ICT Development and Deforestation in Asia-Pacific Region: An Empirical Analysis

Desarrollo de las TIC y deforestación en la región de Asia y el Pacífico: un análisis empírico

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Ayesha Idrees
M.Phil. in Economics
Department of Economics, School of Economics, University of the Punjab, Lahore, Pakistan
Correo: idrees.ayesha84@gmail.com

Dr. Bilal Mehmood
Ph.D. in Economics (Specialization: Digital Economy)
Chairman & Associate Professor, Department of Economics, School of Economics, University of the Punjab, Lahore, Pakistan
Correo: dr.bilal.eco@pu.edu.pk

ORCID: https://orcid,org/ 0000-0001-6245-8269

Abstract

Information and communication technologies (ICTs) have spread throughout the world and are affecting almost every aspect of life. This research examines the effect of ICT adoption levels on deforestation rates in 26 countries of Asia and the Pacific. Independent variables include four ICT determinants and three control variables: population growth, agricultural land expansion and GDP per capita. The Pooled Mean Group (PMG) estimates confirm a strong positive relation between ICT index and deforestation in the region. Population growth, GDP per capita and agricultural area expansion are found to contribute positively towards deforestation. On basis of empirical findings, this study suggests that policies emphasizing integration of ICT diffusion and its application in forestry sector will lead to goals of sustainable forestry and reforestation efforts' success.

Keywords

Deforestation, Information & Communication Technologies, Forest monitoring, Forest management, GDP per capita, Population growth.

Resumen

Las tecnologías de la información y la comunicación (TIC) se han extendido por todo el mundo y están afectando a casi todos los aspectos de la vida. Esta investigación examina el efecto de los niveles de adopción de TIC en las tasas de deforestación en 26 países de Asia y el Pacífico. Las variables independientes incluyen cuatro determinantes de las TIC y tres variables de control: crecimiento demográfico, expansión de las tierras agrícolas y PIB per cápita. Las estimaciones del Pooled Mean Group (PMG) confirman una fuerte relación positiva entre el índice de TIC y la deforestación en la región. Se ha descubierto que el crecimiento demográfico, el PIB per cápita y la expansión de la superficie agrícola contribuyen positivamente a la deforestación. Sobre la base de hallazgos empíricos, este estudio sugiere que las políticas que mejoren la integración de la difusión de las TIC y su aplicación en el sector forestal conducirán a objetivos de silvicultura sostenible y al éxito de los esfuerzos de reforestación.

Palabras clave

Deforestación, Tecnologías de la Información y las Comunicaciones (TIC), Monitoreo forestal, Gestión forestal, PIB per cápita, Crecimiento poblacional.

Introducción

Forests are irreplaceable natural reserves of countries. They enhance survival capacities of mankind by cleaning environment of pollutants and providing range of foods and medicines. Forests store about 45% of terrestrial carbon and contribute to hydrological cycle by assisting cloud formation and precipitation (Bonan, 2008). Forests and nature provide not only environmental but also economic and health benefits. Mahmood and Ramzan show that forests are a bountiful economic resource and hold large potential for growth through development of value-added and high-quality goods and services (Mahmood and Ramzan, 2018). Biodiversity in forests acts as a storehouse of genetic material used in medicines (Jenkins & Schaap, 2018). A special form of nature exposure, 'forest therapy' is identified as a tool for ameliorating health and psychological well-being (Oh et al., 2017).

Man has always scuffled to build finer lifestyles and environment for himself. In an endless struggle for acquiring more comfort and growth, he has compromised one for the other. World's forest reserves are declining rapidly due to forest degradation and deforestation phenomena. Between 2000 and 2018, global net forest area loss recorded at 93Mha (FAO, 2022). About 18.7 million acres of forests, an area approximately the size of Panama, are depleted each year worldwide (World Wildlife Fund, 2019). Commercial logging, soaring urban centers, agricultural expansion, forest fires, mining, lack of good governance and population growth are main drivers of deforestation worldwide (Barbier and Burgess, 2001; Lambin and Geist, 2003; Rademaekers et al., 2010; DeFries et al., 2009). Growth in population, both urban and rural, negatively impacts forests. Increased wood-cutting coupled with expanded farmlands to meet urban demand are major ways by which population growth causes deforestation (Musa et al., 2017). Indonesia has lost considerable forest area since 2000. Local and subsistence agriculture accounted for about 34% of deforested land, followed by commercial agriculture causing 32% of total forest loss between 2000-2009 (Kissinger et al., 2012). Forests are net carbon sinks but rapid deforestation is releasing large amounts of CO_2 in atmosphere. If deforestation is left unabated, forests could turn into net carbon sources (Goodman and Herold, 2014). Deforestation-related emissions of greenhouse gases are the second largest source of CO_2 emissions in the atmosphere (Jenkins and Schaap, 2018). One such study to estimate emissions from gross deforestation was conducted by Harris et al., (2012). The study estimated that Brazil and Indonesia accounted for 55% of total emissions from tropical deforestation between 2000-2005.

Being an unparallel source of extensive climatic, health, tourism, social and economic services, forests have attracted ample attention. Restoring degraded forests, halting deforestation and sustainable use of ecosystems are the key focus of Sustainable Development Goals (SDGs). Natural forest expansion and landscape restoration efforts have brought about an increase in forests in Asia and Europe from 2000 to 2020; whereas forests are still shrinking in Latin America and Africa (FAO, 2020). Role of ICTs in governing forests, maintaining sustainable forestry practices and tackling deforestation is unrivalled. ICTs are vectors enabling greater globalization and are fundamental factors shaping the economic dynamics worldwide. Differences in levels of IT usage could translate into disparities in levels of productivity and rates of economic growth (Mishra et al., 2015; Avgerou, 2003). ICT adoption by enterprises helps them gain competitive advantage (Schubert and Leimstoll, 2006; Trapero et al., 2020).

Forests can contribute to development of a country provided the management of the sector is not plagued with corruption and poor governance (PROFOR, 2001). Forest management information systems use technology to curb illegal loggings, timber processing and wildlife trade (Castren and Pillai, 2017). Many industrialized countries are using digital-sensors such as GIS and technologies to improve forest governance (PROFOR,2011). Applications of ICT-based integrated solutions such as e-governance portals, community radio and advocacy campaigns increase accountability and public participation in forest management practices. ICT expansion improves interaction between governments and citizens by dispersing information quickly and cost-effectively to large audiences. Sideridis and Protopappas (2015) stress that countries can gain more by formation of e-Forestry and e-Environment areas under the domain of e-Government systems (Sideridis and Protopappas, 2015).

Governments around the world are taking steps to avoid and mitigate deforestation by moving towards digital systems wherever possible. Indian Railways launched the biggest e-portal website in Asia, providing e-tickets in an economical way. This development is eco-friendly; it reduced the amount of deforestation done to produce paper (Jayanthi et al., 2014). 'Bing-map' application by Microsoft provides communication ease for cultivation-specific orders and gives users access to GIS based developments (Mayer, 2013). ICT adoption by households and individuals aids in curbing forest degradation and illegal loggings. A forestry approach regards citizens as 'clients of last resort'. Community-based conservation projects involve changing attitudes and practices of indigenous people and are both cost minimizing and welfare maximizing Moutinho (2012).

Literature Review

Allen and Barnes established that population growth and agricultural land expansion are globally found causes of deforestation (Allen and Barnes, 1985). Their estimates for 28 developing countries show that both urban and rural population growth contributed positively towards deforestation, but by different pathways. similar results were found by Jorgenson and Burns, who established that rural population growth was more strongly correlated with deforestation (Jorgenson and Burns, 2007). Rural population causes deforestation by agriculture, biomass demands and subsistence needs.

De Fries et al., analyzed 41 countries around humid tropics to identify factors most strongly associated with forest loss (De Fries et al., 2010). Urban population growth was found to be significantly and positively correlated with deforestation in all study regions: Asia, Africa and Latin America. This was because urban people demand and consume more processed food which stimulates commercial agricultural production. Musa et al., explored the relationship dynamics between urban population growth and deforestation in Bauchi metropolis, Nigeria (Musa et al., 2017). By employing remote sensing and GIS techniques, they found that rapid urban growth was causing rapid deforestation. Cutting trees for infrastructural needs and expanding farmlands to satisfy growing demands of metropolis are identified as main paths through which urbanization leads to deforestation. Eltom et al., established that declining forest land in towns could be attributed to greater forest clearing for housing and infrastructure demands by urban communities (Eltom et al., 2013).

Ramzan and Mehmood found a bi-directional relationship between GDP growth and forest exports in the Asian continent (Ramzan and Mehmood, 2015). The results showed that sustainable forest management supports development and fulfils increasing human needs. Murshed et al., empirically analyzed the relation between income growth and deforestation propensity in Bangladesh (Murshed et al., 2021). The findings proved the inverted U-shaped relationship between deforestation and economic growth. At the initial stages of development, deforestation propensities increased but after reaching a threshold, deforestation started to decrease with further economic growth.

As world population is growing, the demand for forest products is also rising. There is pressure on governments to efficiently govern the development and use of forests. With new problems and objectives, the need for enhanced communication and participation methods arises. ICTs' use in forest governance, monitoring and decision-making process has significantly elevated transparency, accountability and assessment of project implementation (Rametsteiner et al., 2005). Mery et al., state that ICTs, biotechnology and laser applications have profuse uses in forest management (Mery et al., 2010). Forest regrowth, climate-adaptable species, timber resources, pest management, reducing paper consumption and reduced costs are some of the benefits of using advanced technologies in forest sector. The authors call for a need to enhance technological capacity building in developing countries and highlight the lack of research and knowledge about the impacts of technological change on forest sector.

Mayer indicated that the use of ICT based solutions such as sensory devices, telemetry, PROGIS software, mobile phone applications and precision forestry technologies provide updated information and greatly reduce environmental risks (Mayer, 2013). Microsoft company launched its project for quality-assured mapping of land which is of enormous help in sustainable agriculture and forest management. The paper concludes that ICT-infrastructure integration enables sustainable rural development. Mishra et al., established that technology usage in agroforestry practices is of tremendous importance in rehabilitation of degraded land (Mishra et al., 2015). Forest and land management authorities greatly benefit from applications such as resource modeling, spatial and temporal analyses, optimization and identification of species. Nghiem et al.,used time series regression models to examine the relationship between news articles and public interest in conservation topics (Nghiem et al., 2016). By using search volume in Google Trends data, they showed that mass media has a strongly affects public interest. They stress social media inclusion in policy implementation for beneficial repercussions in conservation sciences. ICTs have replaced newspapers with non-paper communication channels to a large degree. The demand for printed information decreases as electronic information sources penetrate. ICTs impact forest-based pulp and paper sector in two alternative ways. On one hand, they reduce profits of the sector, as prices of paper products decrease due to decreased demand. Conversely, ICT developments boost productivity and operationalization of the paper industries. Thus, while profits decline, ICTs provide opportunity to re-structure product mix according to growing demand trends (Katila et al., 2010).

Kangas and Store analyzed the role of teledemocracy in participatory forest planning in Finland by studying a web-based participatory forest planning method used by Finnish forest authorities (Kangas and Store, 2003). The method bore fruitful results with benefits of arousing interest among people and incorporated people's preferences in planning. IT systems enable people to virtually attend events bound to place and time. The article suggests to explore the diverse ways in which IT can influence forestry. Torresan et al.,review usage and data management methods of wireless sensor networks, internet of things and monitoring by citizen science (Torresan et al., 2021). They propose comprehensive monitoring by convergence between repurposed/innovative ground-based monitoring (citizen science) and remote satellite sensors for well-informed forest-monitoring avenues.

ICTs connect the world and thus are useful for gathering information about forests and land uses. Pratihast et al., stress that advancements in ICTs enable local communities' inclusion in forests monitoring(Pratihast et al., 2012). They emphasize that communities can timely and accurately report on recent deforestation incidents than remote sensors through personal digital assistants. Smartphones reporting by community participants is not only cost-effective but can also highlight the area and type of disturbance in near real time. Understanding specific contexts of indigenous communities and involving them in projects yields fruitful results in sustainable forests management. Brown and Reed demonstrated that public participation geographic information system (PPGIS) will provide United-States' forest management authorities with valuable information, make decision-making efficient and resolve land conflicts (Brown and Reed, 2009). In Ucayali province of Peruvian Amazon, some indigenous remote communities were given mobile phones, training to use satellite data and flying drones to confront deforestation. This indigenous-led initiative reduced illegal logging and deforestation rate fell from five-percent annually to nearly zero (GFW, 2018). Ecosia.org is a widely supported web search engine that transfers major portion of its income to WWF for mitigating climate change. Its aceptance is an indicator of people's preference to technological endeavors striving towards fighting climate change and afforestation (Sharma et al., 2020). Yilmaz and Koyuncu analyzed the impact of ICT diffusion on deforestation (Yilmaz and Koyuncu, 2019) on panel data of those 174 countries which have a forest area of 2% or more as a percentage of total land area. The study found that ICT diffusion and deforestation are significantly and negatively associated. The results also suggest that ICT penetration aids forest monitoring and prevents illegal loggings.

Above mentioned studies emphasize that use of ICTs for forest management has manifold benefits for effectiveness and efficiency of forest monitoring, data collection and policy-making to curb deforestation and illegal logging. There is abundance of theoretical and empirical research drawn upon consequences of agricultural technology for forests. However, literature studying the impacts that ICT usage imposes on deforestation is scarce. Only one research has been found to study the direct impacts of ICT penetration for forestry sector. Yilmaz and Koyuncu based their research on the hypothesis that usage of ICT in forest sector reduces deforestation globally (Yilmaz and Koyuncu, 2019). While they researched it for all countries with 2% or more forest area (% of total land area), this study will analyze the relation for Asia and the Pacific.

Theoretical Framework

Various theories lay out the pathways through which forest areas undergo changes over time due to multiple factors. The Forest Transition theory and the Environmental Kuznets Curve hypothesis link environmental improvement with economic development (Mather, 1992; Barbier, 2001). These theories support the premise that as countries become more developed, they begin to pay greater attention to protecting the environment.

Community Engagement theory further suggests that community participation and trust among forest communities, along with information provided by agencies, better prepare them for risk and disaster (Paton, 2008). Bountiful results are observed when indigenous communities are engaged in sustainable forest management (Charnley and Poe, 2007). Community engagement using advanced ICTs is also considered cost-effective and often yields positive results in sustaining forestry practices (Goodwin, 2005; Mayer, 2013; Moutinho, 2012).

Various case studies demonstrate sustainable forest management projects that involve local communities, such as *The Internet, Organizational Change and Community Engagement: The Case of Birmingham City Council and Effective Community Engagement for Sustainability: Wombat Community Forest Management* (Dare, 2011; Dare et al., 2012; Nelson and Pettit, 2004).

The Socio-Technical Systems Theory introduced the concept of socio-technical systems to explain the interactions between humans and technology (Emery and Trist, 1960). This theory argues that technology interacts with humans in various useful ways and influences outcomes. Technologies such as ICTs, machines, and tools establish a mutual relationship with social systems, and together they shape decisions in context-sensitive environments (Ropohl, 1999). Environmental sustainability can therefore be greatly enhanced by socio-technical coordination, and the development of information systems that support environmental sustainability is essential (Dwyer, 2011).

Objective and Hypothesis

This research aims to explore the dynamics of relation between ICT use and deforestation in Asia and the Pacific region.

Hypothesis: *ICT usage lowers the rate of deforestation in Asia-Pacific countries*.

Data and Methodology

Data for 26 Asian and the Pacific countries from 2000 to 2019 is taken from World Development Indicators (WDI). countries with 5% or more forest area as a percentage of total land area were selected.

The model estimated is:

$$DEF_{it} = \beta_0 + \beta_1 IDV_{it} + \beta_2 PGR_{it} + \beta_3 AEX_{it} + \beta_4 GDP_{it} + \varepsilon_{it}$$

The model parameter β_0 allows for the possibility of the country specific fixed-effects and the coefficient of β_{0i} allows for the variation across individual countries.

Tabla 1. ICT Index

Fixed telephone subscriptions (per 100 people)
Individuals using the Internet (% of population)
Fixed broadband subscriptions (per 100 people)
Mobile cellular subscriptions (per 100 people)

Source: International Telecommunication Union

The independent variable IDV is the ICT development index, made by Principal Component Analysis (PCA) method using the four indicators in Table 1. This operationalizes the ICT development as its usage.

DEF is the dependent variable. The annual percentage change in forest stock is calculated by subtracting the forest area of current year from previous year's forest area, then dividing it by previous year's forest area and multiplying by 100 (Yilmaz, 2019; Armenteras et al., 2013; Jorgenson and Burns, 2007). Positive values indicate a decrease in forestland, signaling increased deforestation whereas negative values symbolize decreased deforestation rate.

The expected correlation of population growth (PGR) with deforestation is positive. Deforestation is associated in the short term with rising population (Allen and Barnes, 1985).

$$\varepsilon_{i,t} = \rho_i \varepsilon_{i,t-1} + \omega_{it} \qquad (1.1)$$

$\varepsilon_{i,t}$ is the disturbance from the panel regression and ρ_i shows the autoregressive vector of residuals.

Results and Interpretation

Unit root test

The existence of panel roots is investigated by three panel unit root tests; Levin et al.,(2002) (LL test), Im et al.,(2003) (IPS test) and Maddala and Wu (1999) (MW test) tests. The LL tests are based on homogeneity of the autoregressive parameter, while the IPS tests are based on heterogeneity of autoregressive parameters. Thus, no pooling regressions are associated with IPS tests. MW tests, on the other hand, are based on Fisher type unit root tests that are not restricted to the sample sizes for different samples (Maddala and Wu, 1999). Results from all these tests are given in table 2. The selection of the appropriate lag length was made using the Schwarz Bayesian Information Criterion.

Table 2. Unit Root Tests

	DEF	ΔDEF	IDV	ΔIDV	PGR	AEX	GDP	ΔGDP
Levin, Lin & Chu	-1.47[c]	-2.24[b]	5.69	-1.60[c]	-6.91[a]	-47.19[a]	4.91	-3.98[a]
Im, Pesaran and Shin W-stat	2.81	-3.90[a]	10.66	-1.52[c]	-11.17[a]	-16.38a	8.94	-5.23[a]
Maddala & Wu-ADF-Fisher X^2	29.20	90.76[a]	16.68	75.53[b]	297.3[a]	415.07a	15.56	124.13[a]
Maddala & Wu-PP-Fisher X^2	52.94	132.2[a]	60.04	122.9[a]	91.0[a]	338.0a	12.66	188.0[a]
Remarks	***I***(1)		***I***(1)		***I***(0)	***I***(0)	***I***(1)	

Δ denotes first difference. Both variables are taken in natural logarithms. All tests take non-stationarity as null. **Note:** Table shows the individual statistics and p-values with the lag length selection of one. Intercept is included in all terms with or without first differences. Probabilities of fisher type test are using asymptotic X^2 distributions while other type of tests assumes asymptotic normality.

Source: Author's estimation

Table 2 shows the statistics of panel unit root test. The results suggest that DEF, IDV and GDP have a unit root making them non-stationary. After first differencing, series become stationary as common intercept panel unit root test reject the null of non-stationary at 1% level of significance and individual intercept panel unit root tests are significant at 5% level of significance. Most of the tests infer that three variables are first difference stationary with order of integration 1, while two, PGR and AEX are stationary at level (I(0)).

Cointegration Analysis

After investigating stationarity, three panel-cointegration approaches are employed. These provide for the magnitude of the relationship. These are: Mean Group (MG), Pooled Mean Group (PMG) and Dynamic Fixed Effects (DFE) estimators.

Mean Group (MG) Estimator

Pesaran and Smith provided mean group estimator of dynamic panels for large number of time observations and large number of groups (Pesaran and Smith, 1995). In this method, separate equations are estimated for each group and distribution of coefficients of these equations across groups are examined. It does not consider any possibility of same parameters across groups.

Pooled Mean Group (PMG) Estimator

Pesaran and Smith suggested pooled mean group (PMG) estimator of dynamic panels for large number of time observations and large number of groups (Pesaran and

Smith, 1997). Pesaran, Shin and Smith added further in PMG estimator and extended it. Pooled mean group estimator considers both averaging and pooling in its estimation procedure, so it is considered as an intermediate estimator (Pesaran, Shin and Smith, 1997; 1999). PMG estimator allows variation in the intercepts, short-run dynamics and error variances across the groups, but it does not allow long-run dynamics to differ across the groups.

Dynamic Fixed Effects (DFE) Estimator

In addition to PMG and MG, Dynamic Fixed Effects (DFE) is also used to estimate the cointegrating vector. DFE specification controls the country specific effects, estimated through least square dummy variable (LSDV) or generalized method of moment (GMM). Dynamic fixed effect relies on pooling of cross-sections. Like the PMG estimator, DFE estimator also restricts the coefficient of cointegrating vector to be equal across all panels. Adopting from Pesaran, Shin and Smith, PMG estimable model has an adjustment coefficient φ_i that is known as the error-correction term. In fact, this error-correction term φ_i tells about how much adjustment occurs in each period.

Table 3. Cointegration Results

	Mean Group		Dynamic Fixed Effects		Pooled Mean Group	
	Coefficien t	p-value	Coefficien t	p-value	Coefficien t	p-value
	Long Run Parameters					
IDV	-0.3972 (-1.89)	0.060	-0.0981 (-2.15)	0.032	-0.1816 (-6.29)	0.000
PGR	0.3203 (2.78)	0.006	-0.0332 (1.00)	0.319	-0.8090 (2.55)	0.011
AEX	1.1845 (0.73)	0.463	-0.0242 (0.15)	0.881	1.6667 (3.63)	0.000
GDP	1.1467 (3.54)	0.001	-0.0605 (-1.03)	0.000	0.1740 (2.61)	0.010
Average Convergence Parameter						
Error Correction Term (φ_i)	-0.8151 (-10.18)	0.000	-0.3077 (-9.39)	0.000	-0.3476 (-6.45)	0.000
Short Run Parameters						
ΔIDV	-0.1764 (-5.59)	0.000	-0.0251 (-0.89)	0.373	-0.0318 (-0.28)	0.778
ΔPGR	0.0117 (-1.60)	0.111	-0.0204 (-0.68)	0.496	0.0348 (-2.41)	0.017
ΔAEX	0.5431 (3.95)	0.000	0.1820 (2.72)	0.007	0.1344 (0.70)	0.482
ΔGDP	0.6173 (2.49)	0.014	0.3960 (1.99)	0.048	4.6869 (2.19)	0.030
Intercept	0.3463 (1.81)	0.072	0.0274 (0.90)	0.366	0.1906 (4.30)	0.000

Note: In parenthesis, z statistics are given.

Source: Author's estimation

Results in table 3 reveal the comparison of panel cointegration estimation using MG, DFE and PMG, with and without structural breaks. Introducing structural breaks has improved statistical inference. The group statistic by PMG estimator is significant at 5%, thus we reject the null hypothesis of no cointegration. Both long run and short run parameters of MG, DFE and PMG show a negative association between ICT adoption and deforestation. The results of PMG model show that in the long run, ICT development reduces forest degradation significantly. In the long run, a 1% increase in ICT adoption reduces deforestation by 0.1816%. These results are in line with Yilamz and Koyuncu who showed that ICT diffusion reduces deforestation (Yilamz and Koyuncu, 2019). Further, PMG shows positive long run relationship of population growth, agricultural land expansion and income per capita with deforestation. The coefficients of PGR and AEX have increased in magnitude after the inclusion of structural dummies in PMG estimator. Positive and significant coefficients for population growth and agricultural land expansion validate long-established concerns in deforestation literature.

The result that ICT level significantly lowers deforestation is not surprising as governments in Asian countries are taking benefit of vast potential of ICT inclusion in sustainable forestry and ecological conservation projects. Regional collaborations assisted the countries' e-development journey; China, Japan and Republic of Korea helped in building Lao PDR's technical infrastructure in forestry sector to improve country's control over illegal logging. Computers to monitor forests, radios to broadcast information and SMS-based crime reporting has greatly enhanced forest governance and management capability in the country (Castren and Madhavi, 2015). Other landmark achievements include employing technologies in curbing deforestation such as using phones to detect chainsaw noises in Indonesia (Ferguson, 2013); ICT based forest surveillance systems in New-Zealand and GIS based forest fire and illegal activity monitoring and digital technology in sustainable forestry in Thailand, Indonesia and China (Giri and Shrestha, 2000; Indradjad et al., 2019; Tang et al., 2019; Grant et al., 2019). The *Socio-Technical Systems theory* supports these findings. Developing and integrating technologies that aid in forest monitoring and improve environmental quality has benefited mnay countries. Empirical case studies in Vietnam and Indonesia further illustrate this dynamic, showing how ICT-enabled monitoring and reporting reduce forest degradation. The results are also supported by the *Community Engagement theory* and show that community involvement in forest conservation, by integrating Information and Communication Technologies, contributes significntly to forest conservation. Training of using telecommunication tools is linked with forestry management and reporting enabled collaborative goals of forest conservation and sustained forestry practices to be achieved by governments and indigenous communities under these projects.

Vietnam recently undergone forest transition, with almost 10% forest area as percentage of land area increased in 2020 (48%) compared with 2000 (38%). This expansion is attributed to country's extensive efficiency enhancement projects with special attention on technological upgradation in forestry sector. In Central Vietnam, trained indigenous communities have been reporting illegal tree cutting and forest land conversion incidences through mobile phones. Comparison of community acquired forest inventory data and estimated above-ground biomass with professional expert measurements revealed that the local communities were able to acquire data with accuracy comparable to data acquired by an expert, but against lower costs (Pratihast et al., 2012). Development of Management Information System for the Forestry Sector (FORMIS) and People Participation in Improvement of Forest Governance and Poverty Alleviation in Vietnam (PFG) are two of the various technological initiatives taken by Vietnamese government to combat deforestation (Hung et al., 2020).

ICT penetration in Asia and the Pacific region has been increasing since the last two decades, and holds immense growth potential (MIS, 2018). More than half of all Asia-Pacific countries have reached a mobile-cellular penetration of 100 per cent or above by end of 2013. The region also recorded highest number of mobile-broadband subscriptions. Regional ICT adoption has been enhanced through projects such as *'Boracay-Palawan Submarine Cable System', 'Tonga Cable' and 'China's vast broadband strategy 2013'* (MIS, 2014). Many countries have recently improved their status from least developed to development success stories such as Vietnam, Bangladesh, Philippines, Thailand and India. Others such as China, Japan, New Zealand and Australia continue to be stable economies, with successful afforestation and reforestation projects. With increased ICT diffusion as a result of increasing globalization in the region, profound effects on forests have resulted. Asia has experienced 83% decline in net forest area losses from 2010-2018. For the period 2000-2018, Asia reported forest area expansion of about 30Mha, highest among all other regions of the world (FRA, 2020).

The error correction term (ψ_i) is negative and less than 1 in absolute sense, thus indicating a significant long-run relationship among variables at 1% significance level in all three estimators. In particular, the error correction term has become statistically significant after incorporating structural breaks. The coefficients of GDP are statistically significant and are positively and consistently related with deforestation in all three estimators: MG, DFE and PMG. On the other hand, positive values for coefficient of PGR, AEX and GDP suggest that if there is an increase in any of these variables, forest area will decline in the sample countries. These results are consistent with (Allen and Barnes, 1985).

Hausman Test

Hausman test is used to decide the appropriate estimator between Mean Group and Pooled Mean Group. Since it is already found that cointegration results using MG, DFE and PMG without structural breaks are unable to reveal cointegration. Therefore, we apply Hausman test on MG, DFE and PMG cointegration estimates with structural breaks in order decide the most efficient estimator among them. Table 4 depicts the same.

Table 4. Hausman Test for Selection Between

MG and DFE	MG and PMG
H_o: DFE estimator in efficient and consistent, but MG is not efficient.	**H_o:** PMG estimator in efficient and consistent, but MG is not efficient.
ρ − **value =** 0.858 $\nless$ 0.05	ρ − **value =** 0.858 $\nless$ 0.05
Since **H_o** is not rejected, DFE estimator is efficient and consistent than MG estimator	Since **H_o** is not rejected, PMG estimator is efficient and consistent than MG estimator
Overall Decision: Both DFE and PMG estimators are found to be more efficient and consistent than MG estimator in both Hausman tests, respectively. While PMG estimator dominates the DFE estimator because it permits heterogeneity in short run coefficients. Hence PMG estimates should be relied upon, among the three estimators.	

Source: Author's estimation

The results portray that both DFE and PMG are reliable estimators. Adding, because PMG estimator accounts for homogeneity in the short run coefficients, it is more consistent and efficient than DEF.

Conclusion

This study presents theoretical and empirical model linking how ICT adoption mitigates deforestation driven by agricultural land encroachment and population growth. Case studies and researches reveal that involvement of ICTs in forest conservation projects has been successful in many regions. This study analyzes the explanatory power of ICT on deforestation in the Asia-Pacific region. Panel data for 26 Asian and the Pacific countries with 5% or more forest area are estimated, for time ranging from 2000 to 2019. Four ICT determinants are used to construct an ICT development index. The data is subjected to unit root tests, panel cointegration tests and Hausman tests.

The results reveal that ICT development is significantly and negatively related to deforestation. Information and Communication Technologies help in mitigating deforestation by improving data collection, fast information transfer, reaching remote areas, educating vast populations and improving management efficiencies. The strong negative correlation relation between ICT and deforestation is proved by all estimators i.e., MG, DFE and PMG. Thus, ICTs are crucial factors which must be included in forest policy design and project making. The statistical panel analysis confirms that deforestation (measured as the decline in forest area) is significantly related to population growth and agricultural expansion in a sample of 26 Asian and the Pacific countries. These results support the major hypotheses in the literature; deforestation is driven by rural and urban population growth and agricultural area expansion in the short and long-run. Income per capita is associated positively with deforestation. As most countries in the sample are developing and have not attained a turning point of income, the EKC hypothesis is proved by the results, i.e., deforestation initially rises with GDP growth and starts to fall with further income growth only after a turning point is reached.

Recommendations

Based on empirical analysis, the study recommends following policy implications: (1) Future policies should be focused on increasing ICT penetration and diffusion in forestry sector, and explore ways in which ICT can be efficiently applied to region-specific deforestation issues. (2) Asian countries must efficiently control rate of population growth, so that ongoing consumption and livelihood pressure on forests can be reduced. (3) A possible way of driving population away from subsistence on forests, is by development pathway of forest transition i.e., introducing non-forest livelihoods. This is enhanced by ICT education as ICTs hold immense potential for development and jobs. (4) Many countries provide huge subsidies to protect their agricultural sectors. Such uninformed policies have the effect of providing an incentive for forest clearing to harvest more agricultural areas. Polices in this regard ought to be more informed and advanced, taking into account ICTs' potential in combating deforestation. In a nutshell, policies must be informed by empirical evidence and aimed at realizing the ample socio-technological and economic advancement potential of ICTs in forestry.

Future research may find out the full potential of ICT adoption on deforestation by incorporating other ICT determinants, which are not included in this study. Future research should contribute to existing knowledge by analyzing the relation and impact in other regions.

Appendix: List of Countries

Australia	India	New Zealand	Thailand
Bangladesh	Indonesia	Papua New Guinea	Timor-Leste
Bhutan	Japan	Philippines	Tonga
Brunei Darussalam	Lao PDR	Samoa	Vanuatu
Cambodia	Malaysia	Singapore	Vietnam
China	Myanmar	Solomo Islands	
Fiji	Nepal	Sri Lanka	

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