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Digital Economies and Evolving Regulations: A Parametric and Non-parametric Approach with Bad Output Across Countries

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Abstract

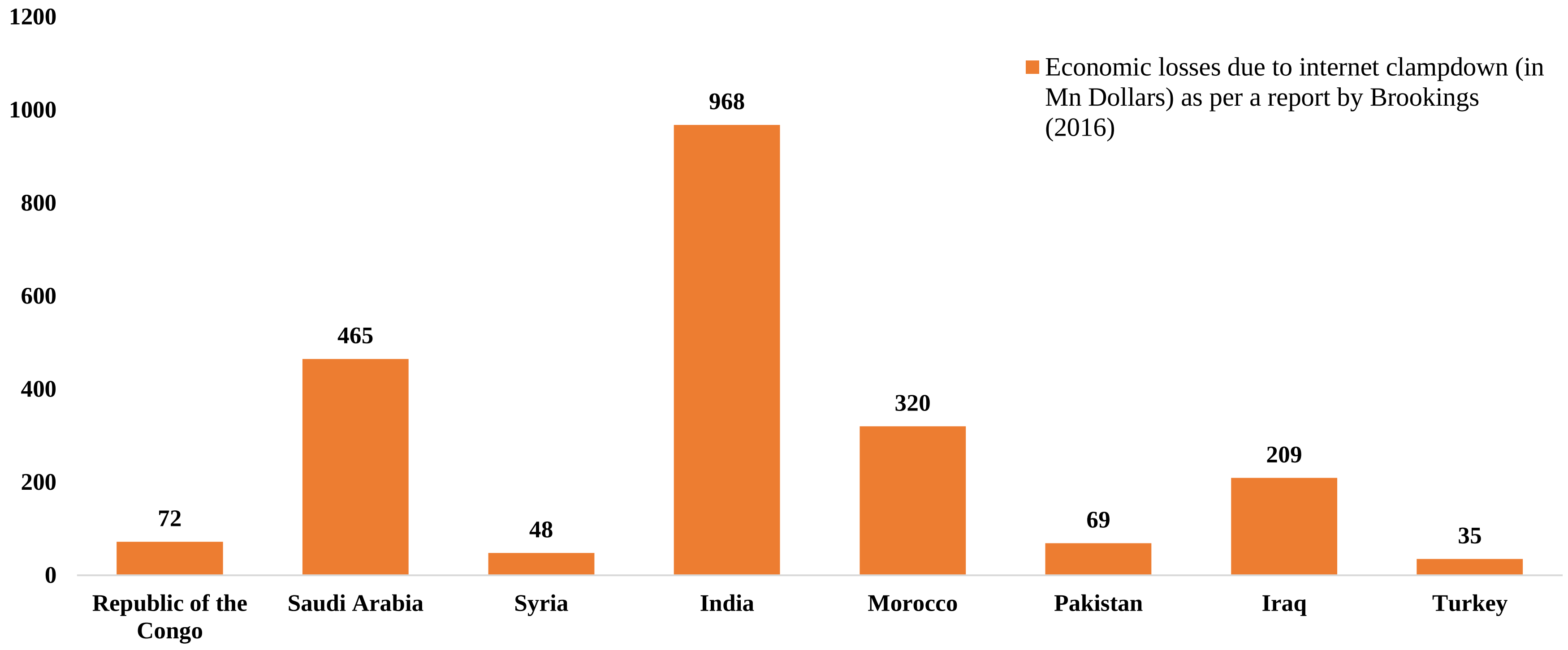
We use the non-parametric Data Envelopment Analysis (DEA) and the parametric Stochastic Frontier Analysis (SFA) to workout efficiency and productivity of the ICT sector across 50 countries for the time period 2016 and 2020. By considering OECD -DSTRI index as bad output, the study intends to estimate the influence of digital trade regulations (or digital services trade restrictiveness) on productivity and efficiency of the ICT sector across countries. The SFA scores are compared with the DEA efficiency scores and Malmquist Index based on four DEA problems are used to work out the total factor productivity of the ICT sector across countries and over two time periods. Cross country regression is run to understand the impact of ICT efficiency and productivity on average annual growth rate of GDP per-capita among other control factors. We use network readiness index of the World Economic Forum along with OECD-DSTRI index as our database. Broadly, our results are three-fold. Firstly, although we found evidence of a surge in technical efficiency scores between 2016 and 2020, from both DEA analysis for all and SFA analysis for middle income countries, we can infer that trade restrictiveness has very little to do with technical efficiency. Secondly, we found no statistical difference in the DEA technical efficiency scores of high and middle-income countries, and we can deduce that all middle-income countries have maneuvered to move up the ladder, as evident from the positive and greater than unity TFP change, while 28 high-income countries have experienced deterioration in TFP. We also found evidence of Asian countries faring better than the European Union countries in context of technical efficiencies. Thirdly, from our empirical results it seems that adoption of ICT and the so-called disruptive 4IR technologies have replaced labor and henceforth, we hypothesize that higher unemployment leads to higher growth rate along with a positive impact of network readiness on the growth rates. It seems that net neutrality and addressing pernicious regulations related to the ICT sector - barrier to competition, among others like foreign entry, mobility of people, regulatory transparency across countries can improve the productivity and efficiency of the ICT sector.

Introduction and Motivation

- Look at the complexities involved in dealing with information and communication sector across nations from all stakeholders point of view , society, governments , businesses and individuals.
- Google map allows everyone including media, and not confined to military establishments, to access and ascertain military positions and possibly can avoid conflicts through wider dissemination of GIS mapping of military positions for usage and actions. However, the same data needs to be secured for few from security point of view.
- The surveillance software like Pegasus and software embedded in hardware, like in airplanes produced by US company Boeing , have impacts on individual privacy and safety of travelers respectively.
- We Indians in our organization want data to be localized and handled by our organization ,who have responsibility to fully understand the importance of data privacy but at the same time balance it out with free flow of academic information to all .
- Additionally, at most we want our data to be hosted by Indian cloud computing companies from data privacy point of view. We Indians have comparative advantage in promising secured systems.
- Technology, ethics, secured systems, domestic regulations, online grievance officers, Broadband policies, governance, quality of education, data privacy, labour contracts, consent of parties, competition policies, among others are all required as solutions to the complexities involved with the ICT sector.
- Would you allow your personal information to be made available to vendors for furthering their businesses through online platforms? Competitive e business model with competition policy can deal with online platforms and the content. The biggest challenge however are the type of content available on the internet and the mobile, easily made available to younger generation. Added to the imbroglio is the AI, ML which allows computer or mobile to remember the past who in turn keeps manifesting out videos or information on the last typed search content. How do we deal with it? Ethics is one way to deal with it backed by religious norms and conventions. In addition, along with ethics more important are technology of encryption and holistic domestic regulations to deal with ICT issues. See Netflix. It has icons for all members. Who is watching what. This is one regulation which uses supervisory channel.
- West wants online data to be processed in their headquarters. More important is to have grievance officers of the social media platforms to be available online and ideally have Indian offices. We also specialize in having cloud companies who can maintain secured servers.

Introduction and Motivation

- We surely want competition in online platforms but the participation should not be skewed. Both foreign and Indian companies should participate.
- Your Uber trip is one trip for you but it is a business point for the vendors who have high frequency data on all movements. Similarly, Google knows your movements. Debate and discussion are required to formalize the problem and give solutions. For example, Net neutrality vs internet closing needs further discussion. Internet closing for few are tools used by governments to secure tranquility in society which most of the times seems to be a pernicious from society and free access point of view. Security concerns may be the primary focus though in these days of new global order.
- At the end debate boils down to free flow of online information vs regulations/ technology/encryptions and the discussion seems to be tilting towards the latter.


Economic losses due to internet clampdown (in Mn Dollars) as per a report by Brookings (2016)
1200
1000
800
600
400
200
0
72
465
48
968
320
69
209
35
Republic of the Congo
Saudi Arabia
Syria
India
Morocco
Pakistan
Iraq
Turkey

Rational of the study

- In the wake of the Fourth Industrial Revolution, it becomes imperative to probe how efficiently the countries worldwide use ICT to augment welfare and competitiveness.

- Given that ICT is part and parcel of the current paradigm, the benefits are being harnessed by the government, businesses, and households, driven primarily by the level of infrastructure, affordability, and technical skills.

- This interaction of demand and supply has a significant bearing on the economy and society. So, any indicator that could gauge ICT utilization, the environment making the ICT conducive, and the outcome of ICT should determine the *Network Readiness* of the countries.

Rational of the study

- Against this backdrop, the third world industrial revolution coupled with the pronounced expansion of international trade poses some inevitable normative questions like:

  - How technically efficient are the Network Readiness of the countries?

  - In the realm of bad output, namely, the Digital Service Trade Restrictiveness Index, have the countries experienced deterioration or improved technical efficiency scores between 2016 and 2020?

  - Are the countries imposing restrictions on the digital service Trade faring better in terms of technical efficiency of Network Readiness?

  - Is there any diversity in the technical efficiency of Network Readiness among High-income countries and Middle-income countries?

ICT Sector Performance across countries keeping evolving regulations in mind

The top regional performers are indicated in the table below

Africa	Arab States	Asia & Pacific
1. Mauritius (53)	1. United Arab Emirates (29)	1. Singapore (2)
2. South Africa (72)	2. Qatar (33)	2. Japan (12)
3. Rwanda (89)	3. Bahrain (40)	3. Australia (13)

CIS	Europe	The Americas
1. Russian Federation (48)	1. Sweden (1)	1. United States (8)
2. Kazakhstan (60)	2. Netherlands (3)	2. Canada (14)
3. Belarus (61)	3. Norway (4)	3. Chile (42)

Note: Global ranks in parentheses. CIS = Commonwealth of Independent States.

Source: The Network Readiness Index 2019: Towards a Future-Ready Society

Network Readiness Index Data

Index	2020		2016	
	Sub-Index	Variables	Sub-Index	Variables
ICT Readiness /Technology	Access	Mobile tariffs	Infrastructure	Electricity production, kWh/capita
				Mobile network coverage, % population
				International Internet bandwidth, kb/s per user
		Handset prices		Secure Internet servers per million population
		Households with internet access		
		mobile network coverage		
		Fixed-broadband subscriptions	Affordability	Prepaid mobile cellular tariffs, PPP $/min.
		International Internet bandwidth		Fixed broadband Internet tariffs, PPP $/month
		Internet access in schools		Internet and telephony sectors competition index, 0–2 (best)
	Content	GitHub commits	Skills	Quality of education system
		Wikipedia edits		Quality of math and science education
		Internet domain registrations		Secondary education gross enrollment rate, %
		Mobile apps development		Adult literacy rate, %
	Future Technologies	Adoption of emerging technologies		
		Investment in emerging technology		
		ICT PCT patent applications		
		Computer software spending		
		Robot density		

	2020		2016	
Index	Sub-index	variables	Sub-index	variables
ICT Usage /People pillar	Individuals	Internet users	Individual usage	Mobile phone subscriptions per 100 population
				Percentage of individuals using the Internet
		Active mobile-broadband subscriptions		Percentage of households with computer
		Use of virtual social networks		Households with Internet access, %
		Tertiary enrollment		Fixed broadband Internet subscriptions per 100 population
		Adult literacy rate		Mobile broadband Internet subscriptions per 100 population
		ICT skills		Use of virtual social networks
	Businesses	Firms with website	Business usage	Firm-level technology absorption
		Ease of doing business		Capacity for innovation
		Professionals		PCT patent applications per million population
		Technicians and associate professionals		ICT use for business-to-business transactions
		Business use of digital tools		Business-to-consumer Internet use
		R&D expenditure by businesses		Extent of staff training
	Governments	Government online services	Government usage	Importance of ICTs to government vision*
		Publication and use of open data		Government Online Service Index, 0–1 (best)
		Government promotion of investment in emerging technologies		Government success in ICT promotion*

index	Sub-index	Variables	Sub-index	Variables
ICT Environment/Governance pillar	Trust	Secure Internet servers	Political and regulatory environment	Effectiveness of law-making bodies
		Cybersecurity		
		Online access to financial account		Laws relating to ICTs
		Internet shopping		Judicial independence
				Efficiency of legal system in settling disputes
				Efficiency of legal system in challenging regulations
	Regulation	Regulatory quality		Intellectual property protection
				Software piracy rate, % software installed
		ICT regulatory environment		Number of procedures to enforce a contract
		Legal framework's adaptability to emerging technologies		Number of days to enforce a contract
		E-commerce legislation	Business and innovation environment	Availability of latest technologies
		Privacy protection by law content		
				Venture capital availability
	Inclusion	E-participation		Total tax rate, % profits
		Socioeconomic gap in use of digital payments		Number of days to start a business
		Availability of local online content		Number of procedures to start a business
		Gender gap in internet use		Intensity of local competition
		Rural gap in use of digital payments		Tertiary education gross enrollment rate, %
				Quality of management schools
				Government procurement of advanced technology products

Index	Sub-index	Variables	Sub-index	Variables
ICT Impact/ Impact pillar	Economy	Medium and high-tech industry	Economic impacts	Impact of ICTs on business models
				ICT PCT patent applications per million population
		High-tech exports		Impact of ICTs on organizational models
		PCT patent applications		Knowledge intensive jobs, % workforce
		Labour productivity per employee	Social impacts	Impact of ICTs on access to basic services
		Prevalence of gig economy		
	Quality of Life			Internet access in schools
		Happiness		ICT use and government efficiency
		Freedom to make life choices		E-Participation Index, 0–1 (best)
		Income inequality		
		Healthy life expectancy at birth		
	SDG Contribution	SDG 3: Good Health and Well-Being		
		SDG 4: Quality Education		

Computation of the NRI Index

- The computation of the NRI is based on successive aggregations of scores, from the indicator level (i.e., the most disaggregated level) to the overall NRI score.

- In general, the unweighted arithmetic mean has been used to aggregate (i) individual indicators within each sub-pillar, (ii) sub-pillars within each pillar, and (iii) the pillars comprising the overall index. The one exception is the Content sub-pillar because indicator 1.2.1 Digital participation and content creation, is itself a sub-index made up of three variables (GitHub commits, Wikipedia pillars and pillars. Any given indicator thus belongs to a pillar and a sub-pillar.

- Each indicator is identified by three digits, where the first digit refers to the pillar, the second digit concerns the sub-pillar, and the third digit denotes the indicator. For instance, indicator 1.2.3 refers to the third indicator (Intellectual property receipts) that is placed in the second sub-pillar (Content), which, in turn, belongs to the first pillar (Technology).

- A total of 62 indicators have been identified for the NRI 2019. Of these indicators, 40 are hard/quantitative data, 12 are index/composite indicator data, and 10 are survey/qualitative data. The complete structure of the NRI with its respective pillars, sub-pillars, and indicators is shown on the next page. edits, and domain registrations)- weighted arithmetic mean has been applied whereby indicator 1.2.1 Digital participation and content creation has a weight of 0.6, and the other two indicators have weights of 0.2 each.

Digital Service Trade Restrictions (OECD-DSTRI)

- The OECD Digital Services Trade Restrictiveness Index (Digital STRI) is a new tool that identifies, catalogues, and quantifies cross-cutting barriers that affect services traded digitally. It consists of two components, the regulatory database and indices, which bring together comparable information from 44 countries. The Digital STRI shows a diverse and complex global regulatory environment affecting trade in digitally enabled services. Moreover, over the past years, the indices show an increasingly tightening regulatory environment highlighting that further international cooperation and dialogue is needed to maximise the benefits of digitalisation.
- The Digital STRI framework is categorised in the following areas:
    - Infrastructure and connectivity
    - Electronic transactions
    - Payment systems.
    - Intellectual property rights
    - Other barriers affecting trade in digitally enabled service
- Methodology: The regulatory data underpinning the Digital STRI have been retrieved from the existing STRI database. For the new measures, data have been collected from publicly available laws and regulations. The Digital STRIs are the result of aggregating the identified trade impediments into composite indices. Three key steps contribute to their construction: scoring, weighting and aggregation. Scoring entails the transformation of qualitative information into quantitative data. Weighting helps to balance the relative importance of the measures. Aggregation is the final step that calculates the cumulative index as the weighted average of the scores.

Literature Review

Author(s)	Area	Variables	Findings
Hardy (1980)	60 nations (15 developed & 45 developing)	GDP & energy consumption per capita, radios (per 1000), telephones (per million)	The telephone supports the organization of economic activity, and thus, it contributes to economic development.
Freund & Weinhold (2002)	The United States	Growth of U.S. trade, Internet, growth of GDP, initial level of trade appreciation in real exchange-rate	Internet affects the economic growth directly via productivity, and it is likely to have an indirect effect via openness.
Vemuri & Siddiqi (2009)	64 countries	Distance, Language dummy variable, Contiguity dummy, colonial connections, Volume of Trade, GDP, Population, Telephone Lines, Personal Computers, Internet Users	Availability of the internet and the infrastructure required for ICT impacts the volume of international trade.
Freund & Weinhold (2004)	34 countries	Annual export growth includes import-country GDP growth, competition and Internet growth, market proximity, and distance between exporter and importer.	The Internet has a substantial impact on the trade, and it has been observed that the trade growth is lower for countries located at a distance.
Cardona et al. (2015)	EU Member States	Dummies for restrictions, distance, language, home bias, exports,	Compared to offline trade, international e-commerce induced redistribution and reduced the cost of a trade.
Falk & Hangsten (2015)	14 European countries	Stock of capital and ICT usages, output, employment, employment, e-sales, additional ICT usage	The growth in labor productivity is positively associated with the changes in e-sales activities. TFP was coupled with the increase in e-commerce sales and was prominent for smaller firms.

Author(s)	Area	Variables	Findings
Ferracane et al. (2019)	Firm-level (countries)	Number of patents/employees, number of recorded subsidiaries, value-added, capital, materials, and investments	Stringent data policies negatively impact the performance of downstream firms dependent on electronic data. It is more substantial for countries with robust technology networks.
Ferracane & Marel (2020)	64 countries	DPRI, the share of ICT capital services in value-added and productivity growth.	Nation's level of development cannot accurately explain the restrictiveness of countries pertaining to online platforms.
Marel & Ferracane (2021)	64 countries	Data policy, domestic regulations, air, and sea transport, financial, insurance and pension, postal, construction, maintenance and repair, charges of IPR, computer, among other	The study develops a data linkage index and concludes that the countries with restrictive data policy suffer from services trade.
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Ferracane & Marel (2020)	64 countries	DPRI, the share of ICT capital services in value-added and productivity growth.	Nation's level of development cannot accurately explain the restrictiveness of countries pertaining to online platforms. Countries with high restrictions on online. Platforms also have a lower productivity growth.
Marel & Ferracane (2021)	64 countries	Data policy, domestic regulations, air, and sea transport, financial, insurance and pension, postal, construction, maintenance and repair, charges of IPR, computer, information, professional and management consulting trade-related technical, audiovisual, and other services.	The study develops a data linkage index and concludes that the countries with restrictive data policy suffer from services trade.

Proposed Model

We present a combination of three methodologies in the current context, a rare incidence; thus, we delve into employing

- Two non-parametric methods, namely,
  - DEA and
  - DEA-based MPI
- A parametric method called Stochastic Frontier Model.
- Regression Analysis

To address the questions posed in the current study, we employ Data Envelopment Analysis. Charnes, Cooper & Rhodes (1978) proposed the term DEA *(Data Envelopment Analysis)*. DEA has become a strong quantitative, analytical tool for assessing and comparing the relative efficiency of firms (Cooper, Seiford & Tone, 2007).
DEA has been applied to estimate the technical efficiency of the DMUs by determining the maximum potential output given the inputs or by minimizing the inputs for the given level of output without assuming any specific functional form of the production process. Decision-Making Units
In the present study, we have employed Banker, Charnes & Cooper (1984) model, which didn't require any transformation function and considered that the decision-making units could operate under increasing, constant, and DRS (decreasing returns to scale), i.e., VRS could also be a situation—considering DMU as countries consuming m inputs to produce output (s). These outputs, as stated, could be desirable(s) and undesirable (k). Here, the bad output needs to be reduced but, in a standard Banker, Charnes, and Cooper (1984) model, both these kinds of outputs are to be increased.

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$$s_{in}(1 = 1,2,3 \dots, m),$$

$$y_{rn}(r = 1,2,3 \dots., s)$$

$$and\ b_{tn}(t = 1,2,3.., k).$$

Now we assume that there won't be any change in the desirable output and that the inputs and wrong outputs can be controlled proportionately; the relative efficiency of any DMUs can be determined as:

Input oriented model (CRS) with undesirable outputs

$$\min \theta_p$$

Subject to

$$\sum_{n=1}^{N} \lambda_n x_{in} \leq \theta_p x_{ip}, \qquad i = 1,2,3 \dots, m;$$

$$\sum_{n=1}^{N} \lambda_n y_{rn} \geq y_{rp}, \qquad r = 1,2,3 \dots, s;$$

$$\sum_{n=1}^{N} \lambda_n b_{tn} \geq \theta_p b_{tp}, \qquad t = 1,2,3 \dots, k;$$

$$\lambda_n \geq 0, n = 1,2, \dots, N \qquad (CRS - CCR\ model)$$

and by Imposing the restriction, $\sum \lambda_n = 1$ $(VRS - BCC\ model)$. The dual; of the above-mentioned model is the output-oriented CCR.

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Output Oriented model(O-O) with undesirable outputs

$$Max \sum_{r=1}^{s} u_r y_{rp}$$

Subject to

$$\sum_{r=1}^{s} u_r y_{rn} - \sum_{i=1}^{m} v_{in} - \sum_{t=1}^{k} \omega_t b_{tn} \leq 0,\ \forall_n$$

$$\sum_{i=1}^{m} v_i x_{ip} +\ \omega_t b_{tp} = 1,$$

$$u_r, v_i, \omega_t \geq 0, \forall_r \forall_i, \forall_t$$

Scale Efficiency

$$SE = \frac{TE^{CRS}}{TE^{VRS}}$$

Treatment of bad outputs in DEA:

Based on the previous studies reviewed, Halkos & Petrou (2019) summarized four approaches to incorporate an undesirable output in DEA. These four approaches are classified according to the two disposability technologies: weak disposal technology and strong disposal technology.

- Ignoring the undesirable output: Here, the undesirable output is overlooked altogether from the production function, seriously affecting the efficiency scores.
- Treating undesirable output(input) as input(output): Here, the output (input) variable is shifted to the input (output) side of the model from the output (input) (Dyson et al., 2001).
- Considering the undesirable output in the non-linear model: Färe et al. (1989) have proposed and implemented a performance index (a hyperbolic efficiency measure) that treats undesirable outputs and desirable outputs differently.
- Applying necessary transformation: In this approach, a monotone decreasing transformation is applied. Halkos & Petrou (2019), in their study, have summarized three methods of transformation based on Ali and Seiford (1990), Golany and Roll (1989), Koopmans (1951), Scheel (2001), Seiford and Zhu (2001) and Lovell et al. (1995).
- Developing a new model: Some new models based on DDF-DEA, ZSG-DEA, among others, have been proposed to tackle the problem of undesirable output.
- Inverse of anti-isotonic factor: The method can destroy the ratio (or interval scale) of the data, after which the resulting data demands transformation (Dyson et al., 2001).
- Subtracting the undesirable factor from a significantly larger number (Dyson et al., 2001).

Malmquist Productivity Index (MPI)

The DEA- based Malmquist Productivity index was constructed by Fare et al. (1992), which was developed as a Geometric Mean of two Malmquist Productivity Index (Chen & Ali, 2004). It is decomposed into catching-up effect (which represents the firm's managerial condition) and frontier-shift effect (which indicates average technological progress/regress).

As per Fare et al. (1994), output-oriented MPI is given by:

$$m_o(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\left(\frac{Y_{t+1}}{f_{t+1}(X_{t+1})}\frac{f_t(X_t)}{Y_t}\right) \times \left(\frac{f_{t+1}(X_{t+1})}{f_t(X_{t+1})}\frac{f_{t+1}(X_t)}{f_t(X_t)}\right)\right]^{\frac{1}{2}}$$

$$\frac{Y_{t+1}}{f_{t+1}(X_{t+1})}\frac{f_t(X_t)}{Y_t} = Change\ in\ Eficiency\ (catching - up\ effect)$$

$$\frac{f_{t+1}(X_{t+1})}{f_t(X_{t+1})}\frac{f_{t+1}(X_t)}{f_t(X_t)} = Change\ in\ Technology\ (Frontier - shift)$$

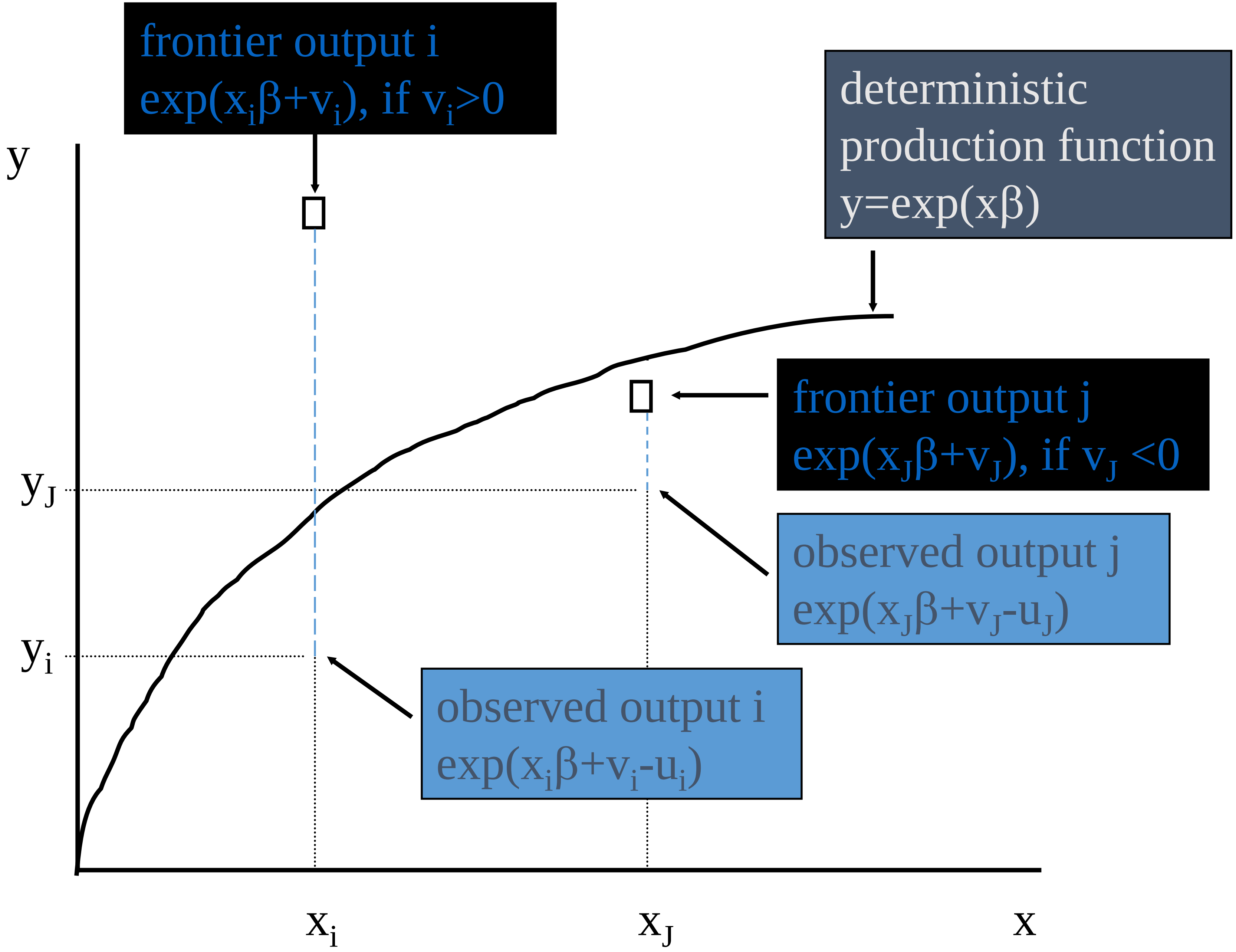
$$if\ Malmquist\ index(M_o) < 1 : Dterioration\ in\ productivity$$

$$if\ Malmquist\ index(M_o) > 1 : Improvement\ in\ productivity$$

$$if\ Malmquist\ index(M_o) = 1 : No\ change\ in\ productivity$$

Stochastic Frontier

- $\ln y_i = x_i \beta + v_i - u_i$
  - v i.i.d. $N(0,\sigma_v^2)$
  - $u \geq 0$
  - v & u independent
  - v accounts for
    - measurement error
    - random factors such as
      - weather
      - strikes
      - luck . . .


frontier output i
exp(x_iβ+v_i), if v_i>0
deterministic
production function
y=exp(xβ)
y
frontier output j
exp(x_Jβ+v_J), if v_J <0
y_J
observed output j
exp(x_Jβ+v_J-u_J)
y_i
observed output i
exp(x_iβ+v_i-u_i)
x_i
x_J
x

Stochastic Frontier Analysis (SFA)

To overcome the limitations of DEA, we apply a parametric model we follow the stochastic frontier production of Battese and Coelli (1995); in a cross-section setup, the stochastic frontier production is:

$$y_i = \exp(x_i\beta + v_i - u_i)$$

$$i = 1, \ldots\ldots N$$

$$\epsilon_i = v_i - u_i$$

$$v_i \sim N(0, \sigma_v^2)$$

$$u_i \sim truncated\ normal$$

$$y_i = output\ for\ the\ i^{th}\ country$$

$$x_i = (1 \times k)\ vector\ of\ inputs\ known\ for\ the\ i^{th}\ country$$

$$\beta = (k \times 1)\ vector\ of\ unknown\ parameters$$
$$v_i \sim N(0, \sigma_v^2)$$

$u_i s$ are non-negative variables following truncated normal distribution (truncated as zero).

$$u_i \sim truncated\ normal\ (z_i\delta, \sigma_u^2)$$

The advantage of assuming truncated normal distribution stems from the fact that it consists of a parameter μ and thus provides a flexible representation of efficiency in the data (Kumbhakar and Lovell, 2003)

$$z_i = (1 \times m) = explanatory\ variables\ for\ technical\ inefficiency$$

$$\delta = \ (m \times 1\ vector\ of\ unknown\ coefficients)$$

TE of the i^{th} country can be estimated as:

$$TE_i = \exp(-u_i)$$

SFA uses the MLE procedure to estimate the technical efficiency of the network readiness across countries. The variance parameter is:

$$\sigma_U^2 = \sigma_u^2 + \sigma_v^2$$

$$\lambda^2 = \frac{\sigma_u^2}{\sigma_v^2}$$

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}\ \ where\ \ 0 \leq \gamma \leq 1$$

In this study, we would consider ICT usage as output and ICT readiness, ICT Environment, and income status of the countries as variables explaining the production frontier. To incorporate undesirable output in our model, we consider an inefficiency component, namely, OECD-DSTRI.

Data for the year 2016 and 2020

Input or Output	Variables	Description	Source
Outputs	ICT Service Trade	ICT service exports (% of exports service, BoP).	WDI
	ICT Usage	The level of ICT adoption by government, businesses, and individuals.	GITR-2016 and Network Readiness Index Report 2020
	ICT Impact	ICTs' Socio-economic impacts.	GITR-2016 and Network Readiness Index Report 2020
Inputs	OECD-DSTRI	OECD-DSTRI captures cross-cutting impediments that affect all types of services traded digitally.	OECD Stats
	ICT Environment	Market conditions, regulatory framework, innovation, and ICT development.	GITR-2016 and Network Readiness Index Report 2020
	ICT Readiness	The Readiness measures the degree to which a country has infrastructure and factors supporting the uptake of ICTs.	The Global Information Technology Report 2016 AND Network Readiness Index Report 2020

Classification of VRSTE (DEA) Score

Range of VRSTE	Countries	
	2016	2020
0.7-0.9	South Africa, Turkey, Czech Republic, Poland, Thailand, Kazakhstan, Latvia, Portugal, Slovenia, Chile, Belgium, Ireland, Hungary	South Africa, India, Indonesia, Latvia
0.90-0.99	Indonesia, Australia, Austria, New Zealand, Iceland, Russian Federation, France, Spain, Lithuania, Slovak Republic, Germany, Estonia, Saudi Arabia, Colombia, Switzerland, Denmark, Finland, United Kingdom, Norway, Israel	Greece, Hungary, Spain, Portugal, Thailand, New Zealand, Turkey, Czech Republic, Belgium, Italy, China, Colombia, Chile, Luxembourg, Slovak Republic, Austria, Lithuania, Estonia, Slovenia, Australia, Iceland, France, Poland, United Kingdom, Germany, Malaysia, Finland, United States, Netherlands, Israel, Kazakhstan, Argentina, Saudi Arabia, Brazil
1	Argentina, Brazil, Canada, China, Costa Rica, Greece, India, Italy, Japan, Republic of Korea Luxembourg, Mexico, Malaysia, Netherlands, Peru, Sweden, United States	Canada, Switzerland, Costa Rica, Denmark, Ireland, Japan, Republic of Korea, Mexico, Norway, Peru, Russian Federation, Sweden

Statistical tests to check for the difference in TE scores across groups and across time

Statistical tests for the difference between the groups	For the difference in high and middle-income countries		For the year 2016 and 2020
	Value for 2016	Value for 2020	
t-test with equal variance	0.1496	-1.2175	-0.8856
t-test with unequal variances (t-value)	-0.1228	-0.9308	-0.8856
W-S test (Z-value)	0.750	-0.587	-0.209
K-S test	0.3214	0.2500	0.1800

Decomposed productivity change between 2016 and 2020

Country	High/Middle Income Country	Technical Change (EFFCH)	Technological Change (TECHCH)	Total Productivity Change (TFPCH)	Pure Technical Change (PECH)	Scale Efficient Change (SECH)
Argentina	0	1.03	1.028	1.059	0.992	1.038
Brazil	0	1.018	1.025	1.043	0.997	1.021
China	0	0.987	0.989	0.975	0.936	1.054
Colombia	0	1.029	1.027	1.057	0.954	1.079
Costa Rica	0	1	1.083	1.083	1	1
Indonesia	0	1.095	1.071	1.173	0.959	1.142
India	0	0.981	1.02	1.001	0.877	1.119
Kazakhstan	0	1.152	1.022	1.177	1.152	1
Mexico	0	1.21	1.043	1.262	1	1.21
Malaysia	0	0.986	1.048	1.033	0.975	1.011
Peru	0	1.234	1.057	1.304	1	1.234
Thailand	0	1.077	1.031	1.11	1.064	1.012
Turkey	0	1.155	0.998	1.152	1.15	1.004
South Africa	0	1.003	1.086	1.089	0.985	1.018
Australia	1	0.988	1.001	0.988	1.026	0.963
Austria	1	0.974	0.912	0.888	1.016	0.959
Belgium	1	1.011	0.92	0.93	1.046	0.967
Canada	1	1	1.098	1.098	1	1
Switzerland	1	1.005	0.967	0.971	1.018	0.987
Chile	1	1.071	1.029	1.103	1.061	1.009
Czech Rep.	1	1.065	0.936	0.997	1.131	0.941
Germany	1	0.994	0.886	0.881	1.023	0.972
Denmark	1	0.999	0.948	0.947	1.017	0.982

Country	High/Middle Income Country	Technical Change (EFFCH)	Technological Change (TECHCH)	Total Productivity Change (TFPCH)	Pure Technical Change (PECH)	Scale Efficient Change (SECH)
Spain	1	0.946	0.937	0.887	0.96	0.986
Estonia	1	0.974	0.988	0.962	1.001	0.973
Finland	1	1.008	0.953	0.961	0.995	1.013
France	1	0.956	0.934	0.893	1.031	0.928
United Kingdom	1	0.945	0.968	0.915	0.982	0.962
Greece	1	1.025	0.928	0.951	0.9	1.138
Hungary	1	1.005	0.973	0.978	1.006	0.999
Ireland	1	1.066	0.943	1.006	1.121	0.951
Iceland	1	1.076	0.864	0.93	1.03	1.044
Israel	1	0.971	0.928	0.901	0.989	0.982
Italy	1	0.928	0.953	0.884	0.934	0.993
Japan	1	1	0.952	0.952	1	1
Republic of Korea	1	1	0.939	0.939	1	1
Lithuania	1	1.045	0.95	0.993	1.009	1.036
Luxembourg	1	0.936	0.955	0.894	0.94	0.996
Latvia	1	0.954	0.996	0.951	1.025	0.931
Netherlands	1	0.928	0.938	0.87	0.983	0.944
Norway	1	1.013	1.025	1.038	1.01	1.002
New Zealand	1	0.946	0.995	0.941	0.977	0.969
Poland	1	1.017	1.034	1.052	1.173	0.867
Portugal	1	1.015	0.925	0.939	1.036	0.98
Russian Federation	1	1.097	0.981	1.076	1.071	1.024
Saudi Arabia	1	1.023	1.043	1.068	1.039	0.985
Slovak Republic	1	0.922	1.021	0.941	0.996	0.926
Slovenia	1	1.013	0.97	0.983	1.087	0.932
Sweden	1	0.974	0.869	0.847	1	0.974
US	1	0.949	0.945	0.896	0.981	0.967
mean		1.014	0.981	0.995	1.011	1.002

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Results from Malmquist Productivity Index (MPI)

Considering the intertemporal variation in Network Readiness Efficiency obtained from MPI, we can summarize the results through four combinations. The results circumscribe all four possible combinations:

- There is a list of countries that have managed to maintain internal managerial efficiency (Technical efficiency) and could even gain from the shift in the frontier (Technology progress). These countries are Argentina, Brazil, Colombia, Costa Rica, Indonesia, Kazakhstan, Mexico, Peru, Thailand, Turkey, South Africa, Australia, Canada, Chile, Norway, Poland, and Saudi Arabia. These countries have been the best-performing countries. They have improved the best possible ICT input (less skilled employees and have incurred low cost) and have maintained the balance between input and outputs.
- There are countries where technical efficiency has improved, but there was a decline in technological change. These countries are, Belgium, Czech Republic, Finland, Greece, Hungary, Iceland, Japan, Republic of Korea, Lithuania, Portugal, Russian Federation, Slovenia, Switzerland, and Turkey. Though these countries were able to elevate the organizational factors, they can introduce advanced technologies. These countries should amass advanced technologies and augment their performance through necessary skill advancement programs.
- Some countries had experienced deteriorating technical efficiency along with the improvement in technological change. These countries are India, Australia, Malaysia, and the Slovak Republic. It is evident from these countries that they have managed to invest in new technologies but were unable to strike a fine balance between inputs and outputs.
- However, there are also some countries where deteriorating technical efficiency was present along with deteriorating technological change. This group comprises China, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, United States, Italy, Israel, Luxembourg, Latvia, Netherlands, and New Zealand. These countries should merit their attention towards the organizational factors about stabilized utilization of input and output and introduce new technologies.

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Results of SFA

VARIABLES	2016	2020
Frontier		
L_environment	0.67***	0.44**
	(0.08)	(0.20)
L_readiness	0.32***	0.279**
	(0.12)	(0.14)
High_income	0.0412	0.0204
	(0.027)	(0.0432)
Constant	-0.0141	1.081**
	(0.455)	(0.494)
Mu		
L_oecd-dstri	0.162	0.224
	(0.348)	(1.634)
Constant	0.189	-0.139
	(0.215)	(1.919)
U-Sigma		
Constant	-5.064**	-3.776
	(2.034)	(7.079)
VSigma		
Constant	-6.056***	
	(0.483)	(0.434)
Sigma U	0.079	0.151
	(0.080)	(.535)
Sigma V	0.048***	0.067***
	(0.011)	(.014)
Lambda	1.642***	2.226***
	(0.080)	(0.531)
Observations	50	50

Standard errors in parentheses

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

DEA Scores across countries for 2016 and 2020

Country	2016				2020		
	Income status	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale
Argentina	0	0.933	1	irs	0.961	0.992	drs
Brazil	0	0.953	1	irs	0.97	0.997	drs
China	0	0.92	1	crs	0.908	0.936	drs
Colombia	0	0.898	0.982	irs	0.924	0.937	drs
Costa Rica	0	1	1	crs	1	1	crs
India	0	0.834	1	irs	0.818	0.877	irs
Indonesia	0	0.805	0.919	irs	0.881	0.881	crs
Kazakhstan	0	0.835	0.86	irs	0.962	0.991	drs
Malaysia	0	0.949	1	irs	0.935	0.975	drs
Mexico	0	0.827	1	irs	1	1	crs
Peru	0	0.811	1	irs	1	1	crs
South Africa	0	0.732	0.776	irs	0.734	0.764	drs
Thailand	0	0.812	0.854	irs	0.874	0.908	drs
Turkey	0	0.772	0.795	irs	0.891	0.915	drs
Australia	1	0.922	0.929	drs	0.91	0.954	drs
Austria	1	0.93	0.93		0.906	0.945	drs
Belgium	1	0.859	0.887	drs	0.869	0.927	drs
Canada	1	1	1		1	1	
Chile	1	0.859	0.885	irs	0.92	0.939	drs
Czech Rep.	1	0.81	0.818	irs	0.863	0.926	drs

	2016				2020		
	Income status	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale
Denmark	1	0.946	0.983	drs	0.945	1	drs
Estonia	1	0.953	0.953	crs	0.927	0.953	drs
Finland	1	0.923	0.983	drs	0.93	0.979	drs
France	1	0.923	0.935	drs	0.883	0.963	drs
Germany	1	0.916	0.952	drs	0.911	0.973	drs
Greece	1	0.873	1	irs	0.895	0.9	irs
Hungary	1	0.845	0.895	irs	0.849	0.901	drs
Iceland	1	0.879	0.933	drs	0.946	0.961	drs
Ireland	1	0.859	0.892	drs	0.916	1	drs
Israel	1	0.994	0.996	drs	0.965	0.985	drs
Italy	1	0.938	1	irs	0.871	0.934	drs
Japan	1	1	1	crs	1	1	crs
Republic of Korea	1	1	1	crs	1	1	crs
Latvia	1	0.843	0.865	irs	0.805	0.887	drs
Lithuania	1	0.906	0.942	irs	0.947	0.95	drs
Luxembourg	1	0.965	1	drs	0.904	0.94	drs

	2016				2020		
	Income status	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale	Constant Returns to Scale (CRSTE)	Variable Returns to Scale (VRSTE)	Scale
Netherlands	1	0.959	1	drs	0.89	0.983	drs
New Zealand	1	0.877	0.932	drs	0.83	0.91	drs
Norway	1	0.945	0.99	drs	0.957	1	drs
Poland	1	0.81	0.822	irs	0.825	0.965	drs
Portugal	1	0.86	0.873	irs	0.873	0.904	drs
Russian Federation	1	0.912	0.934	irs	1	1	crs
Saudi Arab.	1	0.942	0.955	irs	0.965	0.992	drs
Slovak Rep.	1	0.896	0.945	irs	0.826	0.941	drs
Slovenia	1	0.871	0.876	irs	0.883	0.953	drs
Spain	1	0.9	0.942	irs	0.852	0.904	drs
Sweden	1	0.941	1	drs	0.917	1	drs
Switzerland	1	0.939	0.983	drs	0.943	1	drs
United Kingdom	1	0.969	0.984	drs	0.916	0.966	drs
U.S.	1	1	1	crs	0.949	0.981	drs
Average	**0.72**	**0.9009**	**0.944**		**0.91292**	**0.95378**	

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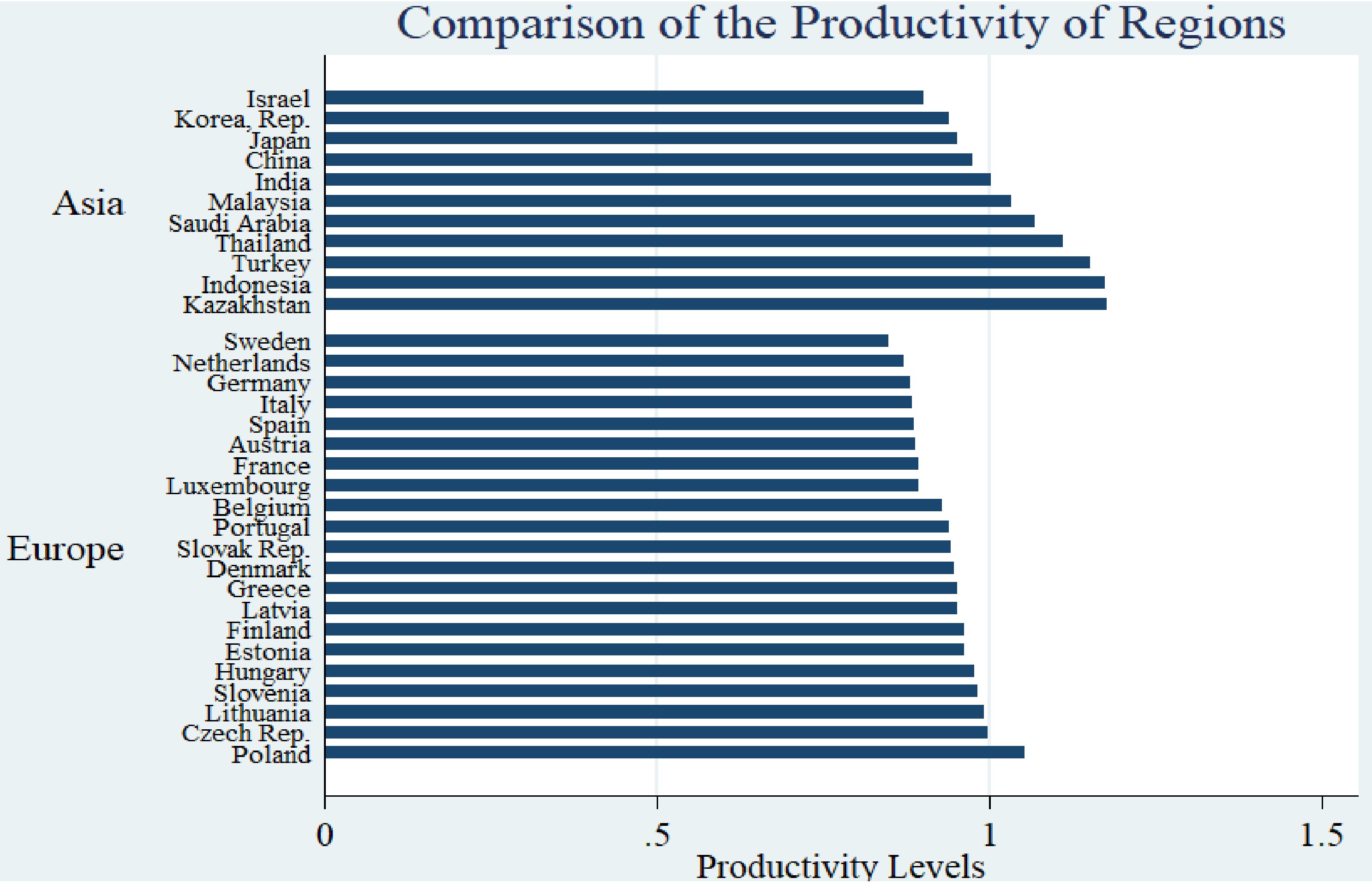
SFA Scores for the ICT sector across countries In 2020 and 2016

Country name	SFA_2020	SFA_2016
Argentina	0.972	0.977
Australia	0.975	0.974
Austria	0.971	0.978
Belgium	0.958	0.959
Brazil	0.973	0.978
Canada	0.973	0.969
Switzerland	0.965	0.977
Chile	0.969	0.938
China	0.969	0.959
Colombia	0.96	0.973
Costa Rica	0.975	0.983
Czech Rep.	0.953	0.942
Germany	0.967	0.976
Denmark	0.98	0.981
Spain	0.965	0.976
Estonia	0.973	0.98
Finland	0.979	0.972
France	0.969	0.978

Country name	SFA_2020	SFA_2016
U K	0.971	0.982
Greece	0.962	0.967
Hungary	0.925	0.951
Indonesia	0.943	0.925
India	**0.926**	**0.891**
Ireland	0.929	0.955
Iceland	0.969	0.968
Israel	0.977	0.98
Italy	0.957	0.978
Japan	0.984	0.987
Kazakhstan	0.965	0.956
Korea, Rep. Republic of Korea	0.984	0.987
Lithuania	0.973	0.977
Luxembourg	0.968	0.983
Latvia	0.944	0.959
Mexico	0.976	0.967
Malaysia	0.976	0.982

Country name	SFA_2020	SFA_2016
Netherlands	0.969	0.982
Norway	0.975	0.978
New Zealand	0.968	0.958
Peru	0.972	0.934
Poland	0.938	0.912
Portugal	0.958	0.957
Russia Russian Federation	0.98	0.965
Saudi Arabia	0.978	0.974
Slovak Rep.	0.906	0.962
Slovenia	0.963	0.955
Sweden	0.975	0.98
Thailand	0.947	0.934
Turkey	0.964	0.927
United States	0.975	0.986
South Africa	0.876	0.855
Mean	0.962	0.962

European Union and Asian Countries



Source: Author's calculation

Cross-country estimates of the factors determining economic growth

VARIABLES (Dependent Variable: Average Annual Growth Rate)	All variables	Without GFCF	Without Usage and GFCF	Robust All variables	Robust without GFCF	Robust without Usage and GFCF	Only ICT related var
ICT Productivity	2.553**	2.301**	3.272***	2.553**	2.301**	3.272**	2.462
	(-0.832)	(-1.013)	(-1.062)	(-0.915)	(-1.032)	(-1.129)	(-2.236)
ICT Technical Efficiency	4.373**	4.531**	2.259	4.373**	4.531**	2.259	-5.697
	(-1.584)	(-1.942)	(-1.923)	(-1.41)	(-1.459)	(-1.369)	(-5.5)
OECD-DSTRI	0.425***	0.387**	0.421**	0.425***	0.387***	0.421***	0.0877
	(-0.114)	(-0.139)	(-0.16)	(-0.0787)	(-0.105)	(-0.122)	(-0.387)
ICT Usage	-2.359*	-3.261**		-2.359**	-3.261*		-0.732
	(-1.229)	(-1.445)		(-0.994)	(-1.701)		(-3.506)
ICT Environment	2.645	2.012	-0.787	2.645	2.012	-0.787	1.69
	(-1.49)	(-1.803)	(-1.515)	(-1.888)	(-1.721)	(-1.446)	(-4.059)
ICT Readiness	6.907***	6.916***	5.988***	6.907***	6.916***	5.988***	-1.502
	(-1.26)	(-1.545)	(-1.725)	(-0.95)	(-1.264)	(-1.781)	(-3.629)
ICT Impact	-2.395	-1.769	-1.524	-2.395*	-1.769	-1.524	4.407
	(-1.536)	(-1.86)	(-2.15)	(-1.158)	(-1.477)	(-1.409)	(-4.055)
GFCF	0.0632**			0.0632**			
	(-0.0247)			(-0.0264)			

VARIABLES (Dependent Variable: Average Annual Growth Rate)	All variables	Without GFCF	Without Usage and GFCF	Robust All variables	Robust without GFCF	Robust without Usage and GFCF	Only ICT related var
Unemployment	0.316*	0.238	0.324	0.316*	0.238	0.324	
	(-0.153)	(-0.183)	(-0.208)	(-0.164)	(-0.221)	(-0.249)	
FD	-0.90***	-0.796***	-0.864***	-0.909***	-0.796***	-0.864**	
	(-0.191)	(-0.228)	(-0.262)	(-0.143)	(-0.256)	(-0.307)	
GDP constant (2016)	0.0472	0.0577	0.118	0.0472	0.0577	0.118	
	(-0.0583)	(-0.0714)	(-0.0767)	(-0.0524)	(-0.0684)	(-0.0687)	
Trade to GDP	0.215	0.0971	0.226	0.215	0.0971	0.226	
	(-0.119)	(-0.134)	(-0.141)	(-0.143)	(-0.169)	(-0.165)	
MDPI	0.292	0.307	0.208	0.292	0.307	0.208	
	(-0.197)	(-0.241)	(-0.275)	(-0.191)	(-0.255)	(-0.315)	
Inflation	0.0797	0.251	0.22	0.0797	0.251	0.22	
	(-0.148)	(-0.162)	(-0.187)	(-0.189)	(-0.198)	(-0.215)	
Democracy Indicator	0.538	1.042	1.412	0.538	1.042*	1.412*	
	(-0.664)	(-0.778)	(-0.88)	(-0.659)	(-0.5)	(-0.728)	
Health Expenditure	-0.831**	-0.855**	-0.985**	-0.831*	-0.855*	-0.985*	
	(-0.297)	(-0.364)	(-0.416)	(-0.383)	(-0.445)	(-0.533)	
High-Income	-0.512*	-0.577*	-0.426	-0.512**	-0.577**	-0.426*	
	(-0.247)	(-0.301)	(-0.34)	(-0.212)	(-0.208)	(-0.238)	
Constant	-21.2***	-15.75***	-16.52***	-21.29***	-15.75***	-16.52**	-14.24**
	(-3.445)	(-3.289)	(-3.788)	(-2.765)	(-4.18)	(-5.441)	(-5.99)

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Conclusions and policy implications

Based on DEA results, we have received four pieces of evidence. In line with previous research findings like You & Yan (2011),

- The model with undesirable output shows higher average technical efficiency scores than the model without undesirable output.
- Second, the model with ICT trade as output shows a marginally higher technical efficiency score than the model without ICT trade.
- Thirdly, the countries, on average, witnessed a surge in technical efficiency between 2016 and 2020.
- Fourthly, trade restrictiveness has very little to do with the technical efficiency of countries.
- Fifthly, there is no variability in the technical efficiency scores of High and Middle-income nations.

From the results of the Malmquist index,

- we can deduce that where all the middle-income countries have maneuvered to move up the ladder, as evident from the positive and greater than unity TFP change, 28 high-income countries have experienced deterioration in TFP.
- The counties need to have better governance, transparency, and accountability to achieve the technical and technological efficiency observed in 50 countries for 2016 and 2020. From the maximum likelihood estimation results of SFA, ICT environment and ICT readiness have a statistically significant positive impact on ICT usage.
- Thirdly, OECD-DSTRI, an undesirable output considered an inefficiency component, negatively impacts the technical efficiency but was found to be insignificant (statistically).
- Gathering actionable insights from the methodology adopted, we can infer that though the technical efficiency scores might have gone up, the total factor productivity change has gone down across 50 countries. This might probably be because of a trade war, deepening democratic recession, and the rising cases of authoritarianism.

Conclusions and policy implications Contd.

- For future research, we suggest an economic analysis of the regulatory framework adopted by countries worldwide.
- Further, there is sufficient scope for studies investigating the impact of the digital service trade restrictiveness index on the economy and international trade. We also suggest the implementation of other frontier methodologies to have a deeper understanding of the technical efficiencies of Network Readiness of countries.
- In the end, we emphasize the persistent attempts by the policymakers to make the ICT environment conducive and ramp up the digital infrastructure and other factors to ensure ICT readiness is improved.
- We also suggest that the countries either do away with the digital service trade restrictions. In other words, governments need to make every attempt to facilitate ICT usage.
- These policies would pave the way for the inclusive growth of countries across the world.
- It seems that net neutrality, reducing pernicious regulations related to the ICT sector, and adopting competition policies across countries can ameliorate the technical productivity and efficiency of the ICT sector.
- Maybe a better measure of OECD-DSTRI incorporating the above may lead to accurately estimating the impact of OECD-DSTRI on the technical productivity and efficiency of the ICT sector across countries.

Limitation of the study

- We have considered both, parametric and non-parametric approaches to efficiency and productivity measurement. However, these approaches are subject to certain limitations and are not fully exhaustive. For example, one may use spatial model in the SFA analysis to integrate spatial dimension with efficiency and productivity measurement (Han et al., 2016).
- Even in the DEA analysis Fuzzy DEA and Network DEA are some new developments for efficiency and productivity measurement.
- A longer longitudinal dataset would be an ideal choice for pursuing research in this area. Distance function approach could be used to include multiple outputs and multiple inputs in the SFA framework (Kumbhakar et al., 2015).
- Furthermore, we are of the opinion that digital content, domestic regulations, competition policy and online platforms are linked and therefore have to be read and understood because of its societal impact especially, the young generation.

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Thank You