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The New Paradigm of Informal Economies Under GAI-Driven Innovation

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Abstract: As globalization deepens, concerns over global fragmentation have intensified, accompanied by rising expectations that the Global South will emerge as a key driver of innovation, competitiveness, advanced markets, and high-quality employment. The widespread diffusion of the Internet and smartphones across developing countries suggests the possibility of leapfrog growth, highlighting the informal economy as a potential source of innovation. Recent developments in generative artificial intelligence (GAI) have further underscored the opportunity for collaborative engagement between developed and developing countries to awaken and harness sleeping innovation resources. This study investigates the dynamism of such international collaboration, focusing on digitalization-related challenges and its contributions to leapfrog growth. The interconnections among Internet usage, smartphone penetration, and economic development are examined, revealing the formation of a self-propagating cycle facilitated by GAI. A mathematical model is constructed to demonstrate the dependency of growth on sleeping resources inherent in the informal economy, which is empirically validated through data from nine African countries. Using the coevolutionary dynamics of Amazon and AWS as a conceptual reference, a novel framework is proposed for international collaborative utilization of sleeping innovation resources, offering new insights into GAI-driven innovation rooted in the informal economy.

Keywords: innovation; informal economy; sleeping resources; GAI-driven innovation; Africa

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1. Introduction

Today, while globalization is progressing, there are strong concerns about the division of the world, and expectations are growing for the Global South to be a driving force for innovation, competitiveness, advanced markets, and high-quality jobs through deeply integrated supply chains between the north and the south. Increasing global concerns on climate change have accelerated these expectations. In such a situation, the spread of the Internet and smartphones has shown the possibility of promoting the "leapfrog"-type growth of developing countries, and in line with this, interest in the informal economy is growing.

The term "informal economy" emerged in the 1970s and was popularized by anthropologist Keith Hart, who conducted research in Ghana [1]. Hart defined the informal

sector as employment outside government agencies, factories, and large-scale commercial activities and classified it into "legitimate activities" (activities that contribute to small-scale economic growth) and "illegitimate activities" (activities whose value to national development is questionable). The International Labor Organization (ILO) [2] immediately built on Hart's work to distinguish between formal and informal employment by criteria such as the ease of entry, the size and ownership of the enterprise, the type of production, and the level of skill, capital, and technology.

However, research over the past few decades has challenged or denied many of Hart's generalizations, and a key aspect of the most commonly used definition of the informal economy in modern times is the lack of regulation by the political and economic institutions of society. This lack of regulation affects legitimacy in three aspects: legal recognition as a business activity (registration, inspection, etc.), payment of taxes and duties, and labor issues (working hours, social security, benefits, etc.). Some argue that formality and informality should be understood as a continuum, not a clear dichotomy.

The lack of institutional regulation in the informal economy affects the status of workers (e.g., unregistered, below minimum wage, and lack of social security), working conditions (e.g., disregard for health, hygiene, and safety requirements), and forms of institutional control. Some scholars argue that the unrecorded practices of large enterprises should also be included in the informal economy. It has been shown that the informal economy exists and has diversity not only in developing countries but also in developed countries. The fundamental distinction between formality and informality lies not in the nature of the final product but in the methods of production and exchange.

Cooperatives can promote formalization by integrating these activities into the mainstream economy. Portes [3] defines the informal economy as a sector that operates outside formal regulations and institutions, emphasizing that it is an essential part, especially in the urban economies of developing countries. Tokman [4] sees the informal sector as a safety net that operates autonomously from the modern capitalist sector and emerges as a result of insufficient economic development. Chen [5] sees the informal economy as a variety of economic activities, enterprises, and workers that are not regulated or protected by the state, emphasizing its role in providing employment and income. Anno [6] considers the informal economy as an economic activity not regulated by the state, emphasizing its regional diversity and important role in employment. Based on these debates, the ILO [7] defines that workers in the informal economy are mainly engaged in microenterprises and small enterprises, lack protection and legal recognition, have no access to financial services or representation, and are vulnerable to many risks. While these definitions reflect the complexity and diversity of the informal economy, its function in fostering innovation has gained academic concerns.

De Beer et al. [8] argue that informal entrepreneurs drive innovation by "doing new things differently". Innovation in the informal economy is characterized by incremental innovations that improve people's lives, in contrast to the formal economy's emphasis on research-intensive technological breakthroughs. However, research on innovation in the informal sector still remains in its infancy.

In recent years, the intersection of advances in AI, machine learning, and generative AI with the informal economy has sparked new debates. While AI technologies have the potential to improve productivity, market access, and financial inclusion, they also face challenges in their implementation, including low digital literacy, a lack of infrastructure, and affordability. In addition, a wide range of debates has been held, including ethical and social concerns such as data privacy and algorithmic bias, impacts on innovation such as loss of flexibility and adaptability, the cultural and contextual compatibility of AI developed in the Global North, and the state of policies and regulations. Furthermore, the interaction

between AI and the cultural and social context of the informal economy is also an important topic of discussion. Pozzo et al. [9] emphasize cultural innovation as a co-creation process in communities and point out the potential for AI to promote knowledge flows and increase inclusion [9]. Heinlein et al. [10] discuss the potential for AI to reshape social structures, cultural practices, and informal economic activities. The United Nations' University [11] emphasizes the potential for AI-driven solutions to contribute to solving challenges such as financial inclusion and social security, especially in the Global South [11]. These discussions show the uniqueness and potential of innovation in the informal economy, as well as the opportunities and challenges in its interaction with AI technology, providing important perspectives for future research and policymaking.

Nonaka [12] proposed the SECI model (socialization, externalization, combination, and internalization) to explain how organizations generate knowledge through the dynamic conversion of tacit and explicit knowledge. He and Burger-Helmchen [13] examined the integration of artificial intelligence (AI) into knowledge management (KM), emphasizing how AI is reshaping traditional KM practices within organizations. Their study begins by reviewing historical KM frameworks, particularly the SECI model, which highlights the transformation between tacit and explicit knowledge. It distinguishes generative AI from earlier AI models based on differences in output characteristics, learning adaptability, and application scope.

The study explores AI's potential to enhance KM processes by examining its influence on social interaction, the development of knowledge communities, and the cultivation of collaborative intelligence that leverages the complementary strengths of AI and human capabilities. AI's transformative role in KM includes advancing knowledge creation, storage, and dissemination and accelerating key SECI processes such as externalization and combination. However, the authors also acknowledge AI's current limitations in handling tacit knowledge and supporting human-centered decision-making.

Ultimately, the research highlights AI's capacity to streamline KM activities, boost efficiency, and unlock new opportunities for organizational innovation. By integrating AI tools with human expertise, organizations can strengthen their capabilities to manage, share, and apply knowledge, laying the foundation for novel approaches to knowledge-driven growth and decision-making across diverse settings.

The intersection of AI, machine learning, and generative AI with the informal economy has sparked fascinating academic debates by highlighting the significance of sleeping resources. De Beer et al. [14] have explored how informal entrepreneurs drive innovation, emphasizing the inventive ingenuity within the informal sector. Their work highlights the need to integrate analyses of innovation and the informal economy conceptually. Ahmad [15] argues that informal sector innovations are often overlooked due to methodological biases. His research calls for revisiting methodologies to better capture the unique dynamics of innovation in informal settings. Tou et al. [16] reimagined a new concept of R&D by referring to Amazon, the darling of the Internet and the world's top R&D leader. Amazon has chosen to use the term "technology and content" as the boundaries between research and development. These boundaries have become blurred in the digital economy, while R&D at Amazon has been conducted by transforming routine or periodic alterations into significant improvements. Tou et al. [17] argue that ICT leaders are trying to absorb external resources for innovation creation, focusing in particular on soft innovation resources (SIRs), which consist of sleeping or underutilized Internet-based resources whose usefulness has increased dramatically with the development of the Internet or resources with functionality beyond economic value that consumers desire, which arise as a result of multifaceted interactions. Studies by Capraro et al. [18] have examined how generative AI can democratize content creation and access, potentially benefiting informal economies.

However, concerns remain about exacerbating inequalities and the uneven distribution of benefits. Watanabe et al. [19] have pointed out the highly compatible nature between Amazon Web Service's (AWS) AI/ML-based self-propagating high functionality that incorporates user learning and generative AI-driven innovation and suggested sustainable co-evolution between informal and formal economies by using AWS's co-evolutionary dynamism as a role model. Research by Mpedi et al. [20] discusses how AI-driven solutions, paired with inclusive social security policies, could transform the informal sector. This includes addressing vulnerabilities and enhancing economic growth. While these debates underscore the transformative potential of AI technologies in awakening "sleeping resources" within not only the informal economy but also the formal economy, the dynamism of awakening and utilizing the sleeping resources contained in the informal economy and the appropriate actions to achieve this have still remained in the black box.

In addition, Notari and Travassos [21] analyze the implementation and cost assessment of 5G NR Open RAN in Brazil, focusing on its impact on economic growth and digital innovation. While not centered on AI, they highlight AI's critical role in enabling Open RAN's flexibility, automation, and cost efficiency—traits key to optimizing next-generation mobile networks. Koukaras et al. [22] discuss communication technologies for smart classrooms by utilizing artificial intelligence (AI). They propose methods to transform education through personalized learning and secure networks, offering insights into the social application of digital technologies and the promotion of innovation. Elleuch [23] proposes an underlay loosely coupled model for public safety networks using device-to-device communication, focusing on reliable infrastructure during emergencies. While it does not directly address AI, it suggests potential links and applications related to AI in digital infrastructure.

In light of the foregoing and inspired by the emerging expectations, this paper aims to shed light on the dynamism with which developed and developing countries are working together to awaken and utilize the sleeping resources inherent in the informal economy. Section 2 reviews the core issues of digitalization in response to the challenges posed by the use of the Internet, the spread of smartphones, and the development of AI/machine learning and generative AI. Section 3 analyzes the contribution of these factors to the "leapfrogging" type of growth in developing countries, as well as the relationship between Internet usage, smartphone penetration, and growth promotion in 39 countries across the North and South. Section 4 demonstrates the formation of a virtuous cycle among these three elements and clarifies the potential for self-propagating growth leveraged by generative AI. Section 5 proposes a contemporary concept for sleeping innovation resources by presenting international collaborative measures for awakening and utilizing these resources in dynamism modeled for the construction of co-evolution dynamism promoted by Amazon and Amazon Web Services (AWS). Section 6 summarizes the noteworthy findings, policy suggestions, and future research.

2. Chronology of Digitalization

The core issues of digitalization in response to the challenges posed by the use of the Internet, the spread of smartphones, the development of AI/machine learning, and generative AI are reviewed in this section. Table 1 summarizes the chronology of digitalization.

Table 1. Chronology of digitalization.

Digitalization Stage	Characteristics	Notable Points	Core Technologies	Social Impacts
Pre-Internet Era (1940s–1980s)	Foundations of digital computing laid with the invention of early programmable computers. Transition from bulky vacuum-tube systems to compact transistor-based systems. Digital technology remained isolated to specific industries (e.g., research, defense, and specialized business systems).	**1945:** Launch of ENIAC, the first general-purpose programmable computer. **1950s–1960s:** Transition from vacuum tubes to transistors, leading to smaller and faster computers. **1980s:** Introduction of personal computers (e.g., IBM PC and Apple II), making computing accessible to individuals.	**Transistors:** Enhanced computational speed and reliability, replacing vacuum tubes. **Mainframe Computers:** Early workhorses for enterprise applications. Early Programming Languages: Fortran, introduced in 1957 and C language, which emerged in the 1970s supported initial software development.	**Industrial Efficiency:** Early computing revolutionized industries like manufacturing, banking, and research by introducing faster data processing. **Military and Scientific Advancement:** The development of computing technologies supported innovations in defense and space exploration, such as NASA's Apollo missions. **Limited Accessibility:** Computers were primarily used by governments, universities, and large corporations, creating a gap between early adopters and the general public.
Internet Era (1990s–Early 2000s)	Explosive growth of global connectivity through the World Wide Web (WWW). Emergence of digital communication tools (e.g., emails and instant messaging). Internet became a central tool for information sharing, commerce, and communication.	**1989:** Tim Berners-Lee invents the World Wide Web. **1995:** Netscape's IPO sparks the rapid growth of web usage; early search engines like Yahoo! emerge. **Late 1990s–2000s:** E-commerce platforms like Amazon, founded in 1994, and eBay, established in 1995 gain traction.	**World Wide Web (WWW):** Revolutionized information accessibility. **Search Engines:** Pioneered efficient Internet navigation. **Protocols:** HTTP, HTML, and URL formed the basis of web architecture.	**Global Connectivity:** The Internet bridged geographical divides, enabling real-time communication and access to information worldwide. **Economic Transformation:** E-commerce platforms like Amazon and digital payment systems spurred global trade and changed consumer behavior. **Cultural Exchange:** The Internet facilitated the rapid spread of ideas, cultural content, and global movements, fostering greater awareness of diverse perspectives. **Digital Divide:** While many gained access, economic and infrastructural barriers left significant populations disconnected.
Smartphone Era (2007–2010s)	Transition from desktop-centric computing to mobile-first ecosystems. Smartphones became compact hubs for communication, productivity, and entertainment. Growth of app-based services and social networking platforms.	**2007:** Launch of the iPhone by Apple. **2008:** Release of Android, opening the market to diverse devices. **2010s:** 4G LTE networks improved mobile Internet speeds dramatically.	**Smartphone Hardware:** Touchscreens, cameras, and sensors revolutionized user interactions. **Mobile Operating Systems:** iOS and Android fostered app ecosystems. **GPS and Cloud Services:** Enabled location-based applications and seamless data access.	**Personal Empowerment:** Smartphones democratized access to technology, placing powerful computing capabilities in the hands of billions. **Social Interaction:** Social media and messaging apps redefined how people connect, share, and collaborate but also led to challenges like cyberbullying and screen addiction. **Access to Services: Apps** revolutionized access to education, healthcare, navigation, and entertainment, transforming daily life. **Privacy Concerns:** The rise in location-based services and extensive data collection raised significant questions about privacy and data security.

Table 1. *Cont.*

Digitalization Stage	Characteristics	Notable Points	Core Technologies	Social Impacts
AI/ML Era (2010s–2020s)	Widespread use of data-driven systems in industries ranging from entertainment to healthcare. Introduction of AI-powered assistants like Siri, Alexa, and Google Assistant. Applications of AI in predictive analytics, automation, and autonomous vehicles.	**2012:** Breakthroughs in deep learning using neural networks (ImageNet competition). **2016:** AlphaGo defeats a world champion Go player, showcasing AI's strategic reasoning. **Late 2010s:** Proliferation of AI in recommendation systems (Netflix and Amazon).	**Neural Networks:** Enabled advances in image recognition and natural language processing. **Cloud Computing:** Supported scalable data processing and storage. **AI Development Frameworks:** TensorFlow and PyTorch facilitated machine learning innovation.	**Automation and Productivity:** AI-driven systems optimized operations across industries, from logistics and healthcare to customer support and marketing. **Workforce Evolution:** While AI created new roles in tech, it also raised fears about job displacement, particularly in automation-heavy fields. **Enhanced Decision-Making:** Big data analytics and AI improved decision-making in fields like medicine (e.g., diagnostics) and finance (e.g., fraud detection). **Ethical Dilemmas:** Societies grappled with issues around bias in AI algorithms, data privacy, and the ethical use of AI technologies.
Generative AI Era (2020s–Present)	AI models capable of creating texts, images, and other media became widely available. Integration of generative AI in various fields, including creative industries, coding, and healthcare. Increased focus on ethical challenges and responsible AI development.	**2022 November:** Launch of ChatGPT, bringing generative AI into public consciousness. Growth of tools like DALL-E for image generation and GitHub Copilot for coding assistance.	**Large Language Models (LLMs):** The GPT series powered text generation and conversational capabilities. **Diffusion Models:** Enabled the creation of photorealistic images and videos. **Ethical AI Frameworks:** Focused on addressing bias and ensuring responsible use.	**Creative Empowerment:** Generative AI democratized creative tasks, enabling individuals and small businesses to generate professional-quality content, art, and code. **Shift in Education and Work:** Tools like ChatGPT transformed learning and professional workflows but also raised concerns about plagiarism and over-reliance on AI. **Economic and Social Disruption:** AI-powered automation and content creation tools challenged traditional roles, prompting new conversations about the future of work. **Ethics and Governance:** The ability of generative AI to produce realistic but false information amplified misinformation risks, driving debates on regulation and accountability.

(i) Pre-Internet Era (1940s–1980s)

This phase marked the foundational developments of digital technology. It began with the invention of early computers like the ENIAC in the 1940s and the advent of microprocessors in the 1970s. Key milestones included the rise in programming languages and databases, which laid the groundwork for digital communication. While networks like ARPANET emerged, the digital landscape was still isolated and primarily limited to academia and defense.

(ii) Internet Era (1990s–Early 2000s)

The 1990s ushered in the Internet revolution, characterized by the creation of the World Wide Web by Tim Berners-Lee in 1991. This period saw rapid connectivity growth, with the email, web browsers like Netscape, and search engines like Google making their debut. E-commerce platforms (Amazon and eBay) and online communication tools (like

instant messaging) began transforming industries and daily life. By the early 2000s, the Internet had become more accessible and integral to personal and professional spheres.

(iii) Smartphone Era (2007–2010s)

The launch of the iPhone in 2007 heralded the smartphone era. It marked the convergence of Internet access, portable computing, and advanced mobile capabilities. Apps transformed how people interacted with technology—shifting to on-the-go solutions for work, communication, entertainment, and more. Social media platforms like Facebook, Twitter, and Instagram flourished during this time, as did location-based services and mobile payments.

(iv) AI/Machine Learning Era (2010s–2020s)

This era is defined by advancements in artificial intelligence (AI) and machine learning (ML). Breakthroughs in algorithms, data analytics, and computational power fueled innovation in areas like image recognition, natural language processing, and autonomous systems. AI-driven applications became ubiquitous in healthcare, transportation, finance, and personalized experiences, e.g., virtual assistants like Siri and Alexa and smart recommendations on platforms like Netflix or Amazon.

(v) Generative AI Era (2020s–Present)

The most recent phase is characterized by the emergence of generative AI (GAI) models like GPT, DALL·E, and others. These systems create human-like texts, images, music, and more. GAI is revolutionizing content creation, problem-solving, and decision-making across industries. Its capabilities are extending into fields like education, business automation, and creative design, pushing the boundaries of what machines can achieve.

The timeline reflects how technology is evolving into an ever more connected, intelligent, and creative force, shaping the way humans live and interact, and ushering in a new paradigm of the informal economy with GAI-led innovation.

3. Digitalization and Growth in Developed and Emerging Countries

The timeline of digitalization reviewed in the previous section highlights how increasing Internet penetration and the subsequent rapid adoption of smartphones worldwide accelerated the digitalization leap in emerging economies, paving the way for a new paradigm of the informal economy in GAI-led innovation.

Inspired by this insight, the key characteristics of digitalization and growth in both developed and emerging economies towards GAI-driven innovation are explored in this section.

3.1. Broader Cycle of Digitalization Fostering the Spread of Smartphones by Increasing Internet Penetration

Increasing Internet penetration fosters the spread of smartphones as part of a broader cycle of digitalization, which is transforming economies, societies, and individual lifestyles as follows:

(i) Infrastructure and Accessibility

As Internet infrastructure improves, even in remote or underdeveloped areas, people gain access to online services and information. This creates a demand for devices that can leverage this connectivity, such as smartphones with their portable, multifunctional capabilities.

(ii) Value of Connectivity

Digitalization enhances the importance of being connected. Governments, businesses, and individuals increasingly operate online through e-governance, digital commerce, social

media, and virtual workplaces. Smartphones become the primary gateway for participation in this digital ecosystem.

(iii) Content and Services

As digitalization advances, the availability of apps and services specifically tailored for mobile users grows—ranging from online banking to entertainment and education. This symbiotic relationship between digital content and smartphones accelerates their adoption.

(iv) Economic Influence

Smartphones are increasingly accessible due to competition and economies of scale, which are fueled by growing demand. This affordability aligns with broader digital goals like financial inclusion and online education, promoting their spread.

(v) Feedback Loop

More smartphone users drive greater demand for advanced Internet services, spurring further investment in digital infrastructure. This, in turn, draws more users into the digital ecosystem, reinforcing the spread of smartphones.

Due to these changes in the interaction between the Internet and smartphones, digitalization creates interdependencies such that Internet penetration drives smartphone adoption, and widespread smartphone use accelerates the process of digital transformation.

3.2. Digital Transformation Leading to Leapfrog

With these transforming interactions between the advancement of the Internet and smartphones, advances in the Internet and smartphones have brought the following socio-economic innovations to emerging countries and have greatly contributed to the dramatic acceleration of the utilization of digital innovation similar to leapfrogging [11].

(i) Relieve from fixed infrastructure dependency;
(ii) Improve access to a wide range of fields such as information, finance, and education;
(iii) Drive innovation, reinvent business models, and accelerate growth;
(iv) Promote internal and external communication and collaboration, pioneering and expanding into new fields;
(v) Enjoy a wide variety of remote-learning opportunities.

This leapfrogging can be attributed to a virtuous cycle (coevolution) of rapid diffusion of advanced digital products in emerging countries comparable to that of developed countries, as demonstrated in Figure 1.

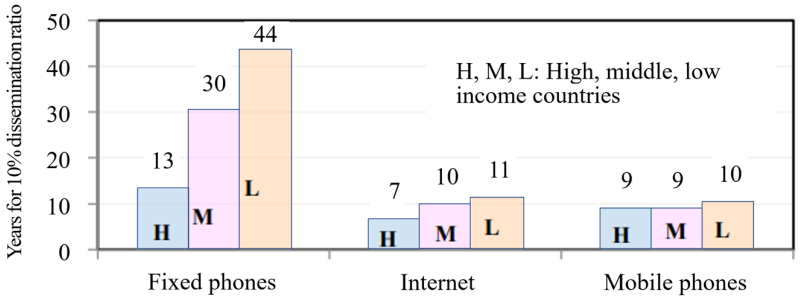


Figure 1. Years for the 10% dissemination ratio for fixed phones, Internet, and mobile phones in high-, middle-. and low-income countries. Source: White Paper on Japan's Information and Communication (2011).

3.3. Virtuous Cycle with Accelerated Growth

Aiming at examining the effects of leapfrogging, the correlation between growth (*V*), Internet use (*ID*), and smartphone dependence (*SP*) in 39 countries in the north and the south as tabulated in Tables 2 and 3 is illustrated in Figure 2 [19].

Table 2. 39 Countries examined.

Area	Developed Countries	Emerging/Developing Countries	Number of Countries
North America	US and Canada		2
Europe	Germany, France, UK, Italy, and Spain	Poland	6
Russia/Ukraine		Russia and Ukraine	2
Middle East	Israel	Turkey, Lebanon, and Jordan	4
Asia/Pacific	Australia, South Korea, and Japan,	Malaysia, China, Indonesia, Vietnam, Philippines, India, and Pakistan	10
Latin America		Chile, Argentina, Mexico, Brazil, Venezuela, and Peru	6
Africa		South Africa, Nigeria, Ghana, Kenya, Senegal, Tanzania, Uganda, Ethiopia, and Burkina Faso	9
Total	11	28	39

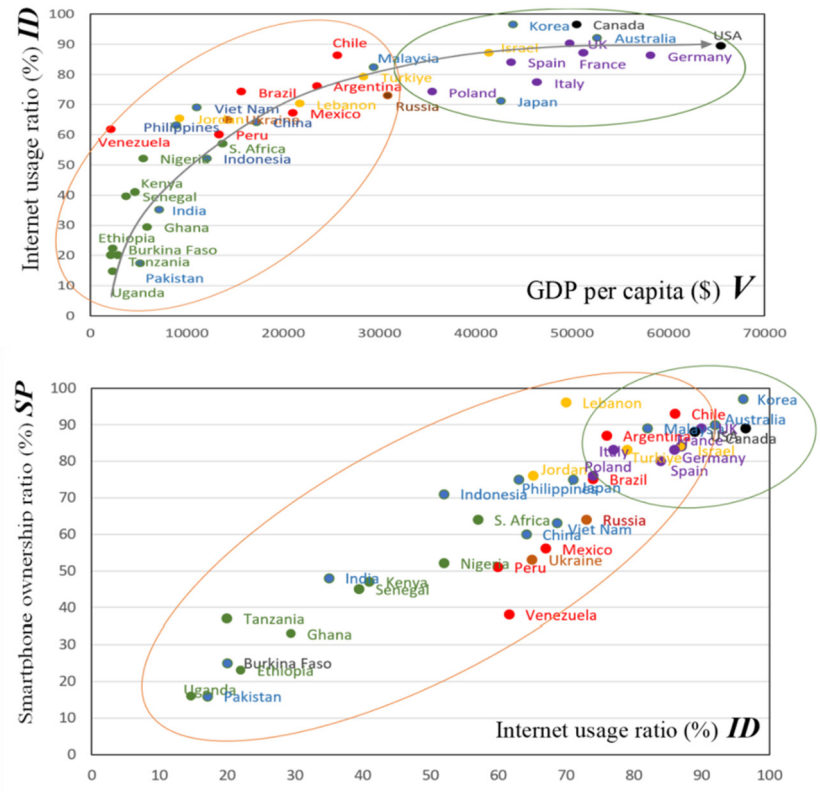


Figure 2. *Cont.*

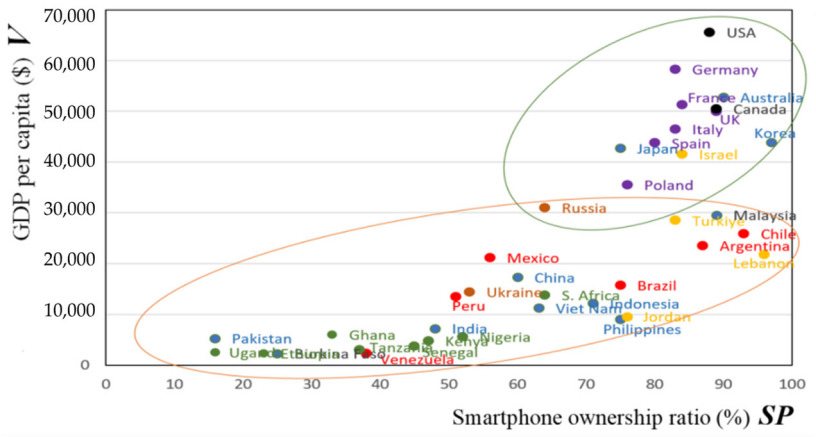


Figure 2. Correlation between digitalization and growth (39 countries in both the North and South in 2019).

Table 3. Digitalization and growth in 39 countries (2015 and 2019).

No.	Country	Code	Area	DC/EC	*V*		*ID*		*SP*		Population (Millions)	
				(Developed/ Emerging)	GDP per Capita (PPP, Current US $)		Internet Usage Ratio (%)		Smartphone Ownership Ratio (%)			
					2015	2019	2015	2019	2015	2019	2015	2019
1	USA	USA	North America	DC	55,904	65,548	87	89	79	88	321	329
2	Canada	CAN	North America	DC	45,489	50,499	90	97	81	89	36	37
3	Germany	DEU	Europe	DC	47,033	58,252	84	86	63	83	81	83
4	UK	GBR	Europe	DC	40,958	49,911	86	90	75	89	65	67
5	France	FRA	Europe	DC	41,221	51,240	73	87	57	84	64	65
6	Italy	ITA	Europe	DC	35,665	46,470	70	77	64	83	60	60
7	Spain	ESP	Europe	DC	35,270	43,740	84	84	74	80	46	47
8	Poland	POL	Europe	EC	26,403	35,488	68	74	46	76	38	38
9	Russia	RUS	Russia/Ukraine	EC	23,744	30,964	71	73	46	64	146	146
10	Ukraine	UKR	Russia/Ukraine	EC	7990	14,381	60	65	30	53	44	44
11	Israel	ISR	Middle East	DC	33,658	41,513	84	87	76	84	8	9
12	Turkey	TUR	Middle East	EC	20,277	28,461	68	79	62	83	78	83
13	Lebanon	LBN	Middle East	EC	18,417	21,758	65	70	59	96	6	7
14	Jordan	JOR	Middle East	EC	12,162	9405	62	65	52	76	8	10
15	Australia	AUS	Asia/Pacific	DC	47,318	52,747	92	92	83	90	24	25
16	Korea	KOR	Asia/Pacific	DC	36,528	43,865	89	96	88	97	50	52
17	Japan	JPN	Asia/Pacific	DC	38,211	42,678	68	71	44	75	127	126
18	Malaysia	MYS	Asia/Pacific	EC	26,141	29,495	59	82	60	89	30	32
19	China	CHN	Asia/Pacific	EC	14,190	17,262	63	64	70	60	1371	1398
20	Indonesia	IDN	Asia/Pacific	EC	11,112	12,116	28	52	27	71	258	271
21	Viet Nam	VNM	Asia/Pacific	EC	6020	11,190	45	69	40	63	92	96
22	Philippines	PHL	Asia/Pacific	EC	7318	8958	36	63	31	75	101	108
23	India	IND	Asia/Pacific	EC	6209	7182	17	35	21	48	1311	1366
24	Pakistan	PAK	Asia/Pacific	EC	4902	5207	10	17	19	16	189	217
25	Chile	CHL	Latin America	EC	23,564	25,825	76	86	70	93	18	19
26	Mexico	MEX	Latin America	EC	18,335	21,096	53	67	49	56	122	128
27	Argentina	ARG	Latin America	EC	22,375	23,535	68	76	59	87	43	45
28	Brazil	BRA	Latin America	EC	15,690	15,741	58	74	47	75	207	211

Table 3. *Cont.*

29	Peru	PER	Latin America	EC	12,077	13,408	50	60	32	51	31	33
30	Venezuela	VEN	Latin America	EC	15,892	2258	64	62	54	38	30	29
31	South Africa	ZAF	Africa	EC	13,197	13,707	35	57	42	64	55	59
32	Ghana	GHA	Africa	EC	4216	5952	22	29	28	33	27	30
33	Kenya	KEN	Africa	EC	3246	4711	36	41	32	47	47	53
34	Ethiopia	ETH	Africa	EC	1739	2274	7	22	8	23	98	112
35	Senegal	SEN	Africa	EC	2425	3728	27	40	23	45	14	16
36	Tanzania	TZA	Africa	EC	2901	2947	20	20	15	37	49	57
37	Uganda	UGA	Africa	EC	1999	2444	11	15	7	16	39	43
38	Nigeria	NGA	Africa	EC	6185	5525	36	52	31	52	182	201
39	Burkina Faso	BFA	Africa	EC	1774	2233	14	20	18	15	18	20

Sources: 1. World Development Indicator, retrieved on 16 December 2015 and 24 June 2019 [24]. 2. Pew Global Attitudes & Trends Question Database, retrieved in Spring 2015 and Spring 2019 [25]. Note: Internet Usage Ratio data for certain countries were sourced from the International Telecommunication Union (ITU). The smartphone ownership ratio for certain countries was estimated based on data from previous and subsequent years.

4. Virtuous Cycle Between Digitalization and Growth

The contribution of the digitalization to the "leapfrogging" type of growth in developing countries is examined in this section, and the relationship between Internet usage, smartphone penetration, and growth promotion in 39 countries across the North and South is analyzed.

4.1. Correlation Between V, ID, and SP

Table 4 displays the regression analyses of (i) V and ID, (ii) ID and SP, and (iii) SP and V. All demonstrate high statistical significance. While V induced ID with slightly higher elasticity in the emerging countries, SP induced V with significantly higher elasticity in the developed countries. ID induced SP with similar elasticity in both economies.

Table 4. Correlation between V, ID, and SP in 39 countries (2015 and 2019).

(i) $V \rightarrow ID$					
2015					
$\ln ID = -2.32 + 0.66 D_1 \ln V + 0.64\ D_2 \ln V$				$adj.\ R^2$	0.784
	(-3.15) (7.81)	(8.86)			
2019					
$\ln ID = -1.46 + 0.58 D_1 \ln V + 0.55\ D_2 \ln V + 1.09 D$				$adj.\ R^2$	0.836
	(-3.12) (11.35)	(12.47)	(4.85)		
(ii) $ID \rightarrow SP$					
2015					
$\ln SP = -0.57 + 0.81 D_1 \ln ID + 0.83\ D_2 \ln ID$				$adj.\ R^2$	0.877
	(-2.36) (11.69)	(14.50)			
2019					
$\ln SP = -0.48 + 0.90 D_1 \ln ID + 0.89\ D_2 \ln ID - 0.55 D$				$adj.\ R^2$	0.907
	(-2.27) (18.30)	(16.52)	(-3.67)		
(iii) $SP \rightarrow V$					
2015					

Table 4. *Cont.*

$\ln V = 5.16 + 1.08D_1 \ln SP + 1.26\ D_2 \ln SP$	*adj.* R^2	0.867
(11.33) (8.09) (11.34)		
2019		
$\ln V = 3.94 + 1.32D_1 \ln SP + 1.54\ D_2 \ln SP - 1.01D$	*adj.* R^2	0.913
(6.48) (8.62) (11.03) (−2.52)		

D: Vietnam = 1 and Others = 0; D_1: $V < 20{,}000$ and D_2: $V > 20{,}000$ in 2015; D_1: $V < 30{,}000$ and D_2: $V > 30{,}000$ in 2019. Figures in parentheses are t-statics; all are significant at the 1% level.

4.2. Digitalization-Driven Leapfrogging and the Growth Cycle

These analyses demonstrate that digitalization has driven leapfrogging and formed a virtuous cycle with accelerating growth, as demonstrated in Figure 3.

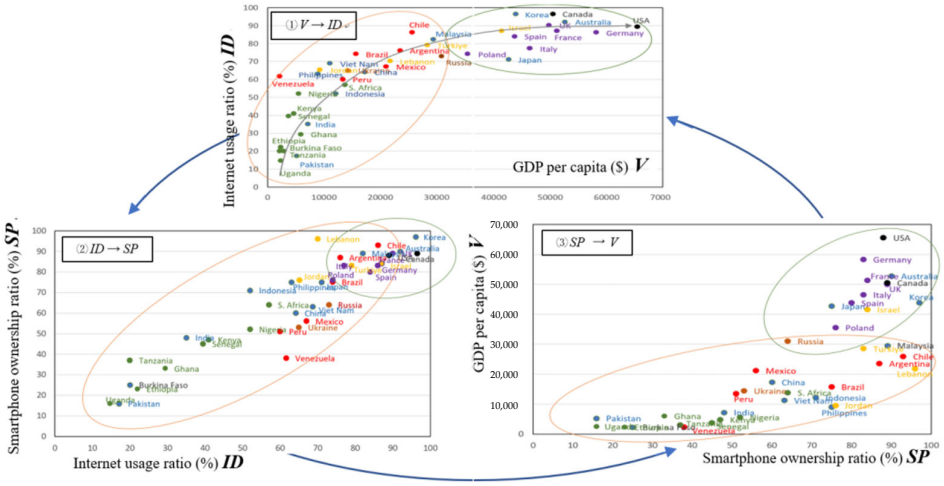


Figure 3. Virtuous cycle between digitalization and growth (39 countries in both the North and South in 2019).

4.3. Comparison of Elasticity Between Emerging and Developed Countries by Digitalization Stage

The virtuous cycle in Figure 3 suggests that by analyzing the correlation between growth and digitalization progress and comparing their elasticity values, it is possible to map out the outlook for digitalization in developing countries towards GAI-driven innovation. In this case, reliable time-series data is the basis, so based on the data shown in Table 3, it is possible to determine the analysis targets for both developed and developing countries in accordance with the standards of the OECD Development Committee (DAC).

Figure 4 compares the elasticities of the respective correlations ((i) $V \rightarrow ID$, (ii) $ID \rightarrow SP$, and (iii) $SP \rightarrow V$) in 2015 and 2019.

Comparing the elasticities corresponding to the transitions of (i) to (iii) above, the following notable observations can be obtained:

(a) A transition from emerging-country dominance to the same level and then to developed-country dominance in both 2015 and 2019;
(b) A sharp increase in the elasticity level corresponding to the transition to (iii) in both emerging and developed countries in both 2015 and 2019;
(c) This increase is more pronounced in 2019 compared to 2015 in both emerging and developed countries.

These observations provide useful implications regarding the innovation-induced dynamics in response to the transition from the informal economy to the formal economy [1,3,7,12].

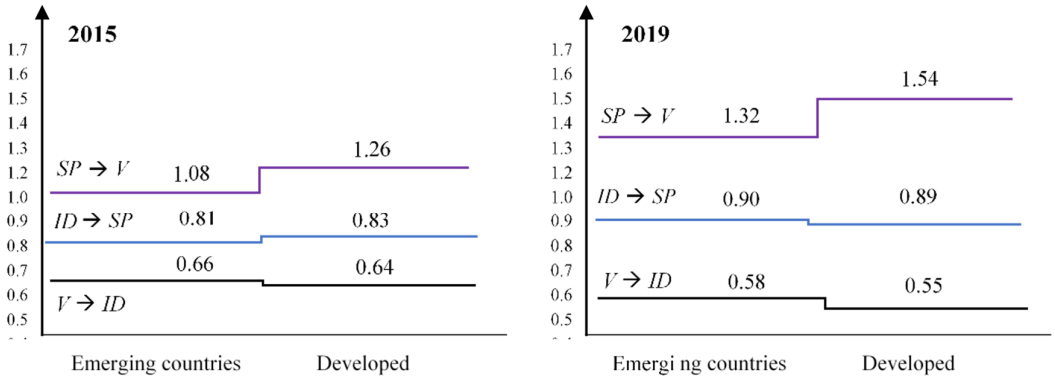


Figure 4. Comparison of elasticity between emerging and developed countries by digitalization stage (2015 and 2019).

4.4. Innovation-Induced Dynamics

The virtuous cycle demonstrated in Figure 3 suggests that the breakthrough of AI/ML may lead to the expanded use of AI/ML in emerging countries [19]. This expansion translates into higher elasticity of smartphone ownership to growth in developed countries, as clearly demonstrated in Figure 4. This dynamism suggests the possibility of contributing to the expansion and sophistication of innovation in the creation of new functions [8].

The dynamic progression from smartphone proliferation to AI/machine learning adoption and eventually to generative AI reflects the cascading transformation of economies and societies with multi-phase dynamism, which envisions the new paradigm of the informal economies under GAI-driven innovation.

4.4.1. Smartphone-Led Digitalization

(i) Economic Inclusion

Widespread smartphone adoption enables greater participation in digital economies. It introduces mobile payments, e-commerce, and gig work, creating new opportunities for individuals and businesses.

(ii) Data Explosion

The constant use of smartphones generates vast amounts of user data, driving the need for tools to analyze and leverage this information.

(iii) Innovation Catalyst

Smartphones spark innovation across industries, from app development to hardware improvements, accelerating economic growth.

4.4.2. AI/Machine Learning-Led Digitalization

(i) Efficiency Gains

AI and machine learning harness smartphone-generated data to optimize processes in manufacturing, logistics, marketing, and more, resulting in significant productivity improvements.

(ii) New Industries

Machine learning-driven solutions lead to the creation of entirely new industries, such as autonomous vehicles and predictive analytics services.

(iii) Enhanced Personalization

AI analyzes user behavior to provide tailored recommendations, improving customer experiences and boosting revenue streams for businesses.

4.4.3. Generative AI-Led Digitalization

(i) Content Revolution

Generative AI introduces unprecedented efficiency and creativity in content creation—whether in marketing, entertainment, or education—further transforming industries.

(ii) Workforce Transformation

Automation and AI-driven tools reshape job markets, encouraging the rise in new roles that require creative and strategic thinking.

(iii) Accelerated Innovation

Generative AI shortens the time from ideation to execution for startups and established companies, leading to faster cycles of innovation and economic dynamism.

4.4.4. Interconnected Dynamism

Each phase builds upon the infrastructure and innovations of the prior one:

(i) Smartphones make the digital world accessible and generate the data that AI/machine learning relies on.
(ii) AI and machine learning refine and extract value from this data, laying the groundwork for generative AI applications.
(iii) Generative AI, in turn, amplifies the economic impact by creating new possibilities that were unimaginable in earlier phases.

The cascading effects of digitalization trigger a feedback loop where each technological advancement amplifies economic growth, fosters innovation, and reshapes societies.

4.5. Awaking Sleeping Resources

4.5.1. Identification of Sleeping Resources

Foregoing the cascading transformation of economies and societies with multi-phase dynamism awakens sleeping innovation resources that are highly shared by emerging/developing countries and proportional to the extent of the share of the state of informal economies, as reviewed in the preceding section.

Table 5 highlights the identity of sleeping resources, and Table 6 suggests the possible distribution of sleeping resources based on the share of the informal economy.

Table 5. Identification of sleeping resources.

Sleeping Resource	Description	Main Regions	Reason
1. Youth Labor Force	Underutilized young workforce	Africa and Asia	Lack of education and job opportunities
2. Untapped Arable Land	Uncultivated farmland	Africa and South America	Lack of investment and infrastructure
3. Knowledge of Urban Elderly	Unutilized knowledge and experience of the elderly	Europe and North America	Lack of opportunities for knowledge transfer and social participation
4. Big Data	Underused large-scale data	Entire world (particularly developed countries).	Underutilization due to regulations and technical limitations
5. Female Labor Force	Potential female workforce under constraints	Africa and Asia	Limited access to education and employment
6. Geothermal Energy	Unutilized geothermal potential	Asia, Africa, and Oceania	Lack of technology and investment
7. Untapped Tourism Resources	Unexplored natural and cultural tourism assets	South America and Africa	Challenges in access, safety, and funding

Table 5. *Cont.*

Sleeping Resource	Description	Main Regions	Reason
8. Traditional Knowledge and Cultural Assets	Unutilized traditional knowledge	Africa, South America, and Oceania	Neglect and lack of commercialization
9. Marine Resources (e.g., Deep-sea Minerals)	Undeveloped deep-sea resources	North America, South America, and Asia	Technical and environmental difficulties
10. Economy under Excessive Regulation	Economic activities hindered by overregulation	Europe and Asia	Delayed deregulation

Sources: Created by the author based on UNDP (2015–2023) [26], UNDP (2015–2023) [27], and WEF (2015–2023) [28].

Table 6. Informal sector contributions to GDP (2010).

Areas	% of Informal Sector GVA in Total GDP
Sub-Saharan Africa	63.6
India	54.2
Asia	30.2
Latin America	29.2

Source: Charmes [29].

4.5.2. Utilization of Sleeping Resources

By utilizing sleeping resources, developed countries are actively promoting their use through ICT and digital transformation (DX). Several examples are summarized in Table 7.

Table 7. Examples of revitalizing sleeping resources through DX in developed countries.

Sleeping Resource	Country	Utilization Description	IT/DX Applied
1. Youth Labor Force	Germany	Vocational education and company training for youth	Online training platforms and AI job matching
2. Untapped Arable Land	United States	Precision agriculture for effective land use	Drones, IoT sensors, and GIS data
3. Knowledge of Urban Elderly	Finland	Online volunteer system utilizing elderly knowledge	Remote support platforms and digital literacy education
4. Big Data	Estonia	Nationwide data integration for government and healthcare	Digital ID and cloud-based government system
5. Female Labor Force	Sweden	Flexible work environment enabling female employment	Remote work tools, cloud HR, and online learning
6. Geothermal Energy	Iceland	Stable geothermal energy supply and control	Data analytics, smart meters, and IoT control
7. Untapped Tourism Resources	Canada	Nature tourism management and digital promotion	AR/VR experiences, visitor data analysis, and mobile guides
8. Traditional Knowledge and Cultural Assets	Japan	Digital preservation and tourism use of cultural assets	3D scanning, virtual museums, and metaverse
9. Marine Resources (e.g., Deep-sea Minerals)	Norway	Exploration and development of seabed resources	AI analysis and remote-operated underwater vehicles (ROVs)
10. Economy under Excessive Regulation	United Kingdom	Business support and administrative simplification	Online applications and API-based service integration

Sources: JETRO and IPA New York [30]; RIETI [31]; and WEF [32].

Thus, from the above, it is evident that many resources are underutilized in Africa, as demonstrated in Table 8.

Table 8. Utilization status of sleeping resources in nine African countries.

	Sleeping Resource	(1) South Africa	(2) Ghana	(3) Kenya	(4) Ethiopia	(5) Senegal	(6) Tanzania	(7) Uganda	(8) Nigeria	(9) Burkina Faso
1.	Youth Labor Force	High Active vocational training and job creation programs	Low High youth unemployment remains an issue	High Startup- and ICT-focused youth employment programs	Low High agricultural employment and low non-farm youth jobs	Low Youth unemployment is a significant issue	Low Youth unemployment remains a serious challenge	Low Youth unemployment remains high	Low Youth employment opportunities remain limited	Low Youth unemployment and underemployment persist
2.	Untapped Arable Land	Low Land reform is ongoing but utilization is limited	High Agricultural expansion using uncultivated land, especially cacao	High Tech-driven agricultural development in rural areas	High Large-scale agricultural leases for development	Low Land use planning delays limit land utilization	High Agricultural development using uncultivated land is underway	High Uncultivated land utilized through agricultural projects	High Efforts to increase agricultural productivity ongoing	High Agricultural development projects utilizing available land
3.	Knowledge of Urban Elderly	Low Limited programs for senior citizen participation	Low No structured programs to engage elderly knowledge	Low Cultural norms limit elderly social roles	Low Few initiatives for utilizing senior knowledge	Low No active programs for elderly participation	Low Few programs for senior engagement	Low No structured policies for elderly knowledge usage	Low Cultural roles limit the elderly's societal contribution	Low Limited policies for senior participation
4.	Big Data	High Advanced use of big data in finance and telecom	Low Limited data infrastructure and usage	High Mobile money and analytics widely used	Low Digital infrastructure is underdeveloped	Low Big data use is still in its early stages	Low Data infrastructure underdeveloped, with limited usage	Low Digital infrastructure is still limited	High Big data applied in the finance and telecom sectors	Low Big data initiatives are still at a nascent stage
5.	Female Labor Force	High Support for female entrepreneurship and employment	Low Low female labor participation	High Strong growth in women-led enterprises	Low Traditional roles limit female workforce participation	Low Limited female participation in the economy	Low Low female participation in the workforce	Low Social and structural constraints limit female workforce	High Women supported in entrepreneurship and workforce participation	Low Female participation in economic activities remains limited
6.	Geothermal Energy	Low Geothermal development remains limited	Low No current geothermal development	High Olkaria geothermal projects actively developed	High Strong geothermal potential with active development	Low Geothermal development not started	High High geothermal potential with ongoing development	High Geothermal development underway	Low No geothermal development underway	Low No current geothermal energy development
7.	Untapped Tourism Resources	High Major development in safaris and eco-tourism	High Growing eco-tourism sector	High Wildlife-based tourism is thriving	High Natural and heritage sites leveraged for tourism	High UNESCO heritage sites actively promoted for tourism	High Eco-tourism and nature-based tourism are promoted	High Eco-tourism is growing	High Diverse natural resources used in tourism	High Eco-tourism utilizing natural sites promoted

Table 8. *Cont.*

8.	Traditional Knowledge and Cultural Assets	High Diverse cultural heritage utilized in tourism	High Traditional crafts and music contribute economically	High Maasai traditions integrated into the tourism economy	High Traditional crafts and textiles gaining global attention	High Music and dance traditions promoted internationally	High Traditional crafts and music contribute economically	High Cultural industries play a role in the economy	High Rich cultural heritage promoted through tourism	High Traditional music and crafts are economically valuable
9.	Marine Resources (e.g., Deep-sea Minerals)	Low Marine resource exploration is minimal	Low No visible efforts in marine resource development	Low Marine development limited to fisheries	Low Landlocked country without marine resources	Low Marine resource development is at an early stage	Low No active marine resource development	Low Landlocked country without marine resources	High Marine exploration and development ongoing	Low Landlocked country with no marine resources
10.	Economy under Excessive Regulation	High Business reform and deregulation in progress	High Supportive policies for SMEs and simplified regulation	High Deregulation and startup ecosystem growth	Low Bureaucracy remains a barrier to business	High Investment promotion and business reforms ongoing	High Efforts ongoing to improve the business environment and deregulation	High Supportive policies for SMEs and simplified regulation	High Reforms enhancing the business environment	Low Bureaucratic processes hinder business development
References		[33–35]	[36–38]	[39–41]	[42–44]	[35,45,46]	[47–49]	[50–52]	[53–55]	[56–58]

5. The Dynamism of AI/ML-Driven Innovation

5.1. Coevolutionary Dynamism Initiated by Amazon

Amazon, the darling of the Internet, has developed a cloud service AWS that contributes to widespread use based on the infrastructure and apps built to develop its business in 2006 with R&D (technology and content) at the core of its management [16].

AWS is the crystal of R&D, which creates brand value and encompasses a coevolution structure that also induces R&D, as demonstrated in Figure 5 and Table 9. [59]

Figure 5. Coevolution between R&D, AWS, and brand value initiated by Amazon.

Table 9. Coevolution between R&D, AWS, and brand value initiated by Amazon. (2008–2020: Quarterly).

$\ln Y = a + b\ln X + cD$ where X, Y : R&D, *AWS*, and *BW*; D : Dummy variable.						
X to Y	*a*	*b*	*c*	$adj.R^2$	*DW*	Dummy
R&D to AWS	−4.64 (−56.78)	1.44 (159.46)		0.999	2.53	
AWS to BV	−1.20 (−6.12)	0.60 (26.00)		0.983	1.53	
BW to R&D	−2.28 (−21.96)	1.16 (41.10)	−0.27 (−3.35)	0.993	2.18	2008, 2019, 2020 = 1, others = 0

Figure in parentheses are t-statistics: all are significant at the 1% level. Brand value: Global Brand Value Report (Brand Finance, 2007–2020).

Through this coevolution, AWS's ML has been accumulated, and new functions (brand value) have been created in a self-propagating way, as demonstrated in Figure 6 and Table 10. [60]

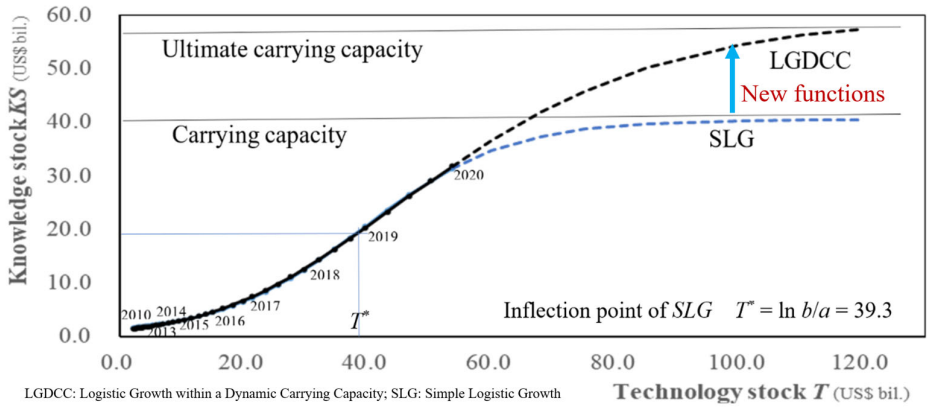


Figure 6. Amazon's R&D-driven AWS stock accumulation trajectory (2010–2020).

Table 10. Amazon's R&D-driven AWS stock accumulation trajectory (2010–2020: Quarterly).

$KS(T)=\frac{N}{1+be^{-aT}}$ (SLG)			$KS(T)=\frac{N}{1+be^{-aT}+\frac{b_k}{1-a_k/a}e^{-a_kT}}$ $(LGDCC)$			
	N	a	b	a_k	b_k	*adj.* R^2
SLG	40467 (65.52)	$8.65*10^{-5}$ (83.25)	28.85 (55.09)			0.998
LGDCC	59557 (7.31)	$1.18*10^{-4}$ (17.87)	40.42 (4.69)	$4.58*10^{-5}$ (4.91)	5.41 (6.58)	0.999

$KS(T)$: knowledge stock of AWS corresponding to T; T: technology knowledge stock; N and N_k: carrying capacity; a, b, a_k, b_k: coefficients. Figure in parentheses are t-statistics: all are significant at the 1% level.

Refer to the mathematical demonstration to create the self-propagating dynamism in Appendix A.

The new features penetrate the counterpart firms and contribute to their development. By assimilating this learning, AWS will further develop and expand, as illustrated in Figure 7 [59].

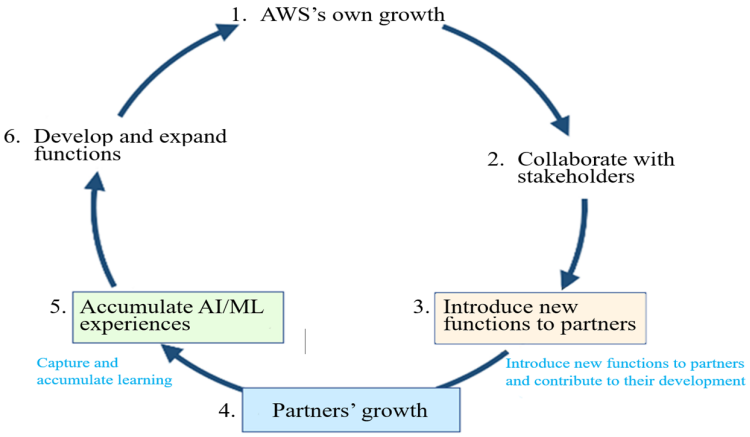


Figure 7. Amazon's coevolution structure assimilating the counterpart firm's growth.

In this way, Amazon rapidly expanded its R&D, as illustrated in Figure 8, and grew into the world's top R&D firm, as demonstrated in Figure 9, by learning and assimilating the growth of its counterpart firms. [60]

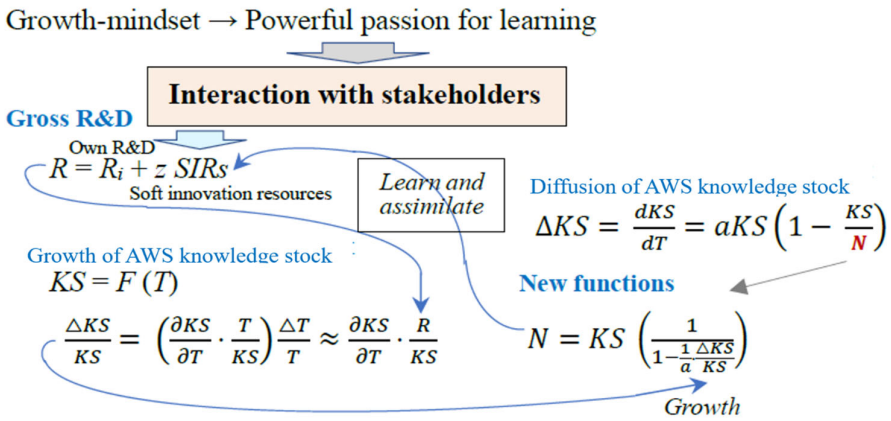


Figure 8. Dynamism of mutual enlightenment embodied in R&D.

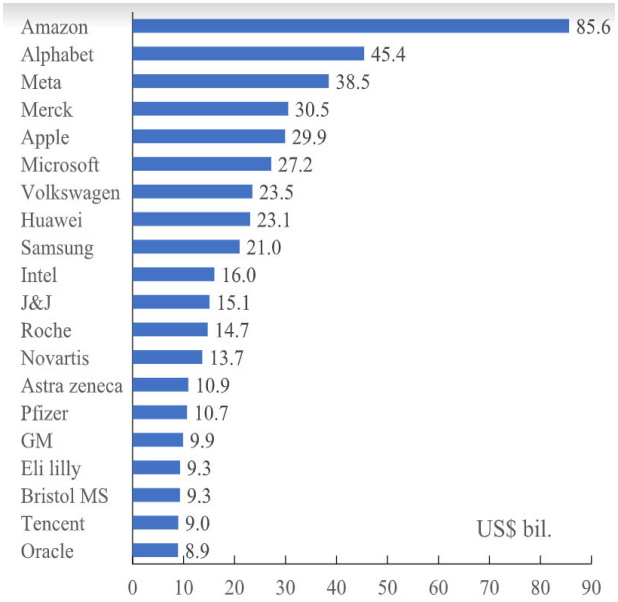


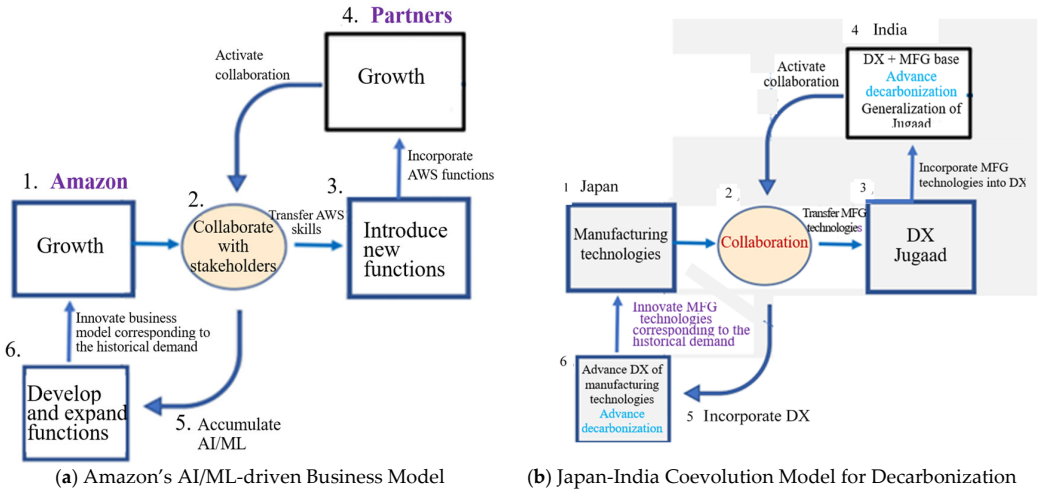
Figure 9. Top 20 R&D firms (2023).

5.2. Global Coevolutionary Dynamism

For the development of the manufacturing industry, which is essential for both developing and developed countries, there are fundamental commonalities between AWS and generative AI (GAI) as both pursue (i) improved operational efficiency, (ii) enhanced decision-making, (iii) accelerated innovation, (iv) supply chain optimization, and (v) data architecture construction [61,62].

At the same time, both are in a coevolution relationship as the evolution of cloud services such as AWS stimulates the evolution of GAI, which in turn induces further evolution of cloud services.

Thus, AI/ML-driven coevolutionary dynamism initiated by Amazon by encompassing the growth of the counterparts suggests global coevolutionary dynamism, as contrasted in Figure 10, and promises a prospect of GAI-driven innovation that enables the effective utilization of sleeping innovation resources inherent in informal economies.



(**a**) Amazon's AI/ML-driven Business Model (**b**) Japan-India Coevolution Model for Decarbonization

Figure 10. Suggestion for global coevolutionary dynamism.

The manifestation of the above coevolution is the key to utilizing GAI, and in order for both the North and the South to reap the benefits, (i) improving access to cloud infras-

tructure for the Global South, (ii) promoting the use of data necessary for AI learning, and (iii) developing AI human resources are essential.

6. Conclusions

This paper examines a new paradigm for informal economies driven by generative AI (GAI) innovation against a backdrop of increasing concerns about global division and the expectation that the Global South will become a driving force for innovation and economic advancement. This study reviewed core issues of digitalization in response to the advancements of the Internet, smartphones, AI/machine learning, and GAI.

Key findings from the paper include the following:

- Digitalization fosters a virtuous cycle among Internet usage, smartphone penetration, and growth, which has enabled a "leapfrogging" type of growth in developing countries.
- Consequently, the informal economy, which holds potential opportunities for innovation, is gaining attention as a "sleeping resource".
- The research clarified the potential for self-propagating growth leveraged by GAI. This growth is shown to be dependent on the awakening and utilization of sleeping resources specific to the informal economy, a reality confirmed through an examination of nine African countries.
- ICT leaders absorb soft innovation resources (SIRs), which are Internet-based resources that have been either sleeping, untapped, or are due to multisided interaction in the markets.
- There are fundamental commonalities between Amazon Web Service (AWS) and generative GAI, with both being in a coevolution relationship where the evolution of cloud services like AWS stimulates the evolution of GAI, which in turn further induces the evolution of cloud services.
- The AI/ML-driven coevolutionary dynamism initiated by Amazon suggests global coevolutionary dynamism, promising a prospect of GAI-driven innovation that enables the effective utilization of sleeping innovation resources inherent in informal economies.
- Based on these findings, the paper offers the following insightful suggestions:
- The manifestation of the coevolution between AWS and GAI is key to utilizing GAI, and for both the North and the South to benefit, it is essential to (i) improve access to cloud infrastructure for the Global South, (ii) promote the use of data necessary for AI learning, and (iii) develop AI human resources.
- Amazon's business management, which uses the term "technology and content" for R&D and transforms routine alterations into significant improvements, should be examined as it corresponds to awakening Internet-based sleeping resources.
- The correspondence between this unique way of business management and the profound implication of India's traditional innovation, Jugaad, which seeks thrifty, flexible, and inclusive solutions in adversity, should be examined.

This paper concludes by suggesting that future work should focus on further examination of sleeping innovation resources in India and Asian countries and the coevolution among them.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Dynamism in Creating Self-Propagating Growth by Awaiting Sleeping Resources

The notable observations on the virtuous cycle of digitalization and growth made in the previous section, especially the remarkably high elasticity of smartphones to growth in both emerging and developed countries (especially the latter), prompt us to hypothesize that digitalization has awakened sleeping innovation resources in emerging countries as shown in Table 6 and absorbed them for innovative progress.

This section attempts to mathematically demonstrate this hypothetical view, and this reality is confirmed through an examination of sleeping resources in nine African countries that are at the forefront of the Global South.

Appendix A.1. Bi-Polarization Fatality of ICT-Driven Development

Information and communication technology (ICT), through its inherent network externalities, alters the correlation between innovations and institutional systems, thereby generating novel innovation characteristics that contribute to exponential growth. Schelling [63] illustrated a range of social mechanisms that evolve and diffuse logistically, driven by such interactions. The progression of the Internet has further intensified these interactions, accelerating the logistic development and diffusion characteristics of ICT, which are typically represented by a sigmoid growth curve [60].

The digital value generated by the Internet of Things (IoT) can be mathematically described as follows:

$$V = F(X,T) = F(X(T),\ T)\ \approx F(T) \text{ Growth rate : } \frac{\Delta V}{V} = \left(\frac{\partial V}{\partial T}\cdot\frac{T}{V}\right)\cdot\frac{\Delta T}{T}\ \approx \frac{\partial V}{\partial T}\cdot\frac{R}{V} \quad \text{(A1)}$$

where V: the value added, T: the gross ICT stock, X: other production factors, and R: R&D investment ($\Delta T \approx R$)

In the long term, assuming $T \approx \frac{R}{\rho+g}$, the growth rate can be expressed as follows:

$$\frac{\Delta V}{V} = \left(\frac{\partial V}{\partial T}\cdot\frac{T}{V}\right)\cdot\frac{\Delta T}{T}\ \approx \frac{\partial V}{\partial T}\cdot\frac{R}{V} = \frac{\partial V}{\partial R}\cdot\frac{\partial R}{\partial T}\cdot\frac{R}{V} = (\rho+g)\frac{\partial V}{\partial R}\cdot\frac{R}{V} \quad \text{(A2)}$$

where ρ : the rate of obsolescence of technology and g: the R&D growth rate at the initial period.

Given the logistic nature of ICT growth, the R&D-driven development trajectory, denoted as $VS(R)$, follows an epidemic-like function, ultimately yielding a standard logistic growth (SLG) function:

$$\frac{dV}{dR} \approx \frac{\partial V}{\partial R} = aV\left(1-\frac{V}{N}\right) \quad \text{(A3)}$$

$$\text{SLG} = V_S(R) = \frac{N}{1+b\,e^{-aR}} \quad \text{(A4)}$$

where N: carrying capacity, a: the velocity of diffusion, and b: the coefficient indicating the initial level of diffusion.

ICT-driven development progresses along a sigmoid trajectory, with growth continuing until it reaches a defined carrying capacity (the upper limit of growth). Along this trajectory, the growth rate increases until the inflection point—corresponding to half of the carrying capacity—is reached, after which it begins to decline. Consequently, the logistic growth characteristic of ICT embodies a bi-polarization fatality, marked by a shift from increasing to decreasing marginal productivity before and after the inflection point. [16]

Appendix A.2. Dilemma Between R&D Expansion and Productivity Decline

This phenomenon generates a dilemma in which R&D expansion beyond the inflection point leads to a decline in productivity and a subsequent reduction in the growth rate.

In response, leading ICT firms have sought practical solutions by transitioning from traditional business models to innovative alternatives. Since the root of this dilemma lies in the intrinsic logistic growth of ICT, it is essential to reconfigure this structural characteristic.

Appendix A.3. Transformation of the Unique Feature of ICT: Self-Propagating Function

When development follows the SLG trajectory, the resulting digital value, $Vs(R)$, reaches a saturation point defined by a fixed upper limit, thus inevitably triggering the aforementioned dilemma. However, if the growth trajectory transitions to logistic growth with a dynamic carrying capacity (*LGDCC*), the digital value, $VL(R)$, can continue expanding as the carrying capacity itself evolves throughout the development process.

Specifically, innovation that generates a new carrying capacity, $NL(R)$, during its diffusion can be modeled by the following extension of Equation (A3):

$$\frac{dV(R)}{dR} = a\,V(R)\left(1 - \frac{V(R)}{N(R)}\right) \tag{A5}$$

Equation (A5) develops the following LGDCC which incorporates self-propagating function as carrying capacity increases corresponding to the $V(R)$ increase, as depicted in Equations (A6) and (A7) [60]:

$$V_L(R) = \frac{N_k}{1 + be^{-aR} + \frac{b_k}{1-a_k/a}e^{-a_kR}} \tag{A6}$$

where N_k: ultimate carrying capacity and a, b, a_k, and b_k: coefficients.

Dynamic carrying capacity $NL(R)$ in this LGDCC is depicted as follows:

$$N_L(R) = V_L(R)\left(\frac{1}{1 - \frac{1}{a}\cdot\frac{\triangle V_L(R)}{V_L(R)}}\right) \;\triangle\; V_L(R) = \frac{dV_L(R)}{dR} \tag{A7}$$

Appendix A.4. Assimilation of Sleeping Resources as a Core of Soft Innovation Resources

Therefore, achieving sustainable growth within this trajectory hinges on the activation of VL(R) in a manner that avoids the dilemma, thereby establishing a virtuous cycle in which increases in $VL(R)$ stimulate the growth of $NL(R)$, which in turn furthers the expansion of $VL(R)$.

Given that ICT possesses an inherent self-propagating capability derived from network externalities, sustainable growth necessitates the activation of this latent function.

Attempts to generate a new carrying capacity reflect a counteracting force against declining prices (or marginal productivity) induced by bi-polarization, particularly when R&D becomes excessive.

This counteracting force compels ICT leaders to absorb innovation-driving resources, particularly soft innovation resources (*SIRs*), from external markets that facilitate inno-

vation while circumventing the dilemma and to incorporate them into their operations. SIRs are conceptualized as condensates and crystallizations of Internet evolution [60], comprising Internet-based resources that have remained dormant or underutilized or emerge from multisided market interactions in which consumers seek functionality exceeding economic utility.

Appendix A.5. R&D Utilizing the Awaken Sleeping Resources

Assimilated SIRs serve to awaken and activate the dormant self-propagating function inherent to ICT. Once activated, this function facilitates the development of LGDCC and promotes the emergence of supra-functional capabilities that transcend economic value, encompassing social, cultural, and emotional dimensions.

As this functionality reflects evolving preferences within the digital economy, its exploration further stimulates user-driven innovation and continued Internet advancement, thereby accelerating the awakening and mobilization of additional SIRs.

Amazon, the darling of the Internet and the world's top R&D leader, conducts its business management in a consistent and systematic way as a system for improving customer experience. It insists that its R&D has been conducted by transforming routine or periodic alterations into significant improvements. [64] This corresponds to awakening Internet-based sleeping resources. This unique way of business management initiated by the world's R&D leader reminds us of the profound implication of India's traditional innovation, Jugaad, that seeks thrifty, flexible, and inclusive solutions in adversity.

Appenidx A.6. Core Function of the Disruptive Business Model

The central mechanism of this disruptive business model, which addresses the dilemma between R&D expansion and productivity decline in the digital economy, lies in activating the latent self-propagating function through a virtuous cycle involving gross R&D (comprising increases in indigenous R&D (*R*i) and assimilated external innovation resources, particularly soft innovation resources (*SIRs*)), growth, and digitalization, with the latter primarily driven by the advancement of the Internet, as illustrated in Figure A1.

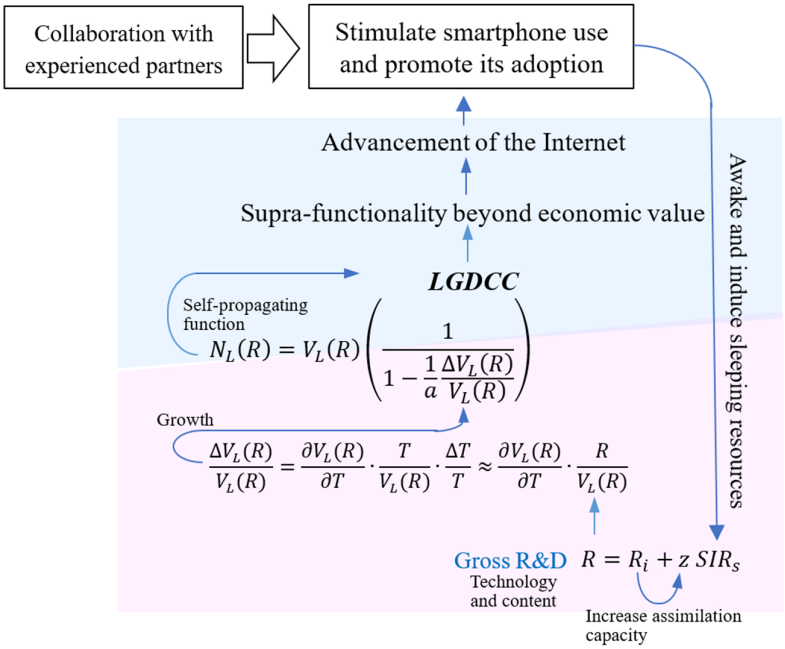

Figure A1. Dynamism of a core function of the disruptive business model.

In light of the vulnerability of this feedback mechanism—stemming from inherent technological and financial uncertainties—its strategic reinforcement emerges as a critical requirement.

Drawing upon the virtuous cycle among growth (*V*), Internet diffusion (*ID*), and smartphone dependence (*SP*), as illustrated in Table 4 and Figure 3 in Section 4, the stimulation of smartphone use, particularly through collaboration with experienced partners, may serve as an effective catalyst for awakening and mobilizing sleeping resources, thereby contributing to the resolution of this fundamental challenge.

The preceding analysis indicates that digitalization has activated dormant innovation resources in emerging and developing economies, catalyzing innovation in developed nations and, in turn, affording the former a leapfrogging opportunity for advancement within the digital economy.

This coevolutionary dynamic is reminiscent of Amazon's AI/ML-driven innovation, which was initiated through its Amazon Web Services (AWS), and suggests promising prospects for generative AI (GAI)-driven innovation.

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