 3.2 and 3.3, the average levels of technology, institutions and governance are lower in this set. Studying the results for 'All countries' provides the broadest available picture of the drivers of economic growth within the studied models as well as how strong the effects from digital technologies and institutions have been on a global scale. Table 7 presents the results from the PMG estimation for the countries other than EU and OECD in columns (1) to (4) and for the full panel in columns (5) to (8).

For the countries other than EU and OECD, the long run growth effects are quite different to other groups with institutional variables being insignificant and technology change only when measured with the amount of broadband users. In the short run, technology variables are mostly insignificant and the institutional variables are only significant for the shorter sample. Looking at the control variables, the group resembles the results of the Non-EU OECD group with human capital and labour force being insignificant.

For the full cross-section of 101 countries, there is a significant positive long run growth effect from both technologies and institutions. For governance, the long run growth effect is positive for the full sample, but negative for the shorter sample. In the short run institutions have a positive and significant effect whereas governance only has a positive effect for the shorter sample.

Table 7: Pooled mean group estimates for other/all countries

	Other countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Long run								
Internet	-0.025	0.050			0.661***	0.117***		
	(0.061)	(0.043)			(0.087)	(0.022)		
Broadband			0.215***	0.711***			0.267***	0.231***
			(0.026)	(0.149)			(0.248)	(0.019)
Institutions	-0.083		0.029		0.280***		0.502***	
	(0.051)		(0.037)		(0.056)		(0.060)	
Governance		-0.090		-0.042		0.250***		-0.072*
		(0.061)		(0.039)		(0.021)		(0.042)
Capital	0.701***	0.602***	0.655***	0.482***	0.438***	0.234***	0.753***	0.516***
	(0.069)	(0.049)	(0.059)	(0.035)	(0.047)	(0.023)	(0.074)	(0.030)
Human Capital	0.077***	0.062**	0.226***	0.205***	0.455***	0.133***	0.310***	0.254***
	(0.030)	(0.025)	(0.032)	(0.024)	(0.036)	(0.009)	(0.030)	(0.022)
Unemployment	-0.559***	-0.553***	0.432	-0.686***	-0.441***	-0.309***	-0.312***	-0.711*
	(0.066)	(0.543)	(0.588)	(0.061)	(0.478)	(0.202)	(0.433)	(0.429)
Labour Force	1.244***	1.209***	0.908***	1.214***	0.233***	0.065	0.627***	0.927***
	(0.102)	(0.079)	(0.101)	(0.062)	(0.219)	(0.044)	(0.106)	(0.061)
Government	0.709	0.610	-0.294***	-0.216	0.995***	1.389***	-0.798	-0.223***
	(0.539)	(0.474)	(0.054)	(0.345)	(0.112)	(0.218)	(0.512)	(0.412)
Trade	0.456***	0.378***	0.427***	0.311***	0.125**	0.072***	0.430***	0.425***
	(0.067)	(0.050)	(0.041)	(0.028)	(0.050)	(0.021)	(0.050)	(0.036)
Convergence								
Real GDP(-1)	-0.089***	-0.089***	-0.136***	-0.147***	-0.002	-0.002	-0.119***	-0.118***
	(0.027)	(0.025)	(0.031)	(0.029)	(0.005)	(0.029)	(0.018)	(0.018)
Short run								
Internet	0.035	0.060*			0.039	0.055**		
	(0.032)	(0.034)			(0.024)	(0.023)		
Broadband			-0.182	-0.701			0.042	-0.539
			(1.690)	(1.342)			(0.108)	(0.775)
Institutions	0.012		0.023**		0.018***		0.234***	
	(0.008)		(0.010)		(0.007)		(0.007)	
Governance		0.010		0.028**		0.010		0.024***
		(0.014)		(0.013)		(0.010)		(0.008)
Capital	0.062***	0.052***	0.049***	0.045***	0.075***	0.070***	0.074***	0.063***
	(0.017)	(0.016)	(0.014)	(0.014)	(0.013)	(0.012)	(0.012)	(0.012)
Human Capital	0.010	0.007	0.012	0.000	0.013	0.002	0.007	-0.000
	(0.015)	(0.016)	(0.018)	(0.020)	(0.010)	(0.010)	(0.012)	(0.010)
Unemployment	-3.148**	-3.367**	-2.959*	-3.192**	-2.111**	-1.893**	-2.051**	-2.241**
	(1.581)	(1.670)	(1.646)	(1.618)	(0.906)	(0.814)	(0.924)	(0.919)
Labour Force	0.150	0.100	0.223	0.023	0.160	0.158*	0.169*	0.224**
	(0.134)	(0.144)	(0.153)	(0.148)	(0.122)	(0.089)	(0.091)	(0.093)
Government	-0.503***	-0.573***	-0.448***	-0.493***	-0.891***	-0.904***	-0.894***	-0.859***
	(0.159)	(0.161)	(0.130)	(0.145)	(0.135)	(0.128)	(0.119)	(0.127)
Trade	0.024	0.012	0.042*	0.021	0.038**	0.030*	0.049***	0.050***
	(0.022)	(0.022)	(0.025)	(0.023)	(0.016)	(0.015)	(0.015)	(0.017)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
Countries	58	58	58	58	101	101	101	101
N	1330	1330	1217	1217	2319	2319	1782	1782
F-stat	4.9***	5.1***	4.9***	4.9***	5.6***	5.6***	5.7***	5.7***
adj. R^2	0.73	0.74	0.75	0.75	0.76	0.76	0.78	0.78

Notes: Pooled mean group estimates of the relationship of real GDP per capita growth (dependant variable) and technology, institutions, governance and control variables. *** significant at 1% level, ** significant at 5%, * significant at 10%, N number of observations.

Looking at the results from the FE estimation, a growth-enhancing effect of digital technologies can also be found for the group of countries outside EU and OECD, as documented in Table 8, colums (1) to (4). The effect is somewhat smaller than in the other country groups and significant only when measured by internet use. Similar to the EU and non-EU OECD, the effect does not depend greatly on the choice of measure for institutions (institutions or governance). However, a notable difference to other groups is that institutions and governance are substantially more significant and positive in all cases. Among the control variables investment, unemployment and trade are significant to some degree. The overall fit of the regression is still good, but somewhat less than for the EU or non-EU OECD.

The growth-enhancing effects of both technology and institutions are highly significant for the full panel with all the 101 countries considered in this paper, as shown in Table 8, regressions (5)-(8), irrespective of what combination of measures is used. This seems to provide support for the hypothesis that the effects of technology, institutions and governance matter above and beyond the traditional factors of growth even if there are substantial differences in the magnitude of the effects in different country groups. The overall fit is still good, even if slightly weaker than for the EU and non-EU OECD groupings. The coefficients on internet use and broadband subscriptions are significant, and so are the coefficients on institutions and governance.

Table 8: Fixed-effects estimates for other/all countries

	Other countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Lagged dep.								
Real GDP(-1)	-0.044***	-0.045***	-0.087***	-0.087***	-0.037***	-0.038***	-0.065***	-0.066***
	(0.008)	(0.007)	(0.016)	(0.015)	(0.006)	(0.006)	(0.011)	(0.010)
ΔTechnology								
Internet	0.042*	0.043**			0.077***	0.076***		
	(0.022)	(0.022)			(0.013)	(0.013)		
Broadband			0.129	0.136			0.110**	0.112**
			(0.116)	(0.117)			(0.049)	(0.049)
ΔInstitutions								
Institutions	0.041***		0.035***		0.037***		0.028***	
	(0.010)		(0.011)		(0.008)		(0.008)	
Governance		0.052***		0.041***		0.050***		0.037***
		(0.012)		(0.013)		(0.009)		(0.010)
ΔControls								
Capital	0.155***	0.147**	0.081	0.080	0.204***	0.196***	0.153***	0.150**
	(0.059)	(0.059)	(0.075)	(0.075)	(0.050)	(0.050)	(0.059)	(0.059)
Human Capital	0.009	0.011	0.008	0.010	0.014*	0.016**	0.012	0.013*
	(0.012)	(0.011)	(0.012)	(0.012)	(0.007)	(0.007)	(0.008)	(0.008)
Unemployment	-1.055***	-1.064***	-0.969***	-0.973***	-1.004***	-1.001***	-0.967***	-0.962***
	(0.126)	(0.122)	(0.137)	(0.133)	(0.075)	(0.074)	(0.082)	(0.080)
Government	0.042	0.044	0.079	0.080	-0.087	-0.087	-0.045	-0.043
	(0.088)	(0.088)	(0.112)	(0.112)	(0.084)	(0.084)	(0.110)	(0.110)
Labour Force	-0.072	-0.067	-0.068	-0.062	0.026	0.020	0.025	0.021
	(0.064)	(0.063)	(0.068)	(0.068)	(0.048)	(0.048)	(0.049)	(0.050)
Trade	-0.040**	-0.040**	-0.036**	-0.035*	-0.028**	-0.029**	-0.032**	-0.031**
	(0.016)	(0.016)	(0.018)	(0.018)	(0.013)	(0.013)	(0.014)	(0.014)
Constant	0.421***	0.426***	0.815***	0.816***	0.377***	0.382***	0.651***	0.657***
	(0.068)	(0.067)	(0.141)	(0.037)	(0.058)	(0.057)	(0.103)	(0.100)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
Countries	58	58	58	58	101	101	101	101
N	1330	1330	974	974	2319	2319	1782	1782
F-stat	11.4***	11.5***	10.2***	10.2***	16.4***	16.4***	16.7***	16.8***
adj. R^2	0.41	0.41	0.45	0.45	0.46	0.47	0.53	0.53

Notes: Fixed-effect (country and time) estimates of the relationship of real GDP per capita growth (dependant variable) and changes in technology, institutions and governance and control variables. White diagonal standard errors and covariance (corrected for degrees of freedom) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%.

The results in Table 8 are mirrored in Table 9 which focuses on the growth effect from the interaction between digital technology and institutions. The table shows that the growth effects are slightly weaker for the other countries, probably reflecting the relatively greater heterogeneity in that group. As indicated before, the homogeneity is greater across the EU and non-EU

OECD than the other countries, potentially due to a greater degree of integration and advancement. Institutions and governance have a significant positive effect in all studied cases. For the full cross-section the interaction of internet use and institutions gets a significant positive sign whereas other interactions get a negative sign. It should also be noted that broadband connections turn insignificant when interaction terms are added. The overall fit is still acceptable, and the hypothesis that economic growth is affected by the interaction of technology change with institutions and governance holds for the full cross-section of 101 countries, especially when internet use is used as the proxy for technological change.

Table 9: Fixed-effects estimates for other/all countries (ctd.)

	Other countries				All countries			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Lagged dep.								
Real GDP(-1)	-0.043***	-0.045***	-0.086***	-0.087***	-0.040***	-0.041***	-0.071***	-0.070***
	(0.008)	(0.007)	(0.016)	(0.015)	(0.006)	(0.006)	(0.011)	(0.011)
ΔTechnology								
Internet	0.051**	0.051**			0.049***	0.045***		
	(0.023)	(0.022)			(0.015)	(0.015)		
Broadband			0.199	0.180			0.038	0.039
			(0.122)	(0.126)			(0.052)	(0.054)
ΔInstitutions								
Institutions	0.044***		0.039***		0.033***		0.025***	
	(0.010)		(0.012)		(0.008)		(0.008)	
Governance		0.055***		0.043***		0.045***		0.034***
		(0.012)		(0.014)		(0.009)		(0.010)
ΔInteractions								
Internet ×	0.019***				0.013***			
Institutions	(0.007)				(0.003)			
Internet ×		0.011*				-0.011***		
Governance		(0.007)				(0.003)		
Broadband ×			0.060**				-0.029***	
Institutions			(0.029)				(0.011)	
Broadband ×				0.025				-0.022***
Governance				(0.021)				(0.008)
ΔControls								
Capital	0.154***	0.145**	0.076	0.076	0.203***	0.197***	0.154***	0.152***
	(0.058)	(0.059)	(0.075)	(0.075)	(0.050)	(0.049)	(0.059)	(0.058)
Human Capital	0.009	0.011	0.007	0.009	0.013*	0.015**	0.012	0.013*
	(0.012)	(0.011)	(0.012)	(0.012)	(0.007)	(0.007)	(0.008)	(0.008)
Unemployment	-1.043***	-1.053***	-0.958***	-0.960***	-1.009***	-1.000***	-0.979***	-0.972***
	(0.126)	(0.122)	(0.139)	(0.134)	(0.075)	(0.074)	(0.081)	(0.080)
Government	0.049	0.049	0.087	0.084	-0.084	-0.084	-0.051	-0.048
	(0.087)	(0.088)	(0.112)	(0.112)	(0.084)	(0.084)	(0.109)	(0.109)
Labour Force	-0.080	-0.066	-0.081	-0.064	0.033	0.026	0.033	0.027
	(0.064)	(0.064)	(0.068)	(0.068)	(0.047)	(0.048)	(0.050)	(0.050)
Trade	-0.039**	-0.039**	-0.033**	-0.033*	-0.029**	-0.029**	-0.031**	-0.031**
	(0.016)	(0.016)	(0.018)	(0.018)	(0.013)	(0.013)	(0.014)	(0.014)
Constant	0.410***	0.422***	0.803***	0.816***	0.407***	0.413***	0.710***	0.704***
	(0.068)	(0.067)	(0.141)	(0.137)	(0.059)	(0.059)	(0.111)	(0.107)
Sample start	1996	1996	1998	1998	1996	1996	1998	1998
Sample end	2019	2019	2019	2019	2019	2019	2019	2019
Countries	58	58	58	58	101	101	101	101
N	1330	1330	974	974	2319	2319	1782	1782
F-stat	11.4***	11.4***	10.2***	10.1***	16.5***	16.6***	16.7***	16.8***
adj. R^2	0.41	0.41	0.45	0.45	0.47	0.47	0.53	0.54

Notes: Fixed-effect (country and time) estimates of the relationship of real GDP per capita growth (dependant variable) and changes in technology, institutions and governance and control variables. White diagonal standard errors and covariance (corrected for degrees of freedom) in parentheses. *** significant at 1% level, ** significant at 5%, * significant at 10%.

6 Conclusions

This paper has discussed the mechanisms and provided the evidence for the growth-enhancing effects of digitalisation, institutions and governance, both independently as well as through their interaction. It follows on a number of seminal papers documenting the importance of framework conditions for economic growth. The work in those papers and this one suggests that countries can easily reap economic benefits by ratcheting up their efforts directed at framework conditions, and this paper suggests that digitalisation is a good candidate for this, in particular if flanked by proper institutions and governance.

More specifically, the empirical results suggest that digitalisation has a strong growth-enhancing effect, even when other factors are controlled for. This applies to all country groupings when digitalisation is measured by internet use. The amount of broadband users is significant for the long run part of pooled mean group estimations and some cases of fixed-effect estimations, whereas the growth effects from internet use seem substantially broader and more stable which suggests that the first phase of digitalisation, more specifically having access to the internet, has had a stronger effect on economic growth than the establishment of advanced infrastructure. However, it should also be noted that the development of advanced infrastructure is still in an early stage in many of the studied countries and the full potential economic growth effects might still be unfolding.

The growth effects of institutions and governance (on their own) are also broadly significant which matches their fundamental role identified in previous literature. The interaction of digitalisation with institutions and governance is significant for several cases, with the interactions between internet use being more important than interactions with broadband use. In some cases the interaction between digitalisation and governance gets a negative sign, which might imply a slowing effect from excessive bureaucracy or difficult legislative control procedures.

Complementing the existing literature, the results of this study seem to provide further evidence of the important role of institutions and governance aspects for economic growth as well as, not surprisingly, the profound role of technological change. They also suggest notable policy implications regarding improvements in the quality of institutions and governance as well as the advancement of and investments to the process of digitalisation - via digital infrastructure and digital skills - with a view of reaching higher rates of economic growth.

To understand the mechanisms and their empirical relevance better, data covering other aspects of digitalisation, institutions and governance, and other 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. Those other sources would 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.

While not unexpected, it should also be noted that of the control variables in the framework used in this study, the level of investment has a very positive effect on economic growth throughout the study and unemployment a highly negative one. The differences between country groups in the significance and magnitude of the effects of government expenditure, labour force, human capital and trade are interesting, and the reasons behind them in the process of economic growth, either individually or in the relations to technological change and institutions, might also be a potential avenue of future research.

References

Acemoglu, D. (2012). Introduction to economic growth. *Journal of Economic Theory*, 147(2):545–550.

Acemoglu, D., Johnson, S., and Robinson, J. A. (2005). Institutions as a fundamental cause of long-run growth. *Handbook of Economic Growth*, 1A:385–472.

Acemoglu, D. and Restrepo, P. (2019). Automation and new tasks: How technology displaces and reinstates labor. *Journal of Economic Perspectives*, 33(2):3–30.

Aghion, P. and Durlauf, S. N. (2005a). *Handbook of Economic Growth*, volume 1B. Elsevier.

Aghion, P. and Durlauf, S. N. (2005b). *Handbook of Economic Growth*, volume 1A. Elsevier.

Anderton, R. and Cette, G. (editors, 2021). Digitalisation: Channels, Impacts and Implications for Monetary Policy. *ECB Occasional Paper*, no 266.

Anderton, R., Jarvis, V., Labhard, V., Vivian, L., Morgan, J., and Petroulakis, F. (2020). Virtually everywhere? Digitalisation and the euro area and EU economies. Degree, effects and key issues. *ECB Occasional Paper*, no 244.

Baccianti, C., Labhard, V., and Lehtimäki, J. (2022). Digitalisation, Institutions and Governance, and Diffusion: Mechanisms and Evidence. *ECB Working Paper*, no 2675.

Barro, R. J. (1996). Institutions and growth, an introductory essay. *Journal of Economic Growth*, 1:145–48.

Bassanini, A., Scarpetta, S., and Hemmings, P. (2001). Economic growth: The role of policies and institutions. Panel data evidence from OECD countries. *OECD Economics Department Working Paper*, no 283.

Bloom, N., Draca, M., Kretschmer, T., and Sadun, R. (2010). The economic impact of ict. *Centre for Economic Performance*. Final Report.

Bouis, R., Duval, R., and Murtin, F. (2011). The policy and institutional drivers of economic growth across OECD and non-OECD economies: New evidence from growth regressions. *OECD Economics Department Working Paper*, no 843.

Bresnahan, T. F. and Trajtenberg, M. (1995). General purpose technologies. *Journal of Econometrics*, 65(1):83–108.

Cardona, M., Kretschmer, T., and Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. *Information Economics and Policy*, 25(3):109–125.

Choi, C. and Yi, M. H. (2009). The effect of the internet on economic growth: Evidence from cross-country panel data. *Economics Letters*, 105(1):39–41.

Cockburn, I. M., Henderson, R., and Stern, S. (2018). The impact of artificial intelligence on innovation. *NBER Working Paper*, no 24449.

Compton, R. A. and Giedeman, D. C. (2011). Panel evidence on finance, institutions and economic growth. *Applied Economics*, 43(25):3523–3547.

David, P. A. (1989). Computer and dynamo: The modern productivity paradox in a not-too-distant mirror. *Warwick Economics Research Paper*, no 339.

David, P. A. (1990). The dynamo and the computer: An historical perspective on the modern productivity paradox. *American Economic Review*, 80(2):355–61.

Degryse, C. (2016). Digitalisation of the economy and its impact on labour markets. *ETUI Research Paper-Working Paper*, no 2016.2.

Dellepiane-Avellaneda, S. (2010). Good governance, institutions and economic development: Beyond the conventional wisdom. *British Journal of Political Science*, 40(1):195–224.

Dreher, A. (2006). Does globalization affect growth? Evidence from a new index of globalization. *Applied Economics*, 38(10):1091–1110.

Gal, P., Nicoletti, G., Renault, T., Sorbe, S., and Timiliotis, C. (2019). Digitalisation and productivity: In search of the holy grail – Firm-level empirical evidence from EU countries. *OECD Economics Department Working Papers*, no 1533.

Glaeser, E. L., La Porta, R., Lopez-de Silanes, F., and Shleifer, A. (2004). Do institutions cause growth? *Journal of Economic Growth*, 9(3):271–303.

Goldfarb, A. and Tucker, C. (2019). Digital economics. *Journal of Economic Literature*, 57(1):3–43.

Gordon, R. J. (2016). *The rise and fall of American growth*. Princeton University Press.

Gradstein, M. (2004). Governance and growth. *Journal of Development Economics*, 73(2):505–518.

Gwartney, J., Lawson, R., Hall, J., Murphy, R., Bennett, D. L., Fike, R., McMahon, F., and Nikolaev, B. (2019). *Economic Freedom of the World: 2019 Annual Report*. Fraser Institute.

Gygli, S., Haelg, F., Potrafke, N., and Sturm, J.-E. (2019). The KOF globalisation index - Revisited. *The Review of International Organizations*, 14(3):543–574.

Helpman, E. (2003). *General Purpose Technologies and Economic Growth*. MIT Press.

Hoffreumon, C. and Labhard, V. (2022). Cross-Country Cross-Technology Digitalisation: A Bayesian Hierarchical Model Perspective. *ECB Working Paper*, no 2700.

Hüther, M. (2016). Digitalisation: An engine for structural change - A challenge for economic policy. *IW Policy Paper*, no 15/2016E.

Jorgensen, D. W. (2005). Accounting for growth in the information age. *Handbook of Economic Growth*, 2:743–815.

Jovanovic, B. and Rousseau, P. L. (2005). *General Purpose Technologies*. Elsevier.

Katz, R. L., Koutroumpis, P., and Collarda, F. M. (2014). Using a digitization index to measure the economic and social impact of digital agendas. *info*, 16:32–44.

Kaufmann, D., Kraay, A., and Mastruzzi, M. (2010). *Worldwide Governance Indicators*. World Bank Group.

Lipsey, R., Carlaw, K. I., and Bekhar, C. T. (2005). *Economic transformations: General purpose technologies and long term economic growth*. Oxford University Press.

Masuch, K., Moshammer, E., and Pierluigi, B. (2017). Institutions, public debt and growth in Europe. *Public Sector Economics*, 41(2):159–205.

Maurseth, P. B. (2018). The effect of the internet on economic growth: Counter-evidence from cross-country panel data. *Economics Letters*, 172:74–77.

Maurseth, P. B. (2020). ICT, growth and happiness. In *Digitalisation and Development*, pages 31–86. Springer.

Méndez-Picazo, M.-T., Galindo-Martín, M.-Á., and Ribeiro-Soriano, D. (2012). Governance, entrepreneurship and economic growth. *Entrepreneurship and Regional Development*, 24(9-10):865–877.

Milkau, U. and Bott, J. (2015). Digitalisation in payments: From interoperability to centralised models? *Journal of Payments Strategy and Systems*, 9(3):321–340.

Mokyr, J. (2005). Long-term economic growth and the history of technology. *Handbook of Economic Growth*, 1B:1113–1180.

Nelson, R. R. (2005). *Technology, institutions, and economic growth*. Harvard University Press.

North, D. C. (1991). Institutions. *Journal of Economic Perspectives*, 5(1):97–112.

OECD (2019). Digitalisation and productivity: A story of complementarities. *OECD Economic Outlook*, 1.

Pesaran, M. H., Shin, Y., and Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, 94(446):621–634.

Sabbagh, K., Friedrich, R., El-Darwiche, B., Singh, M., Ganediwalla, S., and Katz, R. (2012). Maximising the impact of digitisation. In *The Global Information Technology Report 2012. Living in a Hyperconnected World*, pages 121–33. World Economic Forum.

Schreyer, P. (2000). The contributions of information and communication technology to output growth: A study of the G7 countries. *OECD Science, Technology and Industry Working Papers*, no 2.

Solow, R. M. (1957a). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70(1):65–94.

Solow, R. M. (1957b). Technical change and the aggregate production function. *Review of Economics and Statistics*, 39(3):312–20.

Solow, R. M. (2005). Reflections on growth theory. *Handbook of Economic Growth*, 1A:3–10.

Stokey, N. (2020). Technology diffusion. *NBER Working Paper*, no 27466.

Trajtenberg, M. (2018). AI as the next GPT: A political-economy perspective. *NBER Working Paper*, no 24245.

Vu, K., Hanafizadeh, P., and Bohlin, E. (2020). Ict as a driver of economic growth. A survey of the literature and directions for future research. *Telecommunications Policy*, 44(2):75–79.

Williamson, O. E. (1998). The institutions and governance of economic development and reform. *American Economic Review*, 88(2):75–79.

Appendix

A Data

Table A.1: Variables

Variable/Description (and transformation)	**Code**	**Source**
Control of Corruption	CC.EST	World Bank
Government Effectiveness	GE.EST	World Bank
Political Stability and Absence of Violence	PS.EST	World Bank
Regulatory Quality	RQ.EST	World Bank
Rule of Law	RL.EST	World Bank
Voice and Accountability	VA.EST	World Bank
Quality of Governance (average across CC.EST, RQ.EST and RL.EST)	-	Authors
Quality of Institutions (average across GE.EST, PS.EST and VA.EST)	-	Authors
Fixed broadband subscriptions (per 100 people)	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
Investment (% of GDP)	NE.GDI.FTOT.ZS	World Bank
Human Capital, Education Index	-	UNDP
Unemployment (% of labour force)	SL.UEM.TOTL.ZS	World Bank
Labour Force (million, log)	SL.TLF.TOTL.IN	World Bank
Government Expenditure (% of GDP)	NE.CON.GOVT.ZS	World Bank
Trade (% of GDP)	NE.TRD.GNFS.ZS	World Bank

Notes: The countries are listed in Table A.2 in Appendix A.

Table A.2: Countries and Country Aggregates

EU countries (27)
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
Non-EU OECD countries (16)
Australia, Canada, Chile, Colombia, Costa Rica, Iceland, Israel, Japan, Korea, Mexico, New Zealand, Norway, Switzerland, Turkey, United Kingdom, United States
Other countries (58)
Albania, Algeria, Argentina, Armenia, Azerbaijan, Barbados, Belarus, Benin, Bolivia, Brazil, Cambodia, Cameroon, China, 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

Acknowledgements

The work has benefited from comments by colleagues and seminar participants at the European Central Bank, the Bank of Canada, the Federal Reserve Board, the IMF, and the World Bank. In particular, we would like to thank S. Ahma-aho, R. Anderton, A. Dieppe, R. Duval, D. Filip, M. Hallward-Driemeier, P. Schulte and R.J. Singh, as well as an anonymous referee for the ECB Working Paper Series for their thoughts and/or suggestions.
The views expressed in this paper are those of the authors and do not necessarily reflect those of any of the institutions the authors are or were affiliated to.

Vincent Labhard
European Central Bank, Frankfurt am Main, Germany; email: vincent.labhard@ecb.europa.eu

Jonne Lehtimäki
University of Turku, Turku, Finland; email: joleht@utu.fi

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

PDF ISBN 978-92-899-5322-1 ISSN 1725-2806 doi:10.2866/56792 QB-AR-22-100-EN-N