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A Productivity Management Application of the Solow Development Model by the Asian Largest Economies

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Abstract

In application of the Solow development model, other Asian or non-Asian smaller economies may learn from the productivity management model design emulated by the economic development patterns of the largest Asian economies; China, India, Japan, Indonesia, and South Korea. The objective of the study was fundamentally formulated to explore the application of the economic design thinking of the Solow development model on the five Asian largest economies. Using the data envelopment analysis or DEA, the study sought to evaluate the two Solow development models, y/L = f (K/L, L/pop, s/y) or y/Lt = K/Lt (R&Dt)1-depr without using technology, and y/L = f (K/L, L/pop, s/y, R&D/y) or y/Lt = K/Lt (R&Dt Lt)1-depr with technology. The DEA observation specifically applied the Malmquist Productivity Index and Linear Programming model to evaluate the y/L objective function in order to answer the study's four research questions. It was concluded that the Solow development design thinking models, the ones with and without R&D for innovation, didn't show any difference in utilities of both. Any economies for the productivity management models seemed to be relevantly indifferent.

Keywords: Data Envelopment Analysis or DEA, Malmquist Productivity Index or MPI, change in total factor productivity or Δ TFP index, decision-making unit or DMU, linear programming or LP, human development index or HDI.

INTRODUCTION

A quantitative design to measure the relative efficiency and productivity was adopted as a design thought to reveal the economic secrets of the five Asian largest economies' progress using the data envelopment analysis or DEA. It took into account the multiple inputs used by the Solow growth model, which were the design prototypes; the GDP/capita of the labor force (y/L), capital/capita of the labor force (K/L), savings propensity per GDP (s/y), R&D/capita of the labor force, and labor force as a percentage of total population (L/pop); for a given output of the economy (GDP/L). Cooper, W.W. et al. (2011) identified efficiencies and inefficiencies using a Malmquist Productivity Index system of any decision-making unit or DMU. DMU might take the form of the decision-making of a country's economic system. As of December 2019 (IMF estimates), the largest Asian economies were recorded as China (GDP in PPP of USD 27.3 trillion), India (USD 11.4 trillion), Japan (USD 5.7 trillion), Indonesia (USD 3.7 trillion), and South Korea (USD 2.9 trillion). By virtue of the proposed design thinking in this observation, the study sought to reveal the secrets of these largest Asian economies for the benefit of the smaller Asian and non-Asian economies to emulate. The reasons why the study seemed to be interesting were that four out of

five economies were considered emerging within the last ten years, and they were China, India, Indonesia, and South Korea.

Bruton, G.D. et al. (2008) argued that the qualification possessed by an emerging economy, among others, are increasing market orientation and expanding economic foundation, particularly China, considered as an aspirant economy. They were absolutely right as China's GDP (in PPP) grew at a compounded rate of 9.5% p.a. from USD 11.0 trillion in 2009 to USD 27.3 trillion in 2019. Han & Xu (2009) further explored the effects of China's state ownership on strategic entrepreneurship in China, which seemed to be one of its positive points for economic development. As of the year 2019, Japan, which had already achieved a much better economic status in more than a decade, continued to show a good level of efficiency as y/L = USD 77.7 billion and K/L = USD 288.4 billion. In terms of s/y or marginal propensity to save, China indicated a much better rate at 46%, followed by South Korea at 36%. Cumulative capital accumulation of the Chinese and Japanese economies demonstrated a striking percentage of 58.7% and 25.1% from the total five, respectively, as of 2019. Refer to Table 1.

Table 1: Asian Largest Economies' GDP (y), Capital (K), Labor Force (L) and Savings (s) As of 2019 (Estimated)

DESCRIPTION	CHINA	INDIA	JAPAN	INDONESIA	S. KOREA	TOTAL
Total population (In million)	1385	1297	126	263	51	3122
Total labor force (In million) (L)	871	585	74	145	31	1706
GDP in ppp (In billion USD) (y)	27,331	11,468	5,749	3,743	2,229	50520
Cumulative capital (In billion USD) (K):						
-Total credits	35,653	3,579	19,941	789	3,172	63,134
-Total investments (Domestic + FDI)	14,095	3,818	1,403	1,450	833	21,599
Total cumulative capital	49,748	7,397	21,344	2,239	4,005	84,733 *
Total savings (In billion USD) (s)	12,572	3,326	1,552	1,198	802	19,450
R&D for innovation (In billion USD)	553	67	166	2	92	880
Solow-growth ratios:						
Economic stability:						
• GDP/L (y/L) – In Bio. USD	31.4	19.6	77.7	25.8	71.9	
Financial stability:						
• Capital/L (K/L) – In Bio. USD	57.1	12.6	288.4	15.4	129.2	
• Savings/GDP (s/y) – In %	0.46	0.29	0.27	0.32	0.36	
R&D level:						
• R&D/y – In %	2.0	0.6	2.9	0.0	4.1	
Labor force strength:						
• L/population – In %	62.9	45.1	58.7	55.1	60.8	

*Source: Bank of International Settlements (BIS) *Shares of China = 58.7% and Japan = 25.1%.*

Solow development model

The Solow development model was developed by Roberts M. Solow, who won a noble prize in 1987. Solow, R.M. (1956) simply explained that economic growth is fundamentally a dynamic process among inputs; capital, labor, savings and R&D, and the development of output. Changes in the output, which the study coined as y/L, is a function of these inputs. His formulation then

became y/L = f (K/L, L/pop., s/y, and R&D/y). These inputs were regarded as the design thinking prototypes.

The model sought to look at the effects of inputs to the main output, which were comprised of the following two models; one without and with technological changes:

*y/L = f (K/L, L/pop, s/y) □ without technology, or formulated as y/Lt = K/Lt (R&Dt)1-depr

*y/L = f (K/L, L/pop, s/y, R&D/y) □ with technology, or formulated y/Lt = K/Lt (R&Dt Lt)1-depr

where,

y = GDP (infPPP), which is y/L,

K = Capital (In billion USD), comprising of credits and capital (K/L), with depr = depreciation,

L = Labor force (In million population) as a % to total population (L/pop),

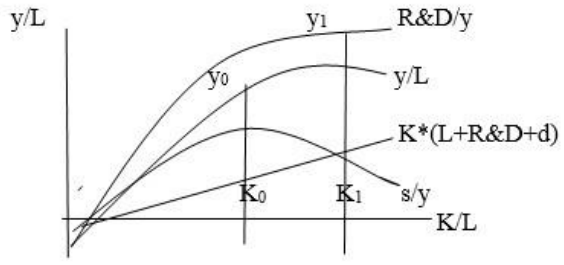
s = Marginal propensity to save (s/y),

R&D = Research & development (In billion USD), as a % of GDP (ppp) (R&D/y),

d = Depreciation.

Zhao, R. (2018) emphasized Solow's sustainability of growth through R&D in the Solow development model, with y/L as the main objective function, reaffirming that R&D for a better technology would make L more effective. This must be underlined.

Figure 1: Solow Development Model: Basis for the 4 Prototypes



Ramanayake R-A, KD. (2019) mentioned a basic principle of the Solow model, which was the application of the law of motion in the capital. This critique was made in response to the constant growth assumption in the Harrod-Domar theory. Solow development model therefore argued that output per labor force or y/L depends positively on the capital per labor force (K/L) and marginal propensity to save as a % of y (s/y), and negatively on the population growth rate. This stand was strongly reinforced by Schiliro, D. (2017), who underlined the importance of financial stability (K/L and s/y) that led to a better y/L.

Underlying conceptual framework and design thinking

Conceptual framework

Several economic theories fundamentally inspired the design thinking that sought to reveal the secrets of the success of becoming large economies in Asia. It sought to inspire the smaller economies as a lesson for them to develop into larger ones as well. The Solow development model prototypes are comprised of economic stability (y/L), financial stability (K/L and s/y), labor force strength (L/pop), and R&D orientation (R&D/y). Refer to Figure 2.

Labor force strength (L/pop) and R&D orientation (R&D/y). Refer to Figure 2.

Figure 2: Successful Productivity Management Model (For the Benefits of Smaller Economies)

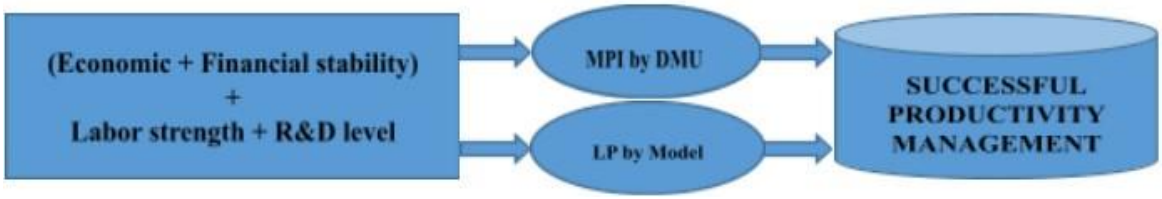


Table 2: Underlying Theories on Solow Development, MPI and Design Thinking

ECONOMIC THEORIES	Year	ECONOMIST	LINKAGE WITH THE CONCEPT
Key theories			
Solow development model	1987	Roberts Solow	Main design thinking
Malmquist productivity index*	1953	Sten Malmquist	Identifier indices (prog. or regress)
Production function	1927	Cobb-Douglas	Paralleled production function
Design thinking	1969	Herbert Simon	Revealing methodology

**Abbreviated as MPI*

Productivity management design thinking

Stemming from the Solow development model and how its individual constructs were used to develop an MPI, the study had employed a design thinking of how the smaller Asian economies may learn from the five larger Asian economies. As Vasdev, S.M. (2013) argued in his thesis, design thinking had extended beyond business in a variety of disciplines, including that of economic development of a country. And the specific field of development, according to Islam, Md.N. (2017), were the macro-level financial stability and realized innovation. In the model, macro-level financial stability in any economic system is a must, but on innovation Solow, R. (1969) confidently reaffirms that economic growth specifically occurs because of innovation, which was further supported by Grossman, G.M. & Helpman, I. (2015), who reinforced the fact by saying "economies differ in ability, and the successful innovators draw different technologies for producing their varieties." This notion is absolutely true with the five Asian largest economies under observation. As innovators, they have their specific strategies to develop the countries' economic development.

By emulating the strategies of the five Asian largest economies, other Asian and non-Asian developing economies are expected to formulate and nurture their economic development strategies. Design thinking in this respect is generally defined as the analytic and creative prototyping of development models by the other developing Asian economies. Razzouk, R. &

Shute, V. (2012) commented that with the collaborative process of design thinking, the designer developing economies' sensibilities and methods are expected to be employed to match people's welfare. And the interaction of people, technology, and business are expected to innovate in order to remain relevant, to achieve welfare for the people, and to become a large economy, which Turnali, K. (2015) synthesized them as good entrepreneurship that should have the component of uniqueness in product development through an R&D process as reaffirmed by Mickahail, B. (2015). Figure 2 depicts the concept of the design thinking of the study.

METHODOLOGY

The objective of the study was fundamentally formulated to explore the application of the economic design thinking of the Solow development model on the five Asian largest economies. Based on the objective of properly emulating the progress of the five Asian largest economies using the proposed design thinking in this study, the main problem of the study focused on how the five economies' progress or regresses could serve as a lesson to learn. The study had therefore sought to answer the following research questions:

1. How were efficiency and total factor productivity of the five Asian largest economies measured in terms of the Solow development model constructs using the MPI system?

2. How significant were the differences of the geo-means of the design thinking prototype indicators of the Solow development model among the five Asian largest economies? The H0: The geo-means of the design thinking prototype indicators of the Solow development model were not significantly different among the five Asian largest economies.

3. Provided the maximization of the GDP per labor force or y/L objective function, which Solow development model, with or without technological changes, was the most efficient one? Why?

4. Using the Solow development design thinking, what were the lessons learned from these five Asian largest economies?

In the framework of answering the research questions, the study used the MPI to identify progress or regresses within the period 2009-2019 and linear programming to determine the most suitable model of Solow growth development. This identification was reinforced by secondary data and Delphi's method through interviews with embassies of these five large economies in Manila for validity purposes. The first research question was analyzed using the non-parametric DEA-MPI, while the second research question used non-parametric Kruskal-Wallis test to explore the level of differences of the four production efficiency prototypes; i.e., the economic stability (y/L), financial stability (K/L and s/y), labor force strength (L/pop) and R&D marginal propensity (R&D/y). The third research question was analyzed using DEA linear programming by applying the Excel solver with the following objective function and constraints of the two models; $y/L = f(K/L, L/pop, s/y)$, without R&D for innovation, and $y/L = f(K/L, L/pop, s/y, R\&D/y)$, with R&D for innovation:

• Maximize the objective function y/L under the two models, with and without R&D.

• Minimize inputs under constraints: K/L, L/pop., s/y, and R&D/y.

The fourth research question used secondary data analysis in the development of a silo for model design. This productivity management silo would serve as a lesson to learn by the smaller economies.

RESULTS AND DISCUSSION

In the realm of answering the research questions, the result of the study discussed three main points; namely, the MPI as an indication of progress and regresses, efficiency via a DEA linear programming model, and the differences of the largest economies' geo-means.

1st Question – DEA-MPI As An Efficiency Measure

In congruence with the conceptual framework of the study, the MPI sought to evaluate the efficiency and productivity of the five Asian largest economies as of 2019. As specified in the methodology, the Δ efficiency index and the TFP Δ index were used to interpret the performance of the five economies. As presented in Table 3, Japan was still revealed as having the highest TFP as of 2019, followed by China and India occupying the 2nd and 3rd position, respectively, at MPI of 0.453 and 0.399. Japan had also performed in the efficiency of s/y and L/pop with an MPI of 1.000. From the five large economies, only the Japanese economy had the earliest progressive maturity and positive development in promoting the country's economic growth compared to the other four as discovered by Odaki & Griffin (2009), in spite of the declining evidence of its TFP in the last decade as recently evaluated by Koji, N. et al. (2019). They recommended the flexible reallocation of capital and labor resources by changing the working process at the corporate level in accordance with the socio-economic and technological environment. One of the Solow development model prototypes, the K/L, seemed to be an important topic in the flexible reallocation of capital and labor. Capital intensity and labor productivity should interact in equilibrium as evaluated by Cuadrado, F.A. et al. (2017). The trade-off of using capital must be in equilibrium with the number of labor force hired, which should be particularly true in the advent of digital innovation.

Table 3: Asian Large Economies' MPIs in Terms of Efficiency Δ and Productivity Δ Indices As of 2019

EFFICIENCY CHANGES INDICES (SOLOW DEV. PROTOTYPE)						
Country	K/L	L/Pop	s/y	R&D/y	TFP	RANK
China	0.312	0.339	0.178	0.493	0.453	2
India	0.865	0.154	0.188	0.141	0.399	3
Japan	0.176	1.000	1.000	0.701	1.000	1
Indonesia	1.000	0.265	0.248	0.013	0.363	4
South Korea	0.316	0.931	0.662	1.000	0.348	5
Geometric mean	0.468	0.419	0.353	0.229		

Source: Analyzed from Bank of International Settlements (BIS)'s economic statistics (2009-2019)

In overall terms, capital mobilization per labor force indicated Indonesia and India as the highest at 1.000 and 0.865, respectively. At the same time, Japan indicated the highest MPI in L/pop and s/y, with South Korea as the highest in R&D investment as of 2019. South Korea had seemed to be the main performer, followed by Japan at an MPI of 0.701. Refer to Table 3. Were

there significant differences among these prototypes? Answers to the question were given in the research question two discussion.

2nd Question – Observation of the MPI Geo-Means Differences

The MPI geo-means differences were observed to prove the efficiencies fragmentation of the DMUs and Solow development model prototypes. As shown in Table 4, Japan demonstrated the highest geo-means in terms of y/L and K/L at 73.926 and 242.853, respectively, in spite of the lower MPI level at 0.176 (refer to Table 3), which, as indicated earlier, was due to the inflexible reallocation of capital-labor resources in the country. China indicated the highest geo-means of 0.461 for s/y and South Korea for R&D/y = 0.041.

Table 4: Kruskal-Wallis Test of Differences of Solow Development Model Prototypes Geo-means

COUNTRY (DMU)	Analysis (X^2)	y/l (USD-M)	K/L (USD-B)	L/pop (%)	s/y (USD-B)	R&D/y (USD-B)
China	-	22.422	41.604	0.017	0.461	0.020
India	-	15.002	10.048	0.025	0.292	0.006
Japan	-	73.926	242.853	0.019	0.271	0.029
Indonesia	-	21.663	12.550	0.021	0.320	0.001
South Korea	-	65.211	119.487	0.018	0.361	0.041
Analysis:						
$X^{2\ (observed)}$	20.775					
$X^{2\ (critical)}$	9.488					
df	4					
p (< 0.05)	0.004					

Source: Evaluated from the OECD economic data.

This fragmented performance of the five Solow development model prototypes was indeed proven by the significant differences of their geo-means during the period 2009-2019, as the level of significance (p = 0.004) at the df = 4 showed that the observed X2 = 20.775 was much higher than the critical X2 = 9.488. The H0 of research question 2 was rejected (p = 0.004 < 0.05 level of significance) by stating that "the geo-means of the productivity management prototype indicators of the Solow development model were significantly different among the five Asian largest economies."

3rd Question – DEA-L.P. Objective Function As An Efficiency Measure

By applying the linear programming objective function within the DEA concept, the Excel solver has been used to answer the efficiency of the two development models conceptualized in the Solow development model, the y/L = f (K/L, L/pop, s/y) □ without national R&D for innovation and y/L = f (K/L, L/pop, s/y, R&D/y) □ with national R&D for innovation. Halsmayer, V. (2014) clearly reiterated that technology, though it was an option, was one of the most imperative development prototypes in any country's development. Creating the LP model in Excel solver meant to maximize the objective function of the DMU mentioned above, the five Asian

largest economies, and come up with the most efficient DMU to prove whether the two development models were indifferent.

Using the above-mentioned Solow development models, which specified the design thinking prototypes, the result of the study revealed that both models were indifferent with the DEA linear programming method. With and without technology alternatives, the most efficient DMU seemed to still point to China as it indicated an integer of 1.000. In other words, y/L = f (K/L, L/pop, s/y) model, without R&D for innovation, was equal to y/L = f (K/L, L/pop, s/y, R&D/y) model, with R&D for innovation. Refer to Table 5.

Table 5: Efficiency of the Solow Development Model Prototypes: With and Without Technology

D M U	WITH TECHNOLOGIES OBJECTIVE FUNCTION EFFICIENCY		WITHOUT TECHNOLOGIES OBJECTIVE FUNCTION EFFICIENCY	
China	1.000	1.000	1.000	1.000
India	5.034	n/a	1.495	n/a
Japan	0.000	n/a	0.303	n/a
Indonesia	1.000	n/a	1.035	n/a
S. Korea	0.000	n/a	0.344	n/a

Source: Evaluated using the DEA of LP program with Excel solver.

In terms of a curve, it shows a similar utility pattern in both models. Refer to Figure 3. The indifference curve or IC indicates that at various points of x (y/L without technology) at the x-axis and y (y/L with technology) at the y axis, any DMU or the five Asian largest economies are indifferent to the use of technologies. Both models seemed to be good for any economy because they had the same utility values. Any shift from IC1 to IC3 due to the changes in the values of the prototypes would retain the same pattern of similar utilities.

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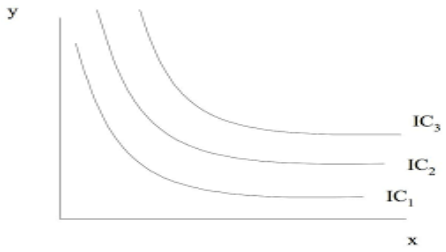
Figure 3: A General Idea of Indifference Curve of Solow Development y/L Prototypes

y/L (with technology)



y/L (without technology)

In order to address the question "why?" - some empirical findings had proven that R&D expenditures were not necessarily effective in an overall term for a country's economic growth. Government directives and effective R&D policies seemed to be needed to motivate its effects on economic growth. Since the finding of this study pointed to China as the most efficient DMU, the R&D prototype would be further inspected because of its indifference in the two models, the one with and without technologies.

Pala, A. (2019) discovered that there were negative effects of China's R&D expenditures on its economic growth. This empirical finding was supported by Liu, C. & Xia, G. (2018) and Boeing, P. et al. (2015), who also concluded that R&D expenditure was not necessarily a strong determinant for motivating China's economic growth. Other than China, like the EU and Turkey, didn't experience strong effects of R&D expenditures as well, evaluated by Kokko, A. et al. (2015) and Tuna, K. et al. (2015). However, some related studies on the effects of R&D on economic growth in the US said otherwise. R&D had some effects on the country's economic development. Weintraub, E.R. (2014) reinforced this design thinking by commenting that as a prototype, both models of the Solow development pattern were supposed to be determinants for a country's economic progress. Both prototype models, which were consistently similar to the other findings using DEA-MPI and DEA-linear programming technique, pointed to China as the most efficient DMU, as proven earlier.

4th Question – Lessons Learned from the Five Asian Largest Economies

Mostly classified as mixed market-based economies with central planning orientation, the five Asian largest economies had achieved their productivity & efficiency level within the parameters introduced by the Solow development model, which was mainly comprised of capital accumulation, labor productivity, and technological advancement. The solution of the objective function y/L = f (K/L, L/pop., s/y, and R&D/y) with the various constraints seemed to summarize the lessons learned from these five Asian largest economies. First, productivity had been boosted through R&D-driven technology development, at least for China, India, Japan, and South Korea. Second, other than this technology-based development, capital deepening through domestic and foreign direct investment, as well as capital accumulation from the banking sector, seemed to be the motor to enhance the rate of K/L or capital per labor force and s/y or marginal propensity to save in the economy of Solow development model.

Third, except in the case of the young labor force in India, quality of labor and human capital seemed to be one important determinant in boosting productivity and efficiency level in the five Asian largest economies. Refer to Table 6.

Table 6: Silo for Model Design for Other Asian Smaller Economies to Lear

COUNTRY	TYPE	COMPETITIVE ECONOMIC ADVANTAGES
China	Socialist economy	Capital investment-based growth, R&D-driven technology.
India	Mixed economy*	Technology & innovation, capital-labor intensity, young labor force.
Japan	Socialist economy	Capital deepening, R&D-driven technology, highest HDI, labor force quality,
Indonesia	Mixed economy*	Capital deepening, capital-labor intensity.
South Korea	Mixed economy*	R&D-driven technology & innovation, highest HDI, labor force quality.

**Mixed system of government control and market economy.*

RESULTS AND DISCUSSION

Based on the analysis of the research questions, the findings of the study were broken down into major findings and their implications:

Major findings

1. In spite of the inflexibility of capital and labor resources reallocation, Japan was still revealed as having the highest TFP as of 2019, followed by China and India, with its s/y and L/pop. Prototypes indicated as the highest MPI, not to mention its second rank in terms of R&D investment.

2. During the period 2009-2019, MPI geo-means of the Solow development model prototypes seemed to be fairly fragmented as their differences indicated a great likelihood ratio between the observed value (X2 = 20.775) compared to the critical value (X2 = 9.488). It meant that the five Asian largest economies had all varied in their performance in terms of efficiency.

3. Both Solow development models, y/L = f (K/L, L/pop., s/y, R&D/y) and y/l = f (K/L, L/pop., s/y), didn't seem to be different from each other. The five Asian largest economies are indifferent in the adoption of both models; besides, empirical findings didn't all support that R&D investment was always an integral determinant part of economic growth.

4. Under the various input constraints, DEA analysis had resulted in an outcome that China was the efficient Asian largest economy, which met the accomplishment of y/L objective function.

Implications

In spite of the indifference in the use and non-use of technology, some implications are anticipated to occur in the Asian largest economies.

1. Increasing TFP would generally tend to drive y/L up from year to year in the future.

2. Because of its steady-state conditions or constant growth of y/L in the future, y/L growth will to a certain extent, be dependent on technological progress.

3. Capital accumulation per labor force or K/L must be considered as a result of technological development and not a cause.

4. The general silo of model design may serve as a lesson to the smaller economies that their development should be faster than that of the saturated economies.

CONCLUSIONS

Based on the findings of the study, it was concluded that the Solow development design thinking models, the y/L = f (K/L, L/pop, s/y), without R&D for innovation, and y/L = f (K/L, L/pop, s/y, R&D/y), with R&D for innovation, didn't show any difference in utilities of both. Any economies using both models seemed to be relevantly indifferent. Part of the conclusion was the outcome that Japan and China seemed to be the agents of efficiency and total factor productivity in their y/L objective function.

Recommendations

Based on the conclusion of the study, it is therefore recommended that the following plans of action be considered:

First, capital intensity and labor productivity must interact in equilibrium:

- Capital intensity through more focused strategic sectors in the economy, and

- Labor productivity with national mechanization programs as well as digital-based innovation.

Second, motivation of more FDIs and domestic investments that promote collaboration of transfer of technology, among others to upgrade labor and human development.

Third, a more focused R&D-driven technological development for innovation must be continuously developed in congruence with the digital innovation criteria.

Fourth, formulation of special human capital programs to improve the quality of national human capital in the country by formulating and implementing the following:

- Advancing comprehensive national and provincial educational programs; i.e., technological know-how educational curriculum, vocational digital innovation education.

- Advancing comprehensive national and provincial health programs, i.e., worksite health promotions, occupational health and safety, insurance programs.

Fifth, domestic deposit accumulation as a percentage of GDP or s/y must be boosted in the countries' banking systems.

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