APO Productivity Index

Measurement of Long-Term Productivity Growth

The Asian Productivity Organization (APO) is an intergovernmental organization committed to improving productivity in the Asia-Pacific region. Established in 1961, the APO contributes to the sustainable socioeconomic development of the region through policy advisory services, acting as a think tank, and undertaking smart initiatives in the industry, agriculture, service, and public sectors. The APO is shaping the future of the region by assisting member economies in formulating national strategies for enhanced productivity and through a range of institutional capacity-building efforts, including research and centers of excellence in member countries.

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APO PRODUCTIVITY INDEX: MEASUREMENT OF LONG-TERM PRODUCTIVITY GROWTH

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APO Productivity Index: Measurement of Long-term Productivity Growth

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CONTENTS

FOREWORD

Productivity measures the extent to which individual input variables contribute to final output. Individual productivity indices, such as labor productivity, which measure and compare productivity levels across different countries based on a single dimension of measurement, are limited since they do not consider all factors that determine productivity. Productivity depends on a broad range of determinants that cannot be represented by an aggregated, unidimensional factor. Not only standard economic variables such as labor and capital but also multidimensional ones such as the quality of institutions determine productivity. Appropriate measurement with solid conceptual underpinnings is thus pivotal in understanding the sources of productivity performance. That understanding will then help set policies targeting critical factors for sustaining productivity improvement.

The rapidly changing landscape may obscure the causal relations among factors determining productivity, meaning that productivity-enhancing as well as general capacities of the economy must be continuously evaluated and integrated into policy. Measurement that takes into account multidimensional characteristics and performance is needed for both policy evaluation and productivity comparisons. Knowledge of productivity-enhancing capacities can also predict prospects for an economy's future performance.

This report introduces the Asian Productivity Organization (APO) Productivity Index (API). The API identifies factors that determine productivity and suggests policies to help sustain its growth. It is a composite index measuring productivity multidimensional characteristics and performance in APO member economies. It aims to measure productivity with respect to individual variables and to evaluate productivity-enhancing as well as general productive capacities of the economy. Compared with other composite indices measuring economic performance, the API is designed solely to measure excellence in productivity enhancement. Its structure and construction are also distinguishable from other indices. Its unique approach aggregates the productivity indices of individual input variables into a single measure of performance.

Evolving productivity challenges such as the productivity deceleration and the impact of the present global pandemic on productivity require policymakers to expand their planning horizons further toward the future. I hope that the API will provide useful guidance in assessing productivity performance for designing policies to enhance it.

Dr. AKP Mochtan
Secretary-General

EXECUTIVE SUMMARY

As we move ahead in a new decade, we are beset by new economic environments and challenges. Most significantly, the COVID-19 pandemic is fundamentally restructuring economies, which are affected by new technologies in dynamic and unforeseen ways.

Despite this rapidly changing landscape, understanding the sources of productivity growth and creating a solid conceptual lens to analyze them is as important an endeavor as ever before. This report identifies factors that determine productivity and suggests policies that can help APO countries sustain productivity growth in future. Toward this end, this report introduces the new APO Productivity Index (API).

The API has two objectives: (1) to measure productivity with respect to individual variables; and (2) to evaluate productivity-enhancing general capacities of the economy. To compare the economies of different nations, the multidimensional performance of productivity can be simplified by constructing a composite index. The results suggest that the productivity gap among APO member countries largely stems from differences in Globalization, Market Regulation, and Institutional Quality. Therefore, to catch up with productivity of the leading APO economies, others need to implement changes in policies to improve international trade, foreign direct investment (FDI), and institutional quality.

This report also found that among the economic input variables, the productivity gaps among APO member countries were much larger in R&D and human capital than in physical capital. This suggests that the roles of R&D and human capital should be emphasized when implementing productivity policies.

The API results indicate that Singapore, the Republic of China (ROC), Japan, and the Republic of Korea (ROK) were the leading APO member countries in the index. The report presents productivity scores for 12 variables, categorized into four types, namely, Economic Input, Globalization, Market Regulation, and Institutional Quality. The results indicate that differences in the productivity scores among APO member countries were not large when considering economic input variables (which include capital stock, human capital, energy, and R&D), as compared with differences in the other indices of Globalization, Market Regulation, and Institutional Quality.

Looking deeper into the composite data of the API, our analysis indicates that the facilitation of technology diffusion among APO member countries through R&D is crucial to reducing the productivity gaps among them. Productivity growth via diffusion of technology can be facilitated through trade openness and FDI inflows. Lifting barriers to trade and FDI inflows will benefit APO member countries. Moreover, the accumulation of human capital through education and training programs is highly important for sustaining productivity growth. A more educated workforce has significantly boosted labor productivity in many countries over the past several decades, though it is expected that the rate of increase in human capital accumulation will begin to slow down, due to aging of populations. In particular, the growth of knowledge base in future will increasingly require skilled labor. Skill requirements will increase as a consequence of skill-biased technological changes. High-quality primary and secondary education will become prerequisites for raising skill levels. Also, the aging of workers will increase the need for retraining, as acquired education and skills will become obsolete.

Rigid regulations reduce flexibility of resource allocation in markets and decrease productivity. Strengthening labor mobility and minimizing labor market risk by increasing labor freedom can increase productivity growth through productivity-enhancing reallocation of workers. Creating a market environment where productive businesses can thrive through sound market regulations will increase productivity.

Institutions shape the incentives for both factor accumulation and innovation and thereby improve the overall allocation efficiency of factors of production. A stronger rule of law and better law enforcement can amplify the positive effect of R&D spending. On the other hand, corruption affects multifactor productivity (MFP) via a misallocation of public and private resources. Corruption also disincentivizes investments in human and physical capital, especially those with high risk and high return profiles, by increasing overall uncertainty and reducing contract enforcement. Political stability affects the investment climate for foreign investors. In countries with lower institutional quality, the return to firms' innovation is lower, discouraging investment in research and adoption of new products. To catch up with the countries that are leading in productivity, it is necessary for the lagging economies to reduce institutional gaps.

THE APO PRODUCTIVITY INDEX

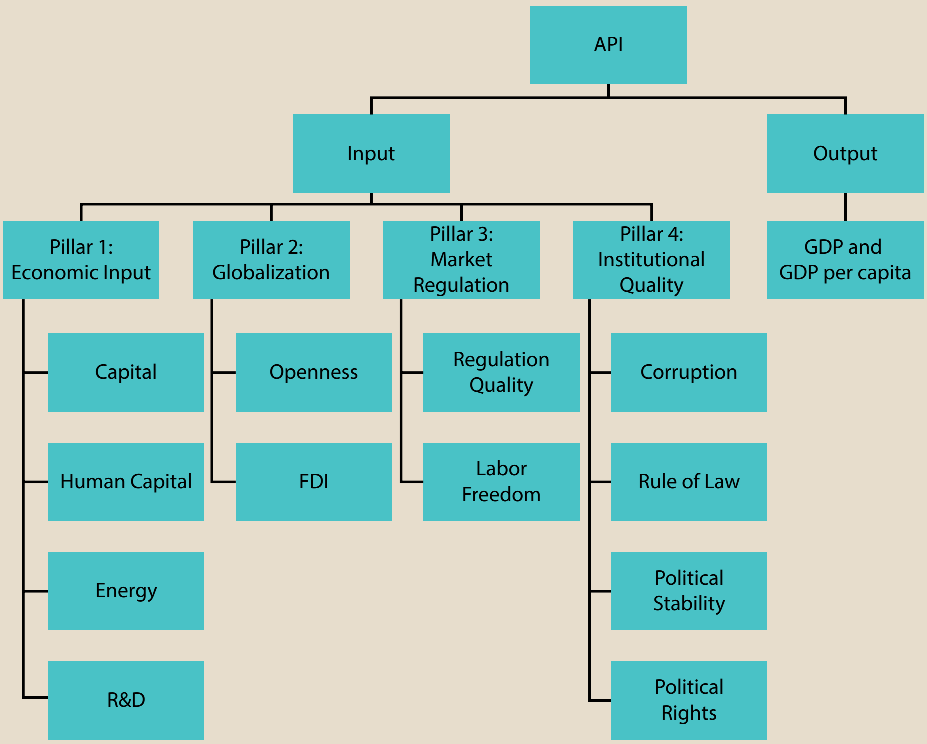
Structure of the APO Productivity Index

The APO Productivity Index (API) takes into account the multidimensional characteristics of productivity. It has two objectives: (1) to measure productivity with respect to individual variables; and (2) to evaluate productivity-enhancing general capacities of the economy. To compare the economies of different nations, the multidimensional performance of productivity can be simplified by constructing a composite index.

There are several composite indices that measure the performance of economies from various aspects. Such indices include the Global Competitiveness Index (GCI) by the World Economic Forum; the Human Development Index (HDI) by the United Nations (UN); and the Global Innovation Index (GII). The API is different from these existing composite indices in that it is designed to measure excellence in productivity enhancement. The API's structure and the way it is constructed also distinguish it from the others. In particular, the productivity indices of individual input variables are constructed before aggregating the indices into a single measure of performance.

FIGURE 1

THE APO PRODUCTIVITY INDEX CONCEPT.



The API has one overall performance indicator at the top and five low-level indicators at the base (see Figure 1). The overall indicator has two domains that define the level of performance: input and output. Input is divided into four pillars (variables of Economic Input, Globalization, Market Regulation, and Institutional Quality) and 12 low-level variables (capital, human capital, energy, R&D, trade openness, FDI, regulation quality, labor freedom, corruption, rule of law, political stability, and political rights). Output consists of GDP and GDP per capita. GDP is used as the output variable for the economic input variables, while GDP per capita is the output variable for market regulation and institutional quality variables. Overall, the API consists of 14 variables, as described in greater detail in Figure 1. A distinguishing feature of the API is that it contains an input–output structure, while other indices usually use the performances of input variables as the indicators of output performances.

Pillar 1: Economic Input Variables

Four economic input variables are used in the API. These are physical capital, human capital, energy, and R&D expenditure. Physical capital is a traditional input for production. In this study, the physical capital variable was constructed using the perpetual inventory method (PIM). For labor input, human capital was used to consider the quantity and the quality of labor. The quality of labor was measured in terms of educational attainment. The endogenous growth theory suggests that human capital is the source of increasing returns to scale in production, and the larger the human capital, the faster the economic growth [1]. The energy variable signifies energy used per capita in kg of oil equivalent. Energy is one of the major intermediate inputs for production. The R&D variable is measured as the R&D expenditure as a percentage of GDP. R&D is an important factor for technological development and diffusion, as it advances the knowledge of a society and its productivity [2].

Pillar 2: Globalization

Globalization can be defined as the reduction of trade and investment costs or the process of increasing the interdependence of the world's markets and businesses. Globalization can be linked with productivity in various ways, including trade liberalization, exposure to new technology, and FDI. As determinants of productivity, this report uses trade openness and FDI as the variables of globalization. Trade openness, measured by export and import as a share of GDP, is known to promote economic growth [3, 4]. Previous literature has found that a more open economy (associated with geographic location and trade policy) tends to be more productive [5, 6]. Trade openness also influences domestic firms' incentives and capabilities for innovation by bringing an influx of foreign competitors into the domestic market and providing access to foreign markets [7]. A more open economy is also positively associated with the size of government spending, which serves as an insurance mechanism [8].

FDI promotes productivity through technological spillovers and transmission of management skills [9–11]. FDI also affects domestic firms' productivity through vertical and horizontal effects [12]. For instance, FDI tends to spread technology to domestic firms in the same industry [13, 14] as well as to firms that either purchase products or sell factors of production [15].

Pillar 3: Market Regulation

Market regulations include both regulatory quality and labor freedom variables. Regulatory quality measures the perceived ability of the government to formulate and implement sound policies and regulations [16]. Numerous studies have concluded that burdensome regulations work like taxation on various economic activities and have a negative impact on employment, investment, and national productivity. Stricter regulations are also associated with high levels of corruption because regulatory constraints lead to opportunities for corrupt behavior, such as bribery, to avoid the costs of regulations or to seek the benefits of regulations [17]. On the contrary, regulatory reforms promote both domestic and foreign direct investments [18, 19]; employment [19–21]; and productivity of the whole economy [22]. The labor freedom component is a quantitative measure that considers various aspects of the legal and regulatory framework of a country's labor market. These include regulations concerning minimum wages, laws inhibiting layoffs, severance requirements, and measurable regulatory restraints on hiring and hours worked. Reduction in stringent employment protection and increase in labor mobility are associated with productivity increase through lowering of skills mismatch and labor market transaction costs [23].

Pillar 4: Institutional Quality

Institutional variables measure the quality of formal and informal institutions. Proxy variables include corruption, rule of law, political stability, and political rights. The quality of institution is a crucial source of economic performance [24–28]. Hall and Jones [29] claim that institutional quality determines productivity across countries, but not conversely. For instance, the lack of property rights over capital, profits, and patents reduces incentives and opportunities to invest, innovate, and obtain foreign technology [26]. Similarly, political corruption reduces output growth [30], TFP [26, 31], FDI [32], and the quality of public investment [33]. In countries where rule of law is well established, governments effectively uphold property rights and prevent corruption [29, 34, 35].

Political corruption is defined as the misuse of public resources for private gains. We measure corruption by the extent to which corruption is perceived to exist among public officials and politicians, using Corruption Perceptions Index (CPI) published by Transparency International. The CPI ranges from 0 (highly corrupt) to 100 (very clean). The rule of law is measured by the extent to which people have confidence in and abide by the rules of the society [16]. In particular, it refers to the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence. The variable is distributed between a range of –2.5 and 2.5.

Political rights capture government intervention in the private lives of individuals. Weak political rights are associated with a low level of public trust because the government tends to ignore property rights. Political rights are measured by the extent to which people are allowed to participate freely and effectively in choosing their leaders or in voting directly on legislation. Political stability is measured by perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.

Table 1 summarizes the variables used for the analysis. GDP was used as the output for capital stock, while GDP per capita was used as the output for other inputs. The output variables are used in a logarithmic form. Energy, R&D, trade, FDI, labor freedom, and corruption variables are also used in the logarithmic form. Regulatory quality, rule of law, and political stability variables are rescaled and converted to positive numbers. The value for the political rights variable is adjusted so that 1 represents 'no rights' and 7 represents 'full rights.' The API is estimated using 2017 data.

Note that the API conceptually differs from other existing indices both in terms of structure and methodology. Most existing measures simply add up a number of different factors, including institutions, infrastructure, education, and labor market variables into a single index. These factors are believed to determine the level of performance of an economy. Because the existing measures do not focus on the extent to which individual factors contribute to the economic performance of a particular country, they are not able to examine the impact of an individual variable, such as

TABLE 1

DEFINITIONS OF THE VARIABLES AND DATA SOURCES.

Variable	Definition	Source
GDP	Real GDP at chained PPP (in 2011 USD)	Penn World Table 9.1 [36]
GDP per capita	Real GDP per capita at chained PPP (in 2011 USD)	Penn World Table 9.1 [36]
Capital stock	Physical capital stock at time *t*, estimated by the perpetual inventory method (PIM)	Penn World Table 9.1 [36]
Human capital	Human capital index takes into account the quality of labor input	Penn World Table 9.1 [36]
Energy use (kg of oil equivalent per capita)	Equivalent to the approximate amount of energy that can be extracted from one kilogram of crude oil (41,868 kilojoules)	World Bank World Development Indicators [76]
Gross domestic expenditure on R&D (GERD) (% of GDP)	This is the total intramural expenditure on R&D performed in the national territory during a specific reference period expressed as a percentage of GDP of the national territory	UNESCO [38]
Trade (% of GDP)	The sum of export and import of goods and services measured as a share of gross domestic product	World Bank World Development Indicators [76]
Foreign direct investment (FDI), net inflows (% of GDP)	The net inflow of investment to acquire a lasting management interest (10% or more of the voting stock) in an enterprise operating in an economy other than that of the investor	World Bank World Development Indicators [76]
Regulation quality	The perceived ability of the government to formulate and implement sound policies and regulations, distributed between scores –2.5 and 2.5	World Bank Worldwide Governance Indicators [37]
Labor Freedom Index	A quantitative measure that considers various aspects of the legal and regulatory framework of a country's labor market, including regulations concerning minimum wages, laws inhibiting layoffs, severance requirements, and measurable regulatory restraints on hiring and hours worked	The Heritage Foundation [39]
Corruption	The extent to which corruption is perceived to exist among public officials and politicians; distributed between scores 0 (highly corrupt) and 100 (very clean)	Transparency International [40]
Political rights	The extent to which people are allowed to participate freely and effectively in choosing their leaders or in voting directly on legislation; distributed between 1 (full rights) to 7 (no rights)	Freedom House [41]
Rule of law	The extent to which people have confidence in and abide by the rules of the society; distributed between scores –2.5 and 2.5	World Bank Worldwide Governance Indicators [37]
Political stability	Political stability and the absence of violence/terrorism, distributed between scores –2.5 and 2.5	World Bank Worldwide Governance Indicators [37]

property rights, on per capita income. By contrast, the API treats institutional quality, globalization, market regulation, and economic variables as separate input factors that contribute to the output of the economy. More specifically, the API methodology uses the concept of technical efficiency to measure the extent to which multidimensional factors contribute to economic performance. Productivity is defined as output divided by input, but efficiency can be defined as relative productivity against a benchmark productivity, that is, productivity divided by the benchmark productivity. The benchmark productivity represents the maximum amount of output that can be produced for a given amount of input under an available technology. This way, we can pinpoint which variable is underperforming or overperforming in terms of productivity enhancement. For instance, while both the API and the GCI employ institutional variables, such as property rights and corruption, the GCI simply treats these variables as one of the 12 factors or pillars that determine the level of performance, without taking into account the productivity of these institutional variables. The next section explains the API methodology in more detail. Table 2 presents other related indices for comparison.

TABLE 2

OTHER RELATED INDICES.

Index	Description, variables, methodology, and source
Global Competitiveness Index (GCI)	**Description:** GCI measures the drivers of productivity (institutions, policies, and factors that determine the level of productivity of an economy) for 140 countries. **Variables:** These comprise 12 pillars (institutions, infrastructure, macroeconomic environment, health and primary education, higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, market size, business sophistication, and innovation). **Methodology:** The 12 pillars are organized into three subindices. The weight assigned to each pillar depends on a country's stage of development. An arithmetic mean is used to aggregate individual indicators within categories. **Source:** World Economic Forum [42]
Global Innovation Index (GII)	**Description:** GII measures multidimensional facets of innovation that improve productivity for 141 countries. **Variables:** These comprise five input pillars (institutions, human capital and research, infrastructure, market sophistication, and business sophistication) and two output pillars (knowledge and technology outputs, creative outputs). **Methodology:** Average of the input and output pillars is taken. Ratio of output pillar/input pillar is used. **Source:** INSEAD [43]
Global Talent Competitiveness Index (GTCI)	**Description:** GTCI measures the ability of 118 countries to compete for talent. **Variables:** These comprise four input pillars (enable, attract, grow, retain) and two output pillars (labor and vocational skills, and sustainable knowledge skills). **Methodology:** Simple arithmetic average of the scores registered on each of the six pillars is taken. **Source:** INSEAD [44]
Human Development Index (HDI)	**Description:** HDI measures human development outcomes (long and healthy life, knowledge, and a decent standard of living) which should affect the productivity of 188 countries. **Variables:** These comprise four indicators (life expectancy at birth, expected years of schooling, mean years of schooling, and gross national income per capita). **Methodology:** Average achievement in human development is measured. **Source:** United Nations Development Programme [45]

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Index	Description, variables, methodology, and source
Global Manufacturing Competitiveness Index (GMCI)	**Description:** GMCI measures the overall manufacturing competitiveness for 40 countries. **Variables:** These comprise three survey sections (business confidence and current environment, manufacturing competitiveness, and demographics). **Methodology:** Average normalized weighted responses, from 10 (low) to 100 (high) are used. **Source:** Deloitte [46]
Energy Productivity and Economic Prosperity Index (EPEPI)	**Description:** EPEPI measures economic output per unit of energy consumed for 131 countries. **Variables:** These comprise six sub-indicators (energy productivity of households, improvement in household energy productivity, service-sector energy productivity, service-sector energy productivity growth, resource productivity in industry, and improvement in resource productivity for industry). **Methodology:** Energy productivity is calculated as GDP per unit of energy consumed (in billions of euros per exajoule). **Source:** ECOFYS [47]
Network Readiness Index (NRI)	**Description:** NRI measures the performance in leveraging information and communications technologies to boost competitiveness, innovation and well-being for 139 economies. **Variables:** These comprise four main subindices (environment, readiness, usage, and impact); 10 pillars (political and regulatory environment, business and innovation environment, infrastructure, affordability, skills, individual usage, business usage, government usage, economic impacts, and social impacts); and 53 individual indicators. **Methodology:** Scores of each indicator are normalized into a scale ranging from 1 (low) to 7 (high). Then, a simple average is used to combine the components. **Source:** Portulans Institute [48]

Source: Kim, et al. [49]

Rankings of the APO Productivity Index

Table 3 shows the results of the API. Four indices, namely, Economic Input, Globalization, Market Regulation, and Institutional Quality, are aggregated to produce the API. The weights applied for the aggregation are 0.194, 0.313, 0.314, and 0.179, respectively (see Figure 2).

Singapore ranks first in the API, followed by the ROC, and Japan by a narrow margin. Hong Kong, the ROK, and Turkey have the next highest scores, respectively. The results indicate that these countries have the highest level of productivity-enhancing capacity among the APO member countries. Meanwhile, IR Iran, Malaysia, Indonesia, Sri Lanka, and Thailand belong to the second-level group. It is noted that the variation of API among the countries is affected more by variations in the Globalization, Market Regulation, and Institutional Quality indices than by the variation in the Economic Input Index. The standard deviations of the Economic Input, Globalization, Market Regulation, and Institutional Quality indices are 0.032, 0.083, 0.072, and 0.058, respectively (see Table 4). The standard deviation of the API is 0.062. This suggests that it is crucial for the countries that are lagging in productivity to improve their market regulation and quality of social and economic institutions to catch up with the leading economies in terms of productivity. It is also recommended that these countries pursue economic policies that increase external relationships with other countries through trade and FDI to improve productivity. Below are details on the subindices that together comprise the API composite as a whole.

TABLE 3

APO PRODUCTIVITY INDEX AND ITS SUBINDICES.

Country/ economy	Economic Input Index	Globalization Index	Market Regulation Index	Institutional Quality Index	APO Productivity Index	Ranking
Bangladesh	0.921	0.765	0.782	0.830	0.812	20
Cambodia	0.897	0.739	0.769	0.944	0.816	19
ROC	0.975	0.992	0.988	0.982	0.986	2
Fiji	0.908	0.827	0.842	0.862	0.854	17
Hong Kong	0.973	0.955	0.955	0.962	0.960	6
India	0.919	0.822	0.871	0.846	0.860	16
Indonesia	0.951	0.869	0.898	0.906	0.900	11
IR Iran	0.932	0.906	0.955	0.997	0.943	7
Japan	0.979	0.998	0.968	0.964	0.979	3
ROK	0.960	0.977	0.974	0.974	0.972	4
Lao PDR	0.969	0.811	0.849	0.950	0.879	13
Malaysia	0.944	0.927	0.927	0.948	0.934	8
Mongolia	0.939	0.851	0.869	0.902	0.883	12
Nepal	0.874	0.740	0.782	0.792	0.788	21
Pakistan	0.938	0.842	0.871	0.878	0.876	14
Philippines	0.933	0.832	0.845	0.885	0.865	15
Singapore	0.979	1.000	1.000	1.000	0.996	1
Sri Lanka	0.974	0.884	0.896	0.910	0.910	10
Thailand	0.931	0.895	0.907	0.960	0.918	9
Turkey	0.979	0.955	0.988	0.969	0.972	5
Vietnam	0.890	0.796	0.825	0.877	0.838	18

TABLE 4

SUMMARY STATISTICS OF THE APO PRODUCTIVITY INDEX.

Variables	Mean	Standard deviation	Minimum	Maximum
Economic Input Index	0.941	0.032	0.874	0.979
Globalization Index	0.875	0.083	0.739	1.000
Market Regulation Index	0.893	0.072	0.769	1.000
Institutional Quality Index	0.921	0.058	0.817	1.000
APO Productivity Index	0.902	0.062	0.788	0.996

FIGURE 2

WEIGHTS FOR THE APO PRODUCTIVITY INDEX.

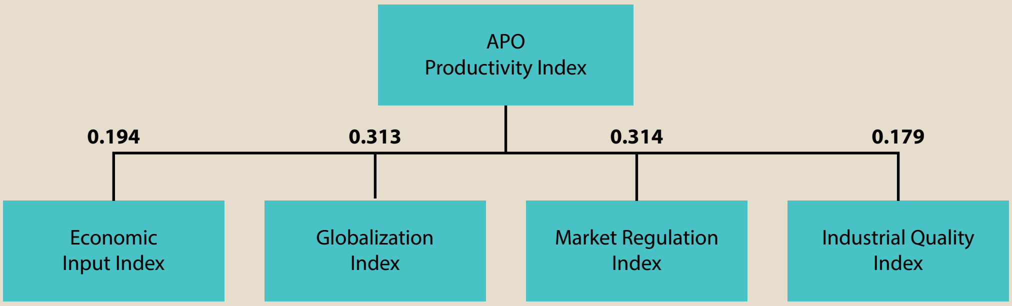

TABLE 5

ECONOMIC INPUT INDEX AND ITS COMPONENTS.

Country/ economy	Capital Stock Index	Human Capital Index	Energy Index	R&D Index	Economic Input Index	Ranking
Bangladesh	0.950	0.881	1.000	0.841	0.921	16
Cambodia	0.994	0.907	0.847	0.851	0.897	19
ROC	0.959	0.996	0.996	0.960	0.975	4
Fiji	1.000	0.863	0.896	0.855	0.908	18
Hong Kong	0.909	0.993	0.996	1.000	0.973	6
India	1.000	0.930	0.907	0.849	0.919	17
Indonesia	0.957	0.936	0.950	0.954	0.951	9
IR Iran	0.963	0.952	0.915	0.911	0.932	14
Japan	0.985	0.975	1.000	0.954	0.979	2
ROK	0.963	0.959	0.975	0.945	0.960	8
Lao PDR	0.974	0.986	0.921	1.000	0.969	7
Malaysia	0.954	0.950	0.953	0.922	0.944	10
Mongolia	0.943	0.881	0.926	0.976	0.939	11
Nepal	0.976	0.925	0.824	0.804	0.874	21
Pakistan	1.000	1.000	0.904	0.883	0.938	12
Philippines	0.961	0.864	0.938	0.935	0.933	13
Singapore	0.924	1.000	1.000	1.000	0.979	1
Sri Lanka	0.954	0.903	1.000	1.000	0.974	5
Thailand	0.954	0.930	0.940	0.903	0.931	15
Turkey	0.978	1.000	0.994	0.956	0.979	3
Vietnam	0.973	0.834	0.881	0.849	0.890	20

TABLE 6

SUMMARY STATISTICS OF THE ECONOMIC INPUT INDEX AND ITS COMPONENTS.

Variables	Mean	Standard deviation	Minimum	Maximum
Capital Index	0.965	0.024	0.909	1.000
Human Capital Index	0.936	0.052	0.834	1.000
Energy Index	0.941	0.053	0.824	1.000
R&D Index	0.921	0.061	0.804	1.000
Economic Input Index	0.941	0.032	0.874	0.979

FIGURE 3

WEIGHTS FOR THE CONSTRUCTION OF THE ECONOMIC INPUT INDEX.

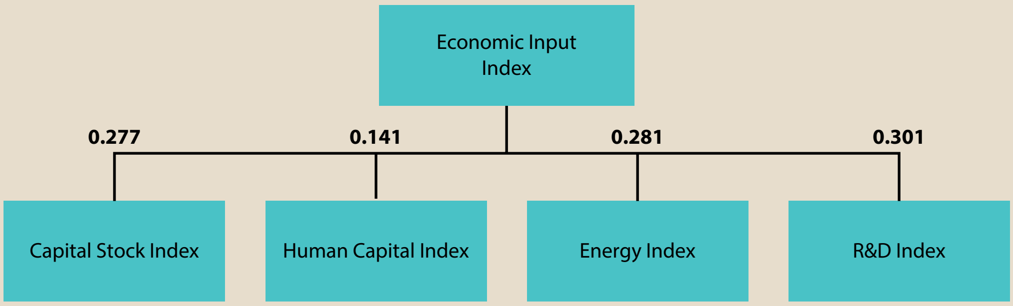

Table 5 shows the results of constructing the Economic Input Index for APO member countries. For each index, the scores range from 0 to 1. A high score implies that a country is very efficient or productive when using an input to increase the output level. Singapore has the highest score in Economic Input Index while Japan and Turkey have similar scores. These countries are followed by the ROC, Hong Kong, Sri Lanka, the ROK, Indonesia, and Malaysia. Nepal, Cambodia, and Vietnam have the lowest scores. Regarding variations in the scores, the Economic Input Index has a much narrower variation than other indices. This suggests that countries with low scores can catch up by increasing the level of economic input variables. For the capital stock variable, Fiji, India, and Pakistan have the highest scores. All APO countries have capital stock scores greater than 0.9. In terms of productivity of human capital, Pakistan, Turkey, and Singapore rank the highest, while Bangladesh, Fiji, and Vietnam rank the lowest. Bangladesh, Hong Kong, Japan, Singapore, and Sri Lanka are the most efficient in using energy for output production, while Hong Kong, Lao PDR, Singapore, and Sri Lanka use R&D expenditure most efficiently.

Table 6 presents the summary statistics of the Economic Input indices (the Kernel density of each index is reported in Appendix C). It reveals that the gap in productivity score is the smallest for the capital index among APO countries, while it is the largest for the R&D index. Figure 3 shows the weights used for constructing the Economic Input Index. The capital stock, human capital, energy, and R&D variables are given the weights of 0.277, 0.141, 0.281, and 0.301, respectively to produce the Economic Input Index.

TABLE 7

GLOBALIZATION INDEX AND ITS COMPONENTS.

Country/economy	FDI Index	Openness Index	Globalization Index	Ranking
Bangladesh	0.763	0.767	0.765	19
Cambodia	0.739	0.739	0.739	21
ROC	1.000	0.984	0.992	3
Fiji	0.827	0.828	0.827	15
Hong Kong	0.955	0.955	0.955	6
India	0.820	0.824	0.822	16
Indonesia	0.866	0.871	0.869	11
IR Iran	0.906	0.906	0.906	8
Japan	0.995	1.000	0.998	2
ROK	0.982	0.972	0.977	4
Lao PDR	0.809	0.814	0.811	17
Malaysia	0.935	0.919	0.927	7
Mongolia	0.851	0.852	0.851	12
Nepal	0.741	0.739	0.740	20
Pakistan	0.803	0.881	0.842	13
Philippines	0.834	0.830	0.832	14
Singapore	1.000	1.000	1.000	1
Sri Lanka	0.883	0.884	0.884	10
Thailand	0.903	0.887	0.895	9
Turkey	0.955	0.954	0.955	5
Vietnam	0.804	0.788	0.796	18

TABLE 8

SUMMARY STATISTICS OF THE GLOBALIZATION INDEX AND ITS COMPONENTS.

Variables	Mean	Standard Deviation	Minimum	Maximum
FDI Index	0.875	0.086	0.739	1.000
Openness Index	0.876	0.082	0.739	1.000
Globalization Index	0.875	0.083	0.739	1.000

FIGURE 4

WEIGHTS FOR THE CONSTRUCTION OF THE GLOBALIZATION INDEX.

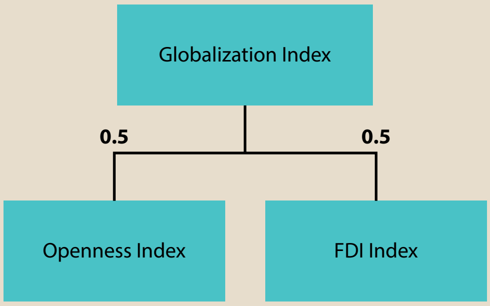

Table 7 shows the results pertaining to the Globalization Index. The index is composed of FDI and trade openness variables. Singapore and the ROC are among the top countries in terms of FDI performance, while Bangladesh, Cambodia, Pakistan, Nepal, and Vietnam have the lowest scores. For the trade openness variable, Japan and Singapore rank the highest, followed by the ROC, the ROK, and Hong Kong. For the Globalization Index, Singapore ranks first, followed by Japan, the ROC, Hong Kong, and the ROK. In constructing the Globalization Index, the trade openness and FDI indices are given equal weights of 0.5 each (see Figure 4).

Table 8 shows the summary statistics for the Globalization Index. The FDI and trade openness indices present a similar distribution of values, and the Globalization Index presents a much larger standard deviation than the Economic Input Index.

TABLE 9

MARKET REGULATION INDEX AND ITS COMPONENTS.

Country/ economy	Labor Freedom Index	Regulatory Quality Index	Market Regulation Index	Ranking
Bangladesh	0.749	0.814	0.782	20
Cambodia	0.748	0.790	0.769	21
ROC	1.000	0.977	0.988	2
Fiji	0.820	0.864	0.842	17
Hong Kong	0.956	0.955	0.955	6
India	0.894	0.849	0.871	13
Indonesia	0.905	0.891	0.898	10
IR Iran	0.910	1.000	0.955	7
Japan	0.966	0.970	0.968	5

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Country/ economy	Labor Freedom Index	Regulatory Quality Index	Market Regulation Index	Ranking
ROK	0.981	0.967	0.974	4
Lao PDR	0.826	0.873	0.849	15
Malaysia	0.918	0.936	0.927	8
Mongolia	0.846	0.892	0.869	14
Nepal	0.778	0.786	0.782	19
Pakistan	0.897	0.846	0.871	12
Philippines	0.835	0.855	0.845	16
Singapore	1.000	1.000	1.000	1
Sri Lanka	0.882	0.909	0.896	11
Thailand	0.896	0.919	0.907	9
Turkey	1.000	0.976	0.988	3
Vietnam	0.804	0.846	0.825	18

TABLE 10

SUMMARY STATISTICS OF THE MARKET REGULATION INDEX AND ITS COMPONENTS.

Variables	Mean	Standard deviation	Minimum	Maximum
Labor Freedom Index	0.886	0.081	0.748	1.000
Regulatory Quality Index	0.901	0.067	0.786	1.000
Market Regulation Index	0.893	0.072	0.769	1.000

FIGURE 5

WEIGHTS FOR THE CONSTRUCTION OF THE MARKET REGULATION INDEX.

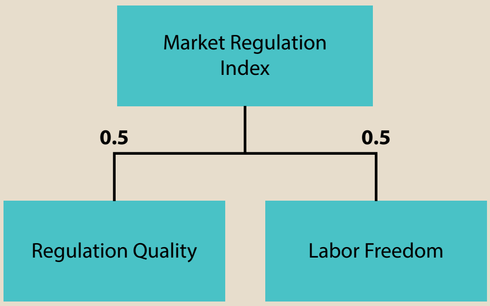


Table 9 presents the results for the Market Regulation Index, which is composed of the labor freedom and regulatory quality variables. For the labor freedom variable, Singapore, the ROC, and Turkey are among the top performers, while Bangladesh and Cambodia have the lowest scores. For the regulatory quality variable, IR Iran and Singapore have the best scores, followed by Hong Kong, Japan, the ROK, and Turkey. Singapore has the highest score in the overall Market Regulation Index. In constructing the index, equal weights of 0.5 are given to the labor freedom and regulatory quality indices (see Figure 5). Table 10, which presents the summary statistics of the Market Regulation Index, shows that the labor freedom variable has a larger variation than the regulatory quality variable.

TABLE 11

INSTITUTIONAL QUALITY INDEX AND ITS COMPONENTS.

Country/ economy	Corruption Index	Political Stability Index	Political Rights Index	Rule of Law Index	Institutional Quality Index	Ranking
Bangladesh	0.869	0.833	0.733	0.840	0.830	20
Cambodia	1.000	0.764	0.833	1.000	0.944	11
ROC	0.992	0.983	0.960	0.984	0.982	3
Fiji	0.875	0.829	0.804	0.888	0.862	18
Hong Kong	0.964	0.978	0.955	0.958	0.962	7
India	0.858	0.868	0.789	0.856	0.846	19
Indonesia	0.921	0.904	0.834	0.929	0.906	13
IR Iran	1.000	0.968	1.000	1.000	0.997	2
Japan	0.969	0.969	0.954	0.962	0.964	6
ROK	0.993	0.986	0.945	0.967	0.974	4
Lao PDR	0.922	0.823	1.000	0.989	0.950	9
Malaysia	0.964	0.950	0.903	0.956	0.948	10
Mongolia	0.926	0.857	0.835	0.926	0.902	14
Nepal	0.812	0.779	0.712	0.817	0.792	21
Pakistan	0.875	1.000	0.772	0.900	0.878	16
Philippines	0.903	0.910	0.805	0.901	0.885	15
Singapore	1.000	1.000	1.000	1.000	1.000	1
Sri Lanka	0.934	0.902	0.850	0.920	0.910	12
Thailand	0.960	0.956	0.999	0.941	0.960	8
Turkey	1.000	0.979	0.919	0.963	0.969	5
Vietnam	0.870	0.816	0.988	0.844	0.877	17

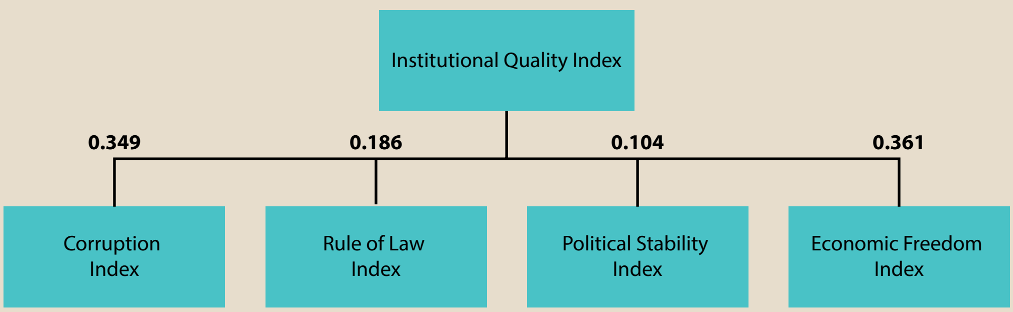
TABLE 12

SUMMARY STATISTICS OF THE INSTITUTIONAL QUALITY INDEX AND ITS COMPONENTS.

Variables	Mean	Standard deviation	Minimum	Maximum
Corruption Index	0.934	0.057	0.812	1.000
Political Stability Index	0.907	0.077	0.764	1.000
Political Right Index	0.885	0.095	0.712	1.000
Rule of Law Index	0.931	0.056	0.817	1.000
Institutional Quality Index	0.921	0.058	0.792	1.000

FIGURE 6

WEIGHTS USED IN THE CONSTRUCTION OF THE INSTITUTIONAL QUALITY INDEX.



The Institutional Quality Index is composed of four subindices, namely, corruption, rule of law, political stability, and political freedom. Table 11 presents the results of the Institutional Quality Index. For the corruption variable, Cambodia, IR Iran, Singapore, and Turkey are among the top performers, followed by the ROK, Japan, Hong Kong, Malaysia, the ROC, and Thailand. Pakistan and Singapore are the top performers in the Political Stability Index, followed by the ROK, the ROC, and Turkey. The results also indicate that the impact of political rights on productivity is the greatest in IR Iran, Lao PDR, and Singapore; while Bangladesh, India, Nepal, and Pakistan are less efficient in using improvements in political rights to increase productivity. For the rule of law variable, Cambodia, IR Iran, and Singapore show the best performance in productivity. In constructing the Institutional Quality Index, corruption, rule of law, political stability, and political rights are given the weights of 0.349, 0.186, 0.104, and 0.361, respectively (see Figure 6). Singapore ranks the highest in the Institutional Quality Index, followed by IR Iran, the ROK, and the ROC. Next are Turkey, Japan, Hong Kong, Thailand, and Lao PDR.

Among the four subindices, Table 12 indicates that the greatest productivity variation happens for the political rights variable, while rule of law causes the smallest variation in productivity scores.

Comparison with 2014 Data

To evaluate the progress of productivity over time, we also estimated the API for the year 2014. Table 13 shows the results for the API as well as its four subindices for 2014. Singapore was the leading country in terms of the API, followed by the ROC, Japan, and the ROK. Overall, there was an increase in the average productivity score from 0.893 in 2014 to 0.902 in 2017. The variation in the score, estimated via the standard deviation, decreased from 0.067 in 2014 to 0.062 in 2017. Bangladesh, Cambodia, Fiji, India, IR Iran, Nepal, and Singapore made progress in their productivity scores in 2017, while the other countries experienced a decrease in their scores.

TABLE 13

APO PRODUCTIVITY INDEX, 2014.

Country/ economy	Economic Input Index 2014	Globalization Index 2014	Market Regulation Index 2014	Institutional Quality Index 2014	APO Productivity Index 2014	Ranking
Bangladesh	0.916	0.750	0.774	0.788	0.791	20
Cambodia	0.912	0.734	0.768	0.817	0.789	21
ROC	0.960	0.992	0.988	0.973	0.983	2
Fiji	0.906	0.826	0.843	0.847	0.848	16
Hong Kong	0.976	0.966	0.968	0.969	0.970	5
India	0.901	0.806	0.811	0.827	0.827	18
Indonesia	0.949	0.859	0.880	0.882	0.884	11
IR Iran	0.942	0.914	0.982	0.985	0.956	6
Japan	0.963	1.000	0.966	0.955	0.975	3
ROK	0.945	0.972	0.980	0.964	0.970	4
Lao PDR	0.982	0.802	0.838	0.890	0.859	13
Malaysia	0.932	0.923	0.921	0.929	0.926	8

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Country/ economy	Economic Input Index 2014	Globalization Index 2014	Market Regulation Index 2014	Institutional Quality Index 2014	APO Productivity Index 2014	Ranking
Mongolia	0.925	0.862	0.872	0.878	0.879	12
Nepal	0.882	0.870	0.774	0.766	0.819	19
Pakistan	0.931	0.821	0.822	0.878	0.850	14
Philippines	0.940	0.821	0.837	0.844	0.849	15
Singapore	0.979	1.000	1.000	1.000	0.998	1
Sri Lanka	0.980	0.875	0.880	0.903	0.898	10
Thailand	0.928	0.889	0.897	0.949	0.910	9
Turkey	0.957	0.945	0.943	0.965	0.951	7
Vietnam	0.897	0.790	0.816	0.871	0.831	17

TABLE 14

SUMMARY STATISTICS OF THE APO PRODUCTIVITY INDEX, 2014.

Variables	Mean	Standard deviation	Minimum	Maximum
Economic Input Index	0.938	0.029	0.882	0.982
Globalization Index	0.877	0.082	0.734	1.000
Market Regulation Index	0.884	0.077	0.768	1.000
Institutional Quality Index	0.899	0.068	0.766	1.000
APO Productivity Index 2014	0.893	0.067	0.789	0.998

Table 14 shows that Economic Input in 2014 had the highest level of average productivity score with a smaller variation among APO countries, while Globalization had the lowest productivity score with the largest variation among the four subindices. Below are the descriptions of the constituent components of the 2014 API.

TABLE 15

ECONOMIC INPUT INDEX, 2014.

Country/ economy	Capital Stock Index	Human Capital Index	Energy Index	R&D Index	Economic Input Index 2014	Ranking
Bangladesh	0.956	0.887	1.000	0.829	0.916	16
Cambodia	1.000	0.934	0.893	0.855	0.912	17
ROC	0.964	0.982	0.959	0.957	0.960	6
Fiji	1.000	0.865	0.901	0.842	0.906	18
Hong Kong	0.924	0.991	1.000	1.000	0.976	4
India	1.000	0.930	0.902	0.819	0.901	19
Indonesia	0.962	0.911	0.930	0.961	0.949	8
IR Iran	0.968	0.976	0.888	0.959	0.942	10
Japan	0.987	0.949	0.963	0.949	0.963	5

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Country/ economy	Capital Stock Index	Human Capital Index	Energy Index	R&D Index	Economic Input Index 2014	Ranking
ROK	0.967	0.937	0.937	0.937	0.945	9
Lao PDR	0.980	0.999	0.962	1.000	0.982	1
Malaysia	0.964	0.942	0.918	0.918	0.932	12
Mongolia	0.934	0.881	0.875	0.965	0.925	15
Nepal	0.976	1.000	0.870	0.799	0.882	21
Pakistan	1.000	1.000	0.926	0.872	0.931	13
Philippines	0.963	0.850	0.957	0.925	0.940	11
Singapore	0.931	1.000	1.000	1.000	0.979	3
Sri Lanka	0.958	0.884	1.000	1.000	0.980	2
Thailand	0.955	0.925	0.893	0.936	0.928	14
Turkey	0.976	1.000	0.960	0.935	0.957	7
Vietnam	0.975	0.833	0.895	0.848	0.897	20

TABLE 16

SUMMARY STATISTICS OF ECONOMIC INPUT INDEX, 2014, AND ITS COMPONENTS.

Variables	Mean	Standard deviation	Minimum	Maximum
Capital Index	0.969	0.022	0.924	1.000
Human Capital Index	0.937	0.054	0.833	1.000
Energy Index	0.935	0.044	0.870	1.000
R&D Index	0.919	0.065	0.799	1.000
Economic Input Index 2014	0.938	0.029	0.882	0.982

In 2014, Hong Kong, Japan, Lao PDR, Singapore, Sri Lanka, and the ROC were the leaders in the Economic Input Index. Cambodia, Fiji, and Pakistan were the best performers in the Capital Stock Index, while Nepal, Pakistan, Singapore and Turkey were the most productive in the use of human capital among the APO countries. Bangladesh, Hong Kong, Singapore, and Sri Lanka recorded the highest productivity scores in the Energy Index; and Hong Kong, Lao PDR, Singapore, and Sri Lanka benefited the most from R&D spending.

Among the four subindices of the Economic Input Index in 2014, Capital Index showed a high average productivity score with a smaller standard deviation, while the R&D Index presented the lowest average score with the largest standard deviation.

In the Globalization Index in 2014, Japan and Singapore were the leading countries, followed by the ROK and the ROC, as they used FDI and trade efficiently in the promotion of productivity. Bangladesh, Cambodia, and Vietnam lagged the most in the Globalization Index.

Also, the FDI and trade openness indices presented similar levels of average productivity scores and variations in 2014. These two subindices showed much higher variation among the APO countries than the subindices of Economic Input Index (see Table 18).

TABLE 17

GLOBALIZATION INDEX, 2014, AND ITS COMPONENTS.

Country/ economy	FDI Index	Openness Index	Globalization Index 2014	Ranking
Bangladesh	0.746	0.755	0.750	20
Cambodia	0.729	0.738	0.734	21
ROC	1.000	0.983	0.992	3
Fiji	0.818	0.834	0.826	14
Hong Kong	0.966	0.966	0.966	5
India	0.802	0.811	0.806	17
Indonesia	0.852	0.867	0.859	13
IR Iran	0.914	0.915	0.914	8
Japan	1.000	1.000	1.000	2
ROK	0.978	0.966	0.972	4
Lao PDR	0.797	0.807	0.802	18
Malaysia	0.926	0.921	0.923	7
Mongolia	0.863	0.862	0.862	12
Nepal	1.000	0.740	0.870	11
Pakistan	0.794	0.848	0.821	16
Philippines	0.817	0.824	0.821	15
Singapore	1.000	1.000	1.000	1
Sri Lanka	0.872	0.878	0.875	10
Thailand	0.895	0.882	0.889	9
Turkey	0.940	0.949	0.945	6
Vietnam	0.791	0.788	0.790	19

TABLE 18

SUMMARY STATISTICS OF THE 2014 GLOBALIZATION INDEX.

Variables	Mean	Standard deviation	Minimum	Maximum
FDI Index	0.881	0.089	0.729	1.000
Openness Index	0.873	0.084	0.738	1.000
Globalization Index 2014	0.877	0.082	0.734	1.000

For the Market Regulation Index, Singapore recorded the highest score, with the best performance on Labor Freedom and Regulatory Quality subindices. IR Iran, Japan, the ROK, and the ROC also recorded strong performance on both the subindices. Bangladesh, Cambodia, India, and Nepal belonged to the group with the lowest scores.

TABLE 19

MARKET REGULATION INDEX, 2014, AND ITS COMPONENTS.

Country/ economy	Labor Freedom Index	Regulatory Quality Index	Market Regulation Index 2014	Ranking
Bangladesh	0.755	0.794	0.774	19
Cambodia	0.762	0.775	0.768	21
ROC	1.000	0.975	0.988	2
Fiji	0.822	0.864	0.843	13
Hong Kong	0.967	0.969	0.968	5
India	0.790	0.833	0.811	18
Indonesia	0.883	0.878	0.880	10
IR Iran	0.964	1.000	0.982	3
Japan	0.962	0.970	0.966	6
ROK	1.000	0.959	0.980	4
Lao PDR	0.816	0.859	0.838	14
Malaysia	0.914	0.928	0.921	8
Mongolia	0.849	0.895	0.872	12
Nepal	0.773	0.776	0.774	20
Pakistan	0.815	0.829	0.822	16
Philippines	0.837	0.837	0.837	15
Singapore	1.000	1.000	1.000	1
Sri Lanka	0.870	0.890	0.880	11
Thailand	0.891	0.903	0.897	9
Turkey	0.939	0.946	0.943	7
Vietnam	0.794	0.839	0.816	17

TABLE 20

SUMMARY STATISTICS FOR THE MARKET REGULATION INDEX, 2014, AND ITS COMPONENTS.

Variables	Mean	Standard Deviation	Min	Max
Labor Freedom Index	0.876	0.084	0.755	1.000
Regulatory Quality Index	0.891	0.072	0.775	1.000
Market Regulation Index 2014	0.884	0.077	0.768	1.000

Between the two subindices of the Market Regulation Index, the Labor Freedom Index showed a lower average productivity score and a larger variation.

In the overall ranking of the Institutional Quality Index in 2014, Singapore recorded the highest productivity score, followed by Hong Kong, IR Iran, the ROK, the ROC, and Turkey. IR Iran and Singapore fared the best on the Corruption Index, while Pakistan, Singapore, and Turkey were the leaders in the Political Stability Index. IR Iran, Lao PDR, and Singapore leveraged the rule of law more efficiently than other countries to raise their productivity. On the political rights front, IR Iran and Singapore presented the highest score.

TABLE 21

INSTITUTIONAL QUALITY INDEX, 2014, AND ITS COMPONENTS.

Country/ economy	Corruption Index	Political Stability Index	Rule of Law Index	Political Right Index	Institutional Quality Index 2014	Ranking
Bangladesh	0.845	0.784	0.720	0.804	0.788	20
Cambodia	0.896	0.751	0.827	0.819	0.817	19
ROC	0.993	0.970	0.957	0.974	0.973	3
Fiji	0.879	0.822	0.806	0.882	0.847	16
Hong Kong	0.980	0.967	0.966	0.966	0.969	4
India	0.851	0.849	0.775	0.827	0.827	18
Indonesia	0.922	0.879	0.828	0.897	0.882	12
IR Iran	1.000	0.949	1.000	1.000	0.985	2
Japan	0.960	0.955	0.949	0.955	0.955	7
ROK	0.985	0.973	0.937	0.959	0.964	6
Lao PDR	0.920	0.801	1.000	0.873	0.890	11
Malaysia	0.952	0.929	0.901	0.935	0.929	9
Mongolia	0.918	0.849	0.839	0.909	0.878	14
Nepal	0.805	0.764	0.708	0.783	0.766	21
Pakistan	0.866	1.000	0.762	0.850	0.878	13
Philippines	0.869	0.853	0.791	0.856	0.844	17
Singapore	1.000	1.000	1.000	1.000	1.000	1
Sri Lanka	0.922	0.888	0.906	0.901	0.903	10
Thailand	0.947	0.940	0.989	0.926	0.949	8
Turkey	0.976	1.000	0.907	0.965	0.965	5
Vietnam	0.873	0.808	0.989	0.840	0.871	15

TABLE 22

SUMMARY STATISTICS FOR INSTITUTIONAL QUALITY INDEX, 2014, AND ITS COMPONENTS.

Variables	Mean	Standard deviation	Minimum	Maximum
Corruption Index	0.922	0.057	0.805	1.000
Political Stability Index	0.892	0.083	0.751	1.000
Political Rights Index	0.884	0.098	0.708	1.000
Rule of Law Index	0.901	0.066	0.783	1.000
Institutional Quality Index 2014	0.899	0.068	0.766	1.000

Table 22 shows the summary statistics for the Institutional Quality Index in 2014. Among its four subindices, the Corruption Index presented the highest average productivity score with the least variation.

Comparison with OECD Countries

This section compares the productivity scores of the APO member economies with those of the OECD economies. As OECD economies are global leaders in terms of labor productivity, this report attempts to evaluate the relative performance of APO member countries against some of the most highly productive economies in the world. To do this, we combined data from both groups of countries and recalculated their efficiencies in productivity. We used 2017 data for 54 countries. It may be noted that Japan, the ROK, and Turkey are both APO and OECD member countries.

TABLE 23

APO PRODUCTIVITY INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Country/ economy	APO member	Economic Input Index	Globalization Index	Market Regulation Index	Institutional Quality Index	APO Productivity Index
Luxembourg	non-APO	0.992	1.000	1.000	1.000	0.999
Singapore	APO	0.982	0.992	0.991	0.992	0.990
Switzerland	non-APO	0.985	0.993	0.987	0.987	0.988
Norway	non-APO	0.975	0.990	0.981	0.982	0.984
USA	non-APO	0.976	0.986	0.973	0.981	0.980
Germany	non-APO	0.963	0.967	0.963	0.964	0.965
Australia	non-APO	0.959	0.971	0.960	0.964	0.964
Austria	non-APO	0.957	0.964	0.960	0.961	0.961
Iceland	non-APO	0.950	0.981	0.951	0.951	0.961
Denmark	non-APO	0.962	0.963	0.958	0.958	0.960
Netherlands	non-APO	0.959	0.963	0.958	0.959	0.960
ROC	APO	0.957	0.958	0.956	0.972	0.960
Italy	non-APO	0.955	0.949	0.954	0.986	0.958
Sweden	non-APO	0.951	0.959	0.952	0.953	0.954
Canada	non-APO	0.951	0.960	0.951	0.951	0.954
Japan	APO	0.952	0.957	0.949	0.953	0.953
France	non-APO	0.953	0.952	0.950	0.956	0.953
Hong Kong	APO	0.964	0.946	0.946	0.951	0.950
Spain	non-APO	0.952	0.943	0.945	0.962	0.948
UK	non-APO	0.950	0.952	0.942	0.946	0.948
Finland	non-APO	0.944	0.952	0.944	0.945	0.947
Israel	non-APO	0.943	0.945	0.941	0.964	0.947
Belgium	non-APO	0.944	0.945	0.947	0.952	0.947
ROK	APO	0.939	0.943	0.944	0.964	0.946
New Zealand	non-APO	0.944	0.946	0.936	0.936	0.941
Turkey	APO	0.961	0.920	0.937	0.962	0.940
Czech Republic	non-APO	0.923	0.927	0.928	0.946	0.930
Slovenia	non-APO	0.922	0.918	0.930	0.936	0.925
Poland	non-APO	0.933	0.915	0.919	0.942	0.924
Greece	non-APO	0.916	0.906	0.920	0.952	0.921
Lithuania	non-APO	0.941	0.911	0.913	0.930	0.920
Slovakia	non-APO	0.931	0.906	0.914	0.940	0.919

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Country/ economy	APO member	Economic Input Index	Globalization Index	Market Regulation Index	Institutional Quality Index	APO Productivity Index
IR Iran	APO	0.910	0.872	0.931	0.987	0.918
Latvia	non-APO	0.945	0.905	0.906	0.927	0.916
Portugal	non-APO	0.925	0.907	0.912	0.919	0.914
Estonia	non-APO	0.921	0.910	0.906	0.919	0.912
Malaysia	APO	0.914	0.899	0.908	0.941	0.912
Chile	non-APO	0.956	0.903	0.898	0.914	0.912
Hungary	non-APO	0.908	0.897	0.908	0.938	0.910
Mexico	non-APO	0.942	0.878	0.893	0.970	0.910
Thailand	APO	0.907	0.867	0.885	0.949	0.894
Sri Lanka	APO	0.971	0.851	0.871	0.904	0.886
Colombia	non-APO	0.943	0.854	0.862	0.921	0.883
Indonesia	APO	0.942	0.836	0.854	0.901	0.870
Mongolia	APO	0.923	0.832	0.855	0.897	0.866
Lao PDR	APO	0.966	0.789	0.825	0.938	0.856
Philippines	APO	0.921	0.804	0.821	0.880	0.842
Pakistan	APO	0.928	0.781	0.817	0.881	0.834
Fiji	APO	0.878	0.803	0.826	0.859	0.833
India	APO	0.897	0.791	0.816	0.840	0.825
Vietnam	APO	0.863	0.776	0.806	0.864	0.815
Cambodia	APO	0.879	0.723	0.751	0.943	0.797
Bangladesh	APO	0.915	0.735	0.768	0.822	0.790
Nepal	APO	0.854	0.712	0.743	0.787	0.758

TABLE 24

SUMMARY STATISTICS OF THE APO PRODUCTIVITY INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Variables	Mean	Standard deviation	Minimum	Maximum
Economic Input Index	0.939	0.029	0.854	0.992
Globalization Index	0.904	0.074	0.712	1.000
Market Regulation Index	0.910	0.061	0.743	1.000
Institutional Quality Index	0.937	0.043	0.787	1.000
APO Productivity Index	0.918	0.055	0.758	0.999

Table 23 presents the results of the API for APO and OECD countries. In 2017, the index ranged from 0.758 to 0.999. Luxembourg, Singapore, Norway, Switzerland, and the USA ranked the highest, followed by Germany and Australia. The ROC, Hong Kong, and Japan occupied upper-level positions, while Turkey and the ROK were in the middle. More than half of the APO countries exhibited lower levels of productivity. Consistent with this result, the Economic Input Index showed the highest productivity score with the smallest variation among the countries (see Table 24).

TABLE 25

ECONOMIC INPUT INDEX FOR BOTH APO AND OECD COUNTRIES.

Country/ economy	APO member	Capital Stock index	Human Capital Index	Energy Index	R&D Index	Economic Input Index
Luxembourg	non-APO	0.936	1.000	1.000	1.000	0.992
Switzerland	non-APO	0.939	0.987	1.000	0.987	0.985
Singapore	APO	0.923	0.991	0.991	0.991	0.982
USA	non-APO	1.000	0.973	0.973	0.973	0.976
Norway	non-APO	0.931	0.981	0.981	0.981	0.975
Sri Lanka	APO	0.954	0.891	1.000	1.000	0.971
Lao PDR	APO	0.974	0.986	0.917	1.000	0.966
Hong Kong	APO	0.909	0.968	0.953	0.993	0.964
Germany	non-APO	0.965	0.960	0.968	0.960	0.963
Denmark	non-APO	0.920	0.957	0.988	0.957	0.962
Turkey	APO	0.970	1.000	0.957	0.938	0.961
Netherlands	non-APO	0.938	0.970	0.962	0.958	0.959
Australia	non-APO	0.950	0.960	0.961	0.960	0.959
Austria	non-APO	0.917	0.970	0.965	0.957	0.957
ROC	APO	0.955	0.969	0.956	0.951	0.957
Chile	non-APO	0.951	0.926	0.933	1.000	0.956
Italy	non-APO	0.937	0.972	0.966	0.940	0.955
France	non-APO	0.951	0.969	0.954	0.943	0.953
Japan	APO	0.973	0.945	0.956	0.945	0.952
Spain	non-APO	0.939	0.981	0.951	0.939	0.952
Sweden	non-APO	0.927	0.959	0.954	0.952	0.951
Canada	non-APO	0.949	0.951	0.951	0.951	0.951
UK	non-APO	0.957	0.942	0.961	0.942	0.950
Iceland	non-APO	0.933	0.971	0.947	0.947	0.950
Latvia	non-APO	0.891	0.930	0.940	0.982	0.945
Finland	non-APO	0.930	0.948	0.948	0.944	0.944
New Zealand	non-APO	0.959	0.948	0.942	0.938	0.944
Belgium	non-APO	0.913	0.971	0.942	0.941	0.944
Israel	non-APO	0.949	0.936	0.953	0.936	0.943
Colombia	non-APO	0.950	0.916	0.932	0.968	0.943

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Country/ economy	APO member	Capital Stock index	Human Capital Index	Energy Index	R&D Index	Economic Input Index
Mexico	non-APO	0.966	0.931	0.928	0.954	0.942
Indonesia	APO	0.946	0.936	0.936	0.949	0.942
Lithuania	non-APO	0.947	0.925	0.949	0.941	0.941
ROK	APO	0.955	0.936	0.937	0.936	0.939
Poland	non-APO	0.980	0.917	0.930	0.928	0.933
Slovakia	non-APO	0.931	0.902	0.943	0.938	0.931
Pakistan	APO	1.000	1.000	0.903	0.879	0.928
Portugal	non-APO	0.886	0.986	0.927	0.900	0.925
Mongolia	APO	0.943	0.865	0.901	0.975	0.923
Czech Republic	non-APO	0.908	0.922	0.930	0.922	0.923
Slovenia	non-APO	0.898	0.913	0.943	0.913	0.922
Philippines	APO	0.959	0.857	0.934	0.933	0.921
Estonia	non-APO	0.930	0.906	0.941	0.906	0.921
Greece	non-APO	0.889	0.931	0.923	0.909	0.916
Bangladesh	APO	0.949	0.881	1.000	0.837	0.915
Malaysia	APO	0.952	0.932	0.908	0.894	0.914
IR Iran	APO	0.957	0.952	0.873	0.902	0.910
Hungary	non-APO	0.911	0.903	0.923	0.893	0.908
Thailand	APO	0.948	0.921	0.905	0.883	0.907
India	APO	0.986	0.930	0.897	0.842	0.897
Cambodia	APO	0.994	0.907	0.844	0.851	0.879
Fiji	APO	1.000	0.856	0.874	0.849	0.878
Vietnam	APO	0.973	0.825	0.864	0.842	0.863
Nepal	APO	0.976	0.925	0.818	0.798	0.854

TABLE 26

SUMMARY STATISTICS OF THE ECONOMIC INPUT INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Variables	Mean	Standard deviation	Minimum	Maximum
Capital Index	0.946	0.028	0.886	1.000
Human Capital Index	0.940	0.039	0.825	1.000
Energy Index	0.939	0.038	0.818	1.000
R&D Index	0.934	0.046	0.798	1.000
Economic Input Index	0.939	0.029	0.854	0.992

TABLE 27

GLOBALIZATION INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Country/economy	APO membership status	FDI Index	Openness Index	Globalization Index
Luxembourg	non-APO	1.000	1.000	1.000
Switzerland	non-APO	0.987	0.999	0.993
Singapore	APO	0.991	0.993	0.992
Norway	non-APO	0.981	0.999	0.990
USA	non-APO	0.973	1.000	0.986
Iceland	non-APO	1.000	0.962	0.981
Australia	non-APO	0.960	0.982	0.971
Germany	non-APO	0.960	0.975	0.967
Austria	non-APO	0.957	0.970	0.964
Denmark	non-APO	0.957	0.970	0.963
Netherlands	non-APO	0.958	0.967	0.963
Canada	non-APO	0.951	0.969	0.960
Sweden	non-APO	0.952	0.967	0.959
ROC	APO	0.951	0.965	0.958
Japan	APO	0.945	0.969	0.957
Finland	non-APO	0.944	0.961	0.952
France	non-APO	0.943	0.961	0.952
UK	non-APO	0.942	0.961	0.952
Italy	non-APO	0.940	0.959	0.949
New Zealand	non-APO	0.936	0.956	0.946
Hong Kong	APO	0.946	0.946	0.946
Israel	non-APO	0.936	0.955	0.945
Belgium	non-APO	0.941	0.949	0.945
ROK	APO	0.936	0.951	0.943
Spain	non-APO	0.934	0.952	0.943
Czech Republic	non-APO	0.922	0.931	0.927
Turkey	APO	0.910	0.929	0.920
Slovenia	non-APO	0.913	0.922	0.918
Poland	non-APO	0.908	0.921	0.915
Lithuania	non-APO	0.906	0.915	0.911

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Country/economy	APO membership status	FDI Index	Openness Index	Globalization Index
Estonia	non-APO	0.906	0.915	0.910
Portugal	non-APO	0.900	0.915	0.907
Greece	non-APO	0.898	0.915	0.906
Slovakia	non-APO	0.902	0.909	0.906
Latvia	non-APO	0.899	0.910	0.905
Chile	non-APO	0.894	0.912	0.903
Malaysia	APO	0.894	0.904	0.899
Hungary	non-APO	0.893	0.901	0.897
Mexico	non-APO	0.870	0.885	0.878
IR Iran	APO	0.863	0.881	0.872
Thailand	APO	0.861	0.872	0.867
Colombia	non-APO	0.843	0.864	0.854
Sri Lanka	APO	0.842	0.860	0.851
Indonesia	APO	0.826	0.846	0.836
Mongolia	APO	0.827	0.838	0.832
Philippines	APO	0.797	0.812	0.804
Fiji	APO	0.796	0.810	0.803
India	APO	0.781	0.800	0.791
Lao PDR	APO	0.783	0.796	0.789
Pakistan	APO	0.764	0.798	0.781
Vietnam	APO	0.773	0.779	0.776
Bangladesh	APO	0.726	0.744	0.735
Cambodia	APO	0.718	0.727	0.723
Nepal	APO	0.705	0.720	0.712

TABLE 28

SUMMARY STATISTICS OF THE ECONOMIC INPUT INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Variables	Mean	Standard deviation	Minimum	Maximum
FDI Index	0.897	0.075	0.705	1.000
Openness Index	0.911	0.073	0.720	1.000
Globalization Index	0.904	0.074	0.712	1.000

TABLE 29

MARKET REGULATION INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Country/economy	APO membership status	Labor Freedom Index	Legal Quality Index	Market Regulation Index
Luxembourg	non-APO	1.000	1.000	1.000
Singapore	APO	0.991	0.991	0.991
Switzerland	non-APO	0.987	0.987	0.987
Norway	non-APO	0.981	0.981	0.981
USA	non-APO	0.973	0.974	0.973
Germany	non-APO	0.966	0.960	0.963
Austria	non-APO	0.957	0.964	0.960
Australia	non-APO	0.960	0.960	0.960
Netherlands	non-APO	0.958	0.958	0.958
Denmark	non-APO	0.957	0.958	0.958
ROC	APO	0.951	0.960	0.956
Italy	non-APO	0.940	0.969	0.954
Sweden	non-APO	0.952	0.952	0.952
Canada	non-APO	0.951	0.951	0.951
Iceland	non-APO	0.947	0.954	0.951
France	non-APO	0.943	0.958	0.950
Japan	APO	0.945	0.953	0.949
Belgium	non-APO	0.941	0.952	0.947
Hong Kong	APO	0.946	0.946	0.946
Spain	non-APO	0.934	0.955	0.945
Finland	non-APO	0.944	0.944	0.944
ROK	APO	0.936	0.951	0.944
UK	non-APO	0.942	0.942	0.942
Israel	non-APO	0.936	0.946	0.941
Turkey	APO	0.910	0.964	0.937
New Zealand	non-APO	0.936	0.936	0.936
IR Iran	APO	0.863	1.000	0.931
Slovenia	non-APO	0.913	0.946	0.930
Czech Republic	non-APO	0.922	0.934	0.928
Greece	non-APO	0.898	0.943	0.920

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Country/economy	APO membership status	Labor Freedom Index	Legal Quality Index	Market Regulation Index
Poland	non-APO	0.908	0.930	0.919
Slovakia	non-APO	0.902	0.926	0.914
Lithuania	non-APO	0.906	0.920	0.913
Portugal	non-APO	0.902	0.921	0.912
Malaysia	APO	0.894	0.922	0.908
Hungary	non-APO	0.893	0.923	0.908
Estonia	non-APO	0.906	0.907	0.906
Latvia	non-APO	0.899	0.913	0.906
Chile	non-APO	0.894	0.903	0.898
Mexico	non-APO	0.870	0.915	0.893
Thailand	APO	0.861	0.908	0.885
Sri Lanka	APO	0.842	0.900	0.871
Colombia	non-APO	0.843	0.881	0.862
Mongolia	APO	0.827	0.883	0.855
Indonesia	APO	0.826	0.881	0.854
Fiji	APO	0.796	0.855	0.826
Lao PDR	APO	0.783	0.868	0.825
Philippines	APO	0.797	0.845	0.821
Pakistan	APO	0.795	0.840	0.817
India	APO	0.792	0.840	0.816
Vietnam	APO	0.773	0.838	0.806
Bangladesh	APO	0.726	0.810	0.768
Cambodia	APO	0.718	0.784	0.751
Nepal	APO	0.705	0.781	0.743

TABLE 30

SUMMARY STATISTICS OF THE MARKET REGULATION INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Variables	Mean	Standard deviation	Minimum	Maximum
Labor Freedom Index	0.897	0.073	0.705	1.000
Regulatory Quality Index	0.924	0.052	0.781	1.000
Market Regulation Index	0.910	0.061	0.743	1.000

TABLE 31

INSTITUTIONAL QUALITY INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Country/ economy	APO membership status	Corruption Index	Political Stability Index	Rule of Law Index	Political Rights Index	Institutional Quality Index
Luxembourg	non-APO	1.000	1.000	1.000	1.000	1.000
Singapore	APO	0.991	0.991	0.991	1.000	0.992
Switzerland	non-APO	0.987	0.988	0.987	0.987	0.987
IR Iran	APO	0.986	0.925	1.000	1.000	0.987
Italy	non-APO	1.000	0.964	1.000	0.940	0.986
Norway	non-APO	0.981	0.985	0.981	0.981	0.982
USA	non-APO	0.983	0.997	0.976	0.978	0.981
ROC	APO	0.983	0.961	0.973	0.951	0.972
Mexico	non-APO	1.000	0.923	0.996	0.877	0.970
Israel	non-APO	0.968	1.000	0.961	0.936	0.964
Germany	non-APO	0.961	0.977	0.964	0.960	0.964
ROK	APO	0.986	0.959	0.956	0.940	0.964
Australia	non-APO	0.967	0.969	0.961	0.960	0.964
Spain	non-APO	0.978	0.959	0.961	0.934	0.962
Turkey	APO	0.999	0.946	0.952	0.918	0.962
Austria	non-APO	0.968	0.963	0.957	0.957	0.961
Netherlands	non-APO	0.958	0.967	0.958	0.958	0.959
Denmark	non-APO	0.957	0.967	0.957	0.957	0.958
France	non-APO	0.962	0.968	0.953	0.943	0.956
Japan	APO	0.959	0.950	0.951	0.945	0.953
Sweden	non-APO	0.952	0.959	0.952	0.952	0.953
Greece	non-APO	0.961	0.931	0.971	0.903	0.952
Belgium	non-APO	0.951	0.961	0.954	0.941	0.952
Iceland	non-APO	0.955	0.947	0.952	0.947	0.951
Canada	non-APO	0.951	0.955	0.951	0.951	0.951
Hong Kong	APO	0.953	0.957	0.946	0.955	0.951
Thailand	APO	0.956	0.915	0.934	0.999	0.949
UK	non-APO	0.942	0.966	0.944	0.942	0.946
Czech Republic	non-APO	0.965	0.929	0.944	0.922	0.946
Finland	non-APO	0.944	0.949	0.944	0.944	0.945
Cambodia	APO	1.000	0.741	1.000	0.833	0.943
Poland	non-APO	0.944	0.926	0.958	0.908	0.942
Malaysia	APO	0.960	0.922	0.947	0.903	0.941
Slovakia	non-APO	0.960	0.911	0.947	0.902	0.940
Lao PDR	APO	0.900	0.801	0.989	1.000	0.938
Hungary	non-APO	0.964	0.904	0.940	0.900	0.938
New Zealand	non-APO	0.936	0.936	0.936	0.936	0.936
Slovenia	non-APO	0.947	0.923	0.939	0.913	0.936

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Country/ economy	APO membership status	Corruption Index	Political Stability Index	Rule of Law Index	Political Rights Index	Institutional Quality Index
Lithuania	non-APO	0.944	0.918	0.932	0.906	0.930
Latvia	non-APO	0.939	0.918	0.928	0.904	0.927
Colombia	non-APO	0.935	0.897	0.945	0.849	0.921
Estonia	non-APO	0.922	0.920	0.921	0.906	0.919
Portugal	non-APO	0.930	0.904	0.921	0.900	0.919
Chile	non-APO	0.917	0.914	0.919	0.894	0.914
Sri Lanka	APO	0.931	0.873	0.912	0.849	0.904
Indonesia	APO	0.916	0.869	0.925	0.830	0.901
Mongolia	APO	0.921	0.837	0.922	0.827	0.897
Pakistan	APO	0.866	1.000	0.900	0.772	0.881
Philippines	APO	0.895	0.874	0.898	0.804	0.880
Vietnam	APO	0.864	0.793	0.837	0.988	0.864
Fiji	APO	0.874	0.809	0.884	0.803	0.859
India	APO	0.857	0.831	0.850	0.785	0.840
Bangladesh	APO	0.850	0.801	0.840	0.733	0.822
Nepal	APO	0.802	0.747	0.816	0.710	0.787

TABLE 32

SUMMARY STATISTICS OF THE INSTITUTIONAL QUALITY INDEX FOR APO COUNTRIES AND OECD COUNTRIES.

Variables	Mean	Standard deviation	Minimum	Maximum
Corruption Index	0.946	0.042	0.802	1.000
Political Stability Index	0.922	0.063	0.741	1.000
Political Right Index	0.943	0.041	0.816	1.000
Rule of Law Index	0.914	0.068	0.710	1.000
Institutional Quality Index	0.937	0.043	0.787	1.000

Table 25 reports the Economic Input Index for both APO and OECD groups of countries. In 2017, the index ranged from 0.854 to 0.992 (see Table 26). This indicates that the differences in the productivity-enhancing capacities of the economic input variables were not as large as the gaps in the overall productivity index between APO countries and OECD countries. Tables 27, 29, and 31 present the results for the Globalization, Market Regulation, and Institutional Quality indices. The results show that the Globalization Index ranged from 0.712 to 1.000 (see Table 28); the Market Regulation Index ranged from 0.743 to 1.000 (see Table 30); and the Institutional Quality Index ranged from 0.787 to 1.000 (see Table 32). These results indicate that the gaps in the overall productivity scores between APO and OECD countries came from the differences in the capacities associated with the globalization and market regulation variables as well as the institutional quality variable, and not from the productivity differences in the economic input variables. It is noted that several APO member countries such as Sri Lanka and Lao PDR, as well as Singapore and Hong Kong, ranked among the highest on the Economic Input Index. This result differs from those of the other indices.

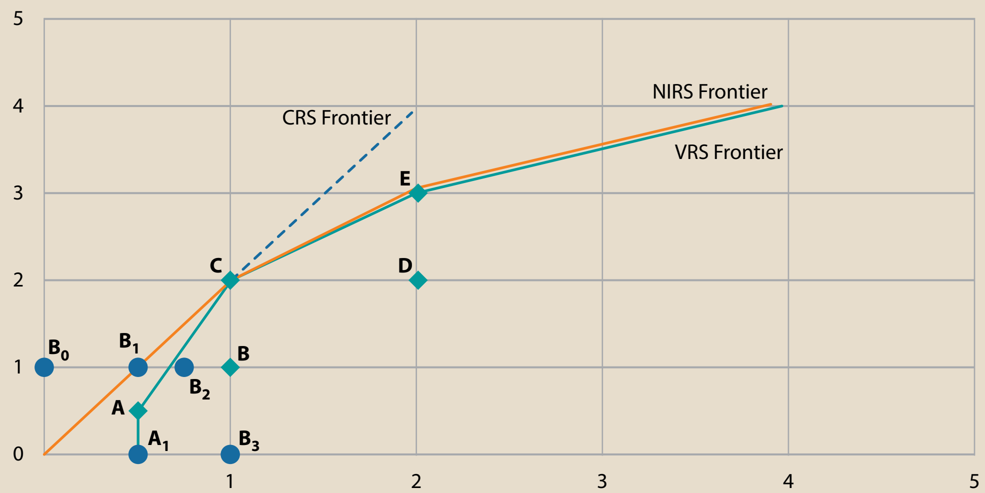
CONSTRUCTION OF THE APO PRODUCTIVITY INDEX: A TWO-STAGE APPROACH

Figure 7 shows that constructing the API takes two stages. First, we measure the individual performance indices for the 12 variables using data envelopment analysis (DEA). DEA, a non-parametric approach, uses linear programming methods to construct a linear envelope bounding the data, relative to which efficiencies can be calculated. If x_i and y_i are inputs and outputs, and u and v are scalar values chosen for each production unit, respectively, such that the efficiencies of each unit are maximized but are not greater than 1, then:

$$\begin{gathered} maximize_{u,v}(u' y_i) \\ \text{Subject to } \mathrm{v}' x_i = 1, \\ u' y_i - v' x_i \leq 0, j = 1, \ldots, N \text{ and } u, v \geq 0 \end{gathered} \tag{1}$$

FIGURE 7

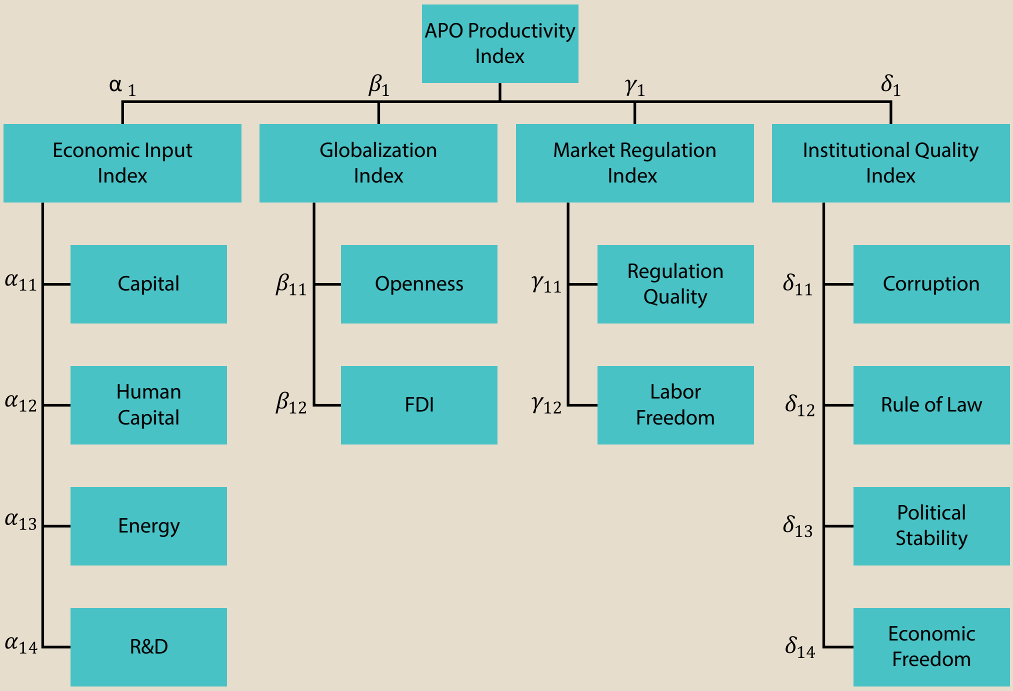
PRODUCTION FRONTIER.



The x-axis and the y-axis in the figure represent input level and output level, respectively. The assumptions of returns to scale affect the productivity performance of individual countries. The constant variable returns to scale (CRTS) frontier represents the most efficient output level, given the input levels under the assumption of CRTS. The non-increasing returns to scale (NIRS) frontier is the frontier curve under the assumption of NIRS. The variable returns to scale (VRTS) frontier is the frontier curve under the assumption of VRTS. If technology represents CRTS, countries C and B1 are efficient because they are on the production frontier, but A and E are not efficient. On the contrary, if it represents VRTS, then countries A and E are on the efficient path. Assuming an input level of 1, the relative productivity of country B is measured by BB_3/CB_3. In our case, for the measurement of the API, it is assumed that technology represents VRTS. Then, we calculate subindices for the Economic Input, Globalization, Market Regulation, and Institutional Quality indices. Let EII denote the aggregate index for the Economic Input Index, GI denote Globalization Index, IQI denote the index for the institutional quality variables, and MRI denote the aggregate index for the market regulation variables. Then, each subindex is a weighted average of the individual indices in each pillar. The parameters, α_{1i}, β_{1i}, γ_{1i}, and δ_{1i} are weights for each sub index.

FIGURE 8

CONSTRUCTION OF THE APO PRODUCTIVITY INDEX: A TWO-STAGE APPROACH.



The weights are calculated by factor analysis. For the extraction of factor loadings, the principal components factor approach is applied. Then, the weights for each index are calculated as the normalized squared factor loadings, and each subindex can be represented as follows:

$$\mathrm{EII} = \sum_{i=1}^{4} \alpha_{1i} EV_i \qquad (2)$$

$$\mathrm{GI} = \sum_{i=1}^{2} \beta_{1i} GV_i \qquad (3)$$

$$\mathrm{MRI} = \sum_{i=1}^{2} \gamma_{1i} MRV_i \qquad (4)$$

$$\mathrm{IQI} = \sum_{i=1}^{4} \delta_{1i} IQV_i \qquad (5)$$

The API can be constructed as the weighted average of subindices and the weights are also calculated by the factor analysis [50].

$$API = \alpha_1 EII + \beta_1 GI + \gamma_1 MRI + \delta_1 IQI \qquad (6)$$

Conclusion and Policy Recommendations

Through the API, this report identifies the factors associated with the productivity-enhancing capacity of APO countries to suggest policies that can help them sustain their productivity growth in future. As mentioned in the introduction, global productivity had been increasing before the occurrence of the global financial crisis, reflecting a pick-up of productivity growth in emerging and developing countries. However, the productivity growth acceleration in emerging markets and developing countries ended around the Great Recession (2007–2009), and the recent decline in productivity growth has reignited the debate on the productivity paradox. On an average, mature economies have experienced a higher multifactor productivity (MFP) growth than emerging markets and developing countries. Global productivity growth is expected to slow down and become more dependent on MFP growth. Therefore, it is important to analyze the determinants of MFP not only to achieve, but also to sustain, a high level of productivity growth.

The APO Productivity Index, which summarizes the productivity-enhancing capacity of countries, is composed of specific subindices. We designed the structure of the productivity measure and estimated the countries' ranking in terms of the productivity-enhancing capacity. We calculated productivity scores for 12 variables, categorized into four types: Economic Input, Globalization, Market Regulation, and Institutional Quality. Economic input variables refer to physical capital, human capital, energy use, and R&D expenditure. Globalization variables refer to trade openness and FDI inflow. Market regulation variables refer to the degree of labor freedom and regulatory quality. Lastly, institutional quality variables refer to indicators of corruption, political stability, political rights, and the rule of law, which we used to construct the index.

We estimated the productivity frontier for APO member countries and for both APO and OECD countries and constructed the productivity index for each case. We found a large variation in the productivity scores among APO countries. Leading countries, such as Singapore and Japan, consistently recorded the highest index scores and also performed very well in most of the subindices. A notable feature of the productivity scores of APO member countries was the small variation of the economic input variables (which include capital stock, human capital, energy, and R&D) as compared with differences in the other variables of Globalization, Market Regulation, and Institutional Quality. This suggests that the productivity gap among APO member countries largely stems from differences in Globalization, Market Regulation, and Institutional Quality. Although capital deepening was mainly responsible for the improvement of labor productivity over time, the roles of Globalization, Market Regulation, and Institutional Quality are becoming more relevant in explaining cross-country productivity gaps among APO countries.

Thus, we can conclude that whether countries that are lagging the leading APO countries can catch up in productivity will depend on changes in policies toward international trade and FDI, as well as improvements in institutional quality. We also found that among the economic input variables, the productivity gap among APO member countries was much bigger in R&D and human capital than in physical capital. This suggests that the roles of R&D and human capital should be emphasized in the implementation of productivity policies.

We observed similar policy implications when the productivity scores of APO countries were compared with those of OECD countries. We found that the overall productivity scores of APO member countries were much lower than those of OECD countries. However, the performances of APO member countries were much better in the Economic Input Index than in the Globalization, Market Regulation, and Institutional Quality indices. This implies that the productivity differences between APO and OECD countries mainly resulted from performance gaps in the areas of Globalization, Market Regulation, and Institutional Quality. Within the Economic Input Index, variations in productivity scores were larger in the R&D and Human Capital indices than in the Physical Capital index. Once again, it should be emphasized that narrowing the gaps in productivity between APO and OECD countries requires the augmentation of market institutions and the improvement of external relationships through trade and FDI inflows, besides accumulating traditional input variables and extending the R&D and human capital capabilities.

The OECD [53] predicts that over the next few decades, global productivity growth will slow down in most countries and productivity growth will increasingly depend on improvements in MFP. There are various determinants of MFP growth such as R&D, human capital, globalization, and institutional quality, which have been included in this report. In our analysis, facilitating technology diffusion among APO member countries through R&D is crucial for reducing the productivity gap among member countries. Productivity growth via diffusion of technology can be facilitated through trade openness and FDI inflows, so lifting the barriers to trade and FDI inflows will benefit APO member countries.

The accumulation of human capital through educational and training programs is highly important for a sustainable productivity growth. An increase in the number of highly educated workers has significantly boosted labor productivity in many countries over the past few decades. However, with the aging of populations, it is expected that the rate of increase in human capital accumulation will slow down. In particular, the growth of knowledge base in future will require an increasingly skilled labor force. Skill requirements will increase as a consequence of skill-biased technological changes. High-quality primary and secondary education will become prerequisites for raising skill levels. At the same time, the aging of workers will increase the need for retraining, as the education and skills acquired earlier become obsolete.

Previous literature indicates that the MFP dispersion of countries is affected not only by trade openness and innovation but also by market regulation and institutional quality. Rigid regulations reduce flexibility of resource allocation in markets and decrease productivity. Strengthening labor mobility and minimizing labor market risk by increasing labor freedom can increase productivity growth through a productivity-enhancing reallocation of workers.

Creating a market environment where productive businesses can thrive through sound market regulations will increase productivity by facilitating a wider penetration of available technologies. Institutions shape the incentives for both factor accumulation and innovation and thus, improve the overall allocation efficiency of the factors of production. A stronger rule of law and better law enforcement amplify the positive effect of R&D spending. Corruption affects MFP via a misallocation of public and private resources. Corruption also disincentivizes investments in human and physical capital, especially the ones with high risk and high return profiles, by increasing overall uncertainty and reducing contract enforcement. Political stability affects the climate for foreign investors. In countries with lower institutional quality, the return to firms’ innovation is lower, thereby discouraging investment in research and adoption of new products. To catch up with the leading countries in terms of productivity, other countries must reduce these institutional gaps.

ANNEXURE A

CHARACTERIZATION OF PRODUCTIVITY GROWTH

Figure 1 shows labor productivity growth estimates of different groups of countries in the world over the last three decades. The figure suggests that the global labor productivity increased, with some fluctuations, until the 2008 Global Financial Crisis (GFC). It also shows that there was a pickup in productivity growth of emerging and developing countries, which more than offset the slowdown in mature economies. Mature economies include the 28 members of the EU; Iceland, Norway, Switzerland, Australia, Canada, Hong Kong, Israel, New Zealand, Singapore, the ROK, the ROC, Japan, and the USA. On the other hand, emerging markets and developing economies include Latin America, Middle East and North Africa, sub-Saharan Africa, Russia, Central Asia, and Southeast Europe, as well as PR China, India, and other developing Asian countries. Other developing Asian countries include Bangladesh, Cambodia, Indonesia, Malaysia, Myanmar, Pakistan, the Philippines, Sri Lanka, Thailand, and Vietnam.

Besides minor fluctuations of around 2%, labor productivity growth in mature economies started to fall after the year 2000. The fall accelerated during 2007–09, followed by a recovery of about 3% during 2010, another sharp decline in 2011, and a leveling out at around 1% during 2011–19. The productivity growth acceleration in emerging markets and developing countries ended around the Great Recession period (2007–09), when it sharply fell from around 6% to almost 1%. A recovery in 2010 brought it back to about 6%, but by 2012 there was another sharp decline to 3% and further declines (with some fluctuations) to about 2% by 2019. The recent decline in productivity growth has revived a debate on the productivity paradox [51].

Figure 2 shows the regional distribution of labor productivity growth. Countries are selected from each regional area. The figure shows that there is a large variation in labor productivity among emerging markets and developing countries and the average level in Figure 2 tends to mask the gaps in labor productivity growth among the countries. PR China and India led the growth among emerging markets and developing economies while other developing economies in the Middle East, North Africa and sub-Saharan Africa represented much lower examples of growth than mature economies such as the USA and Japan.

Labor productivity growth can be decomposed into two components: the growth of capital per worker (capital deepening), and the growth of MFP. Let us assume that a production function takes the Cobb–Douglas form. Then, we can specify the following function:

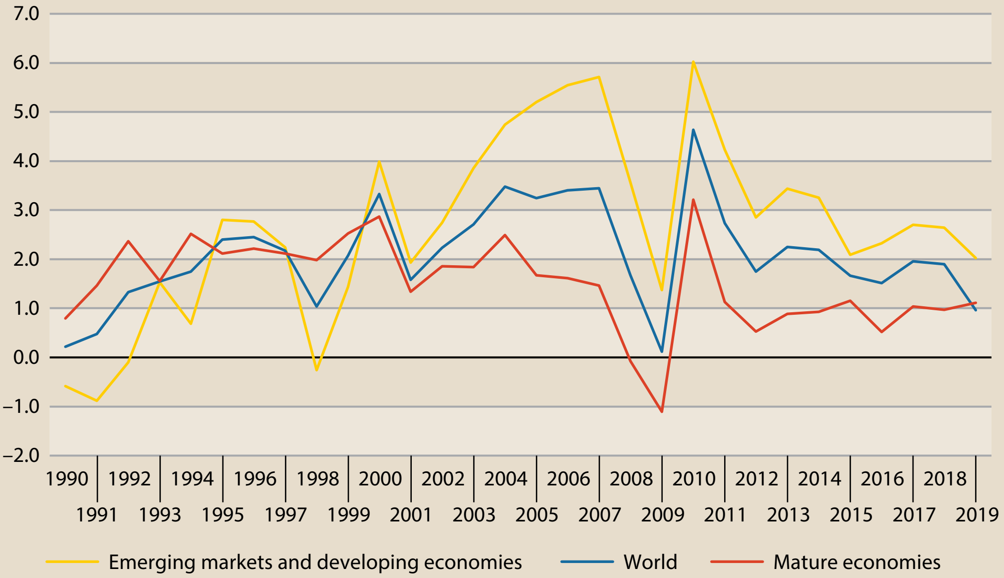
$$Y_t = A_t {K_t}^{\alpha} {L_t}^{1-\alpha} \tag{1}$$

where, Y_t is output (such as GDP); A_t is MFP; K_t is capital; and L_t is labor involved in producing Y_t. The coefficient α represents the capital income share in the production process. In logarithm form, the equation can be specified as follows:

$$y_{t=} a_t + \alpha k_t + (1-\alpha) l_t \tag{2}$$

FIGURE 1

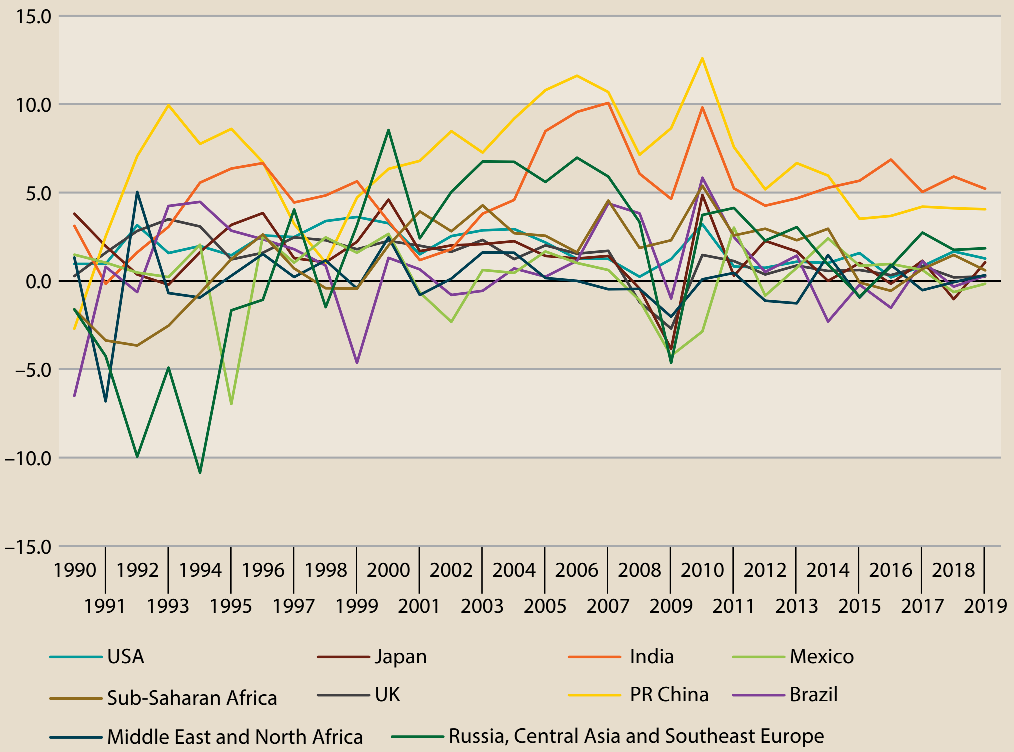
LABOR PRODUCTIVITY GROWTH RATES.



Source: Author's calculation based on Conference Board [52] data.

FIGURE 2

REGIONAL DISTRIBUTION OF LABOR PRODUCTIVITY GROWTH.



Source: Author's calculation based on Conference Board [52] data.

where $y_t = \log Y_t$, $a_t = \log A_t$, $k_t = \log K_t$ and $l_t = \log L_t$.

Then, the growth rate of output can be written as follows:

$$\Delta y_t = a_t + \alpha \Delta k_t + (1 - \alpha)\Delta l_t \tag{3}$$

Let $G_t = \frac{Y_t}{L_t}$ be the measure of labor productivity, then the labor productivity growth will be $\Delta g_t = \Delta y_t - \Delta l_t$. Rearranging the relationship, the labor productivity growth will be:

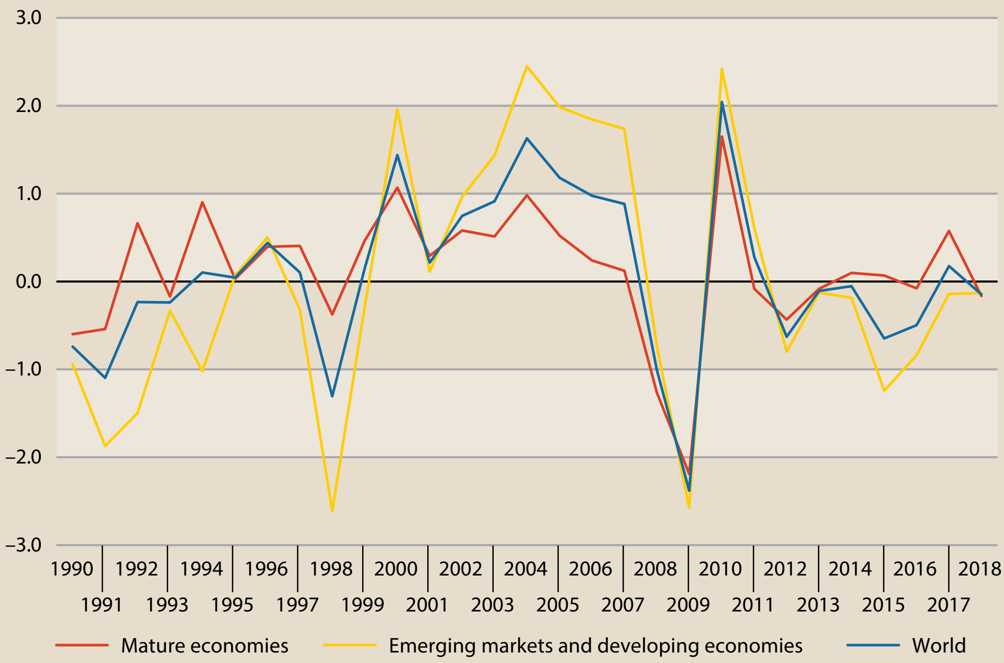
$$\Delta g_t = \alpha(\Delta k_t - \Delta l_t) + \Delta a_t \tag{4}$$

The first term in the right-hand side is the growth in capital per worker (capital deepening) weighted by its share in the production process; and the second term is the growth in MFP, which is sometimes referred to as the Solow residual.

Figure 3 shows the estimates of MFP for mature economies; emerging markets and developing economies; and the world as a whole. One can see that, outside of several fluctuations, mature economies on an average experienced higher MFPs than the average for emerging markets and developing economies before 2000. However, the latter surpassed the former in MFP growth rate until the beginning of the global financial recession in 2008 when they roughly equaled and remained so till 2014. Thereafter, the difference reversed again and persisted through 2017. Thus, after the financial crisis, the MFP growth in emerging markets and developing economies did not regain its upward trend and remained below that of mature economies through 2017. In 2018, the growths roughly equaled and were nearly zero for all the groups.

FIGURE 3

MULTIFACTOR PRODUCTIVITY GROWTH RATES.



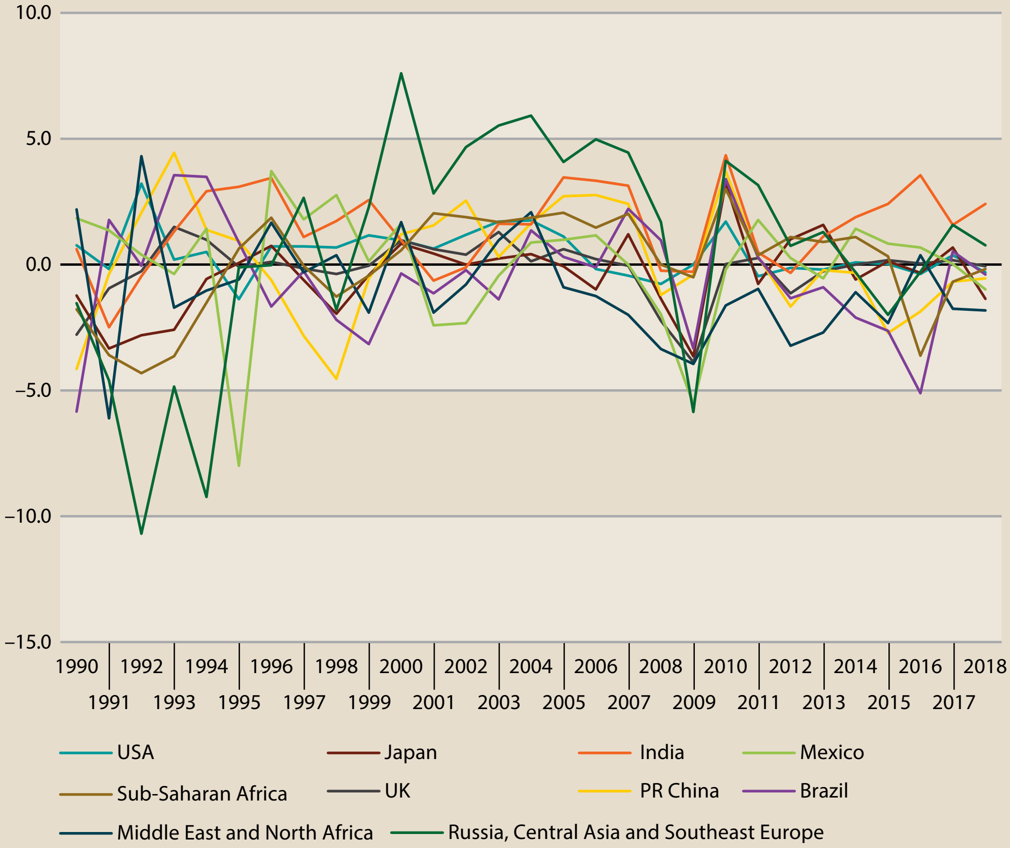
Source: Author's calculation based on Conference Board [52] data.

Figure 4 indicates that there is a large variation in MFP growth across countries with different levels of development. India presented the highest average level of MFP growth of 1.8% on average during 1990–2018 but many countries recorded a negative average growth as well. These included Japan, the UK, Brazil, and Middle East and North African countries.

Capital deepening was estimated as the difference between labor productivity growth and MFP growth, as seen in Figure 5. The figure shows that since the early 1990s, capital deepening has remained relatively higher in emerging markets and developing economies except for a few select years. In particular, after 2000, increased capital deepening has been an engine of labor productivity growth and despite the recent decline in this trend, capital deepening in emerging markets and developing economies has remained at a much higher level than in mature economies.

FIGURE 4

REGIONAL DISTRIBUTION OF MULTIFACTOR PRODUCTIVITY GROWTH.

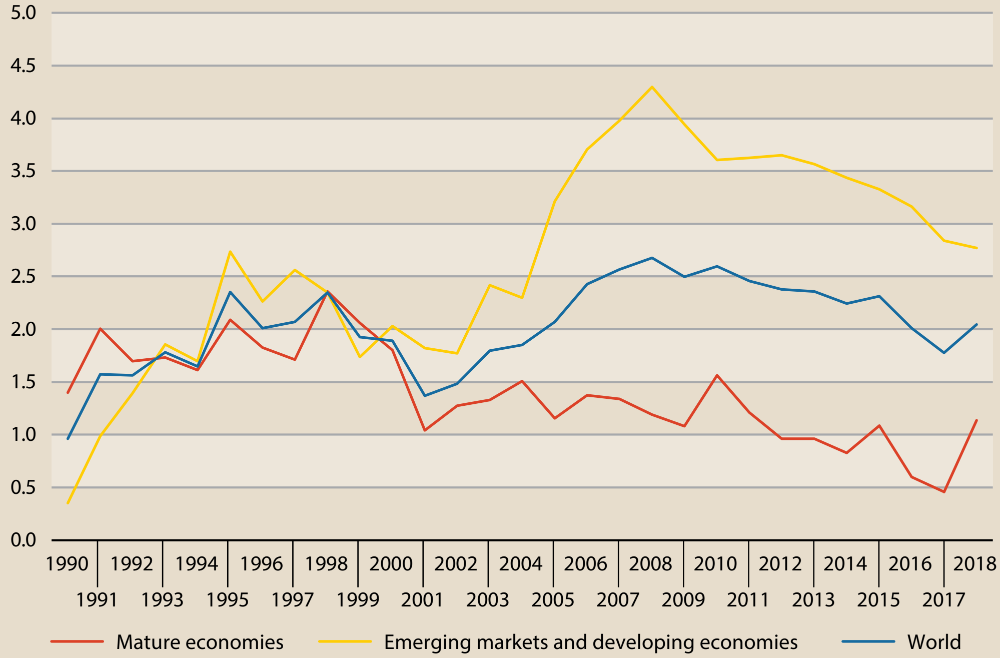


Source: Author's calculation based on Conference Board [52] data.

The OECD analysis indicates evidence of conditional convergence in labor productivity growth during the 1950–95 period [53]. This suggests that productivity grew faster in economies that followed the USA, which had the highest aggregate productivity level. However, the convergence process halted after 1995. This may suggest that as economies converge to the frontier, the ability to capitalize on innovation becomes more important in the most advanced countries, and technological leaders increase their productivity gap with laggards (see Figure 6) due to the potential of digital technologies to unleash winner-takes-all dynamics [54].

FIGURE 5

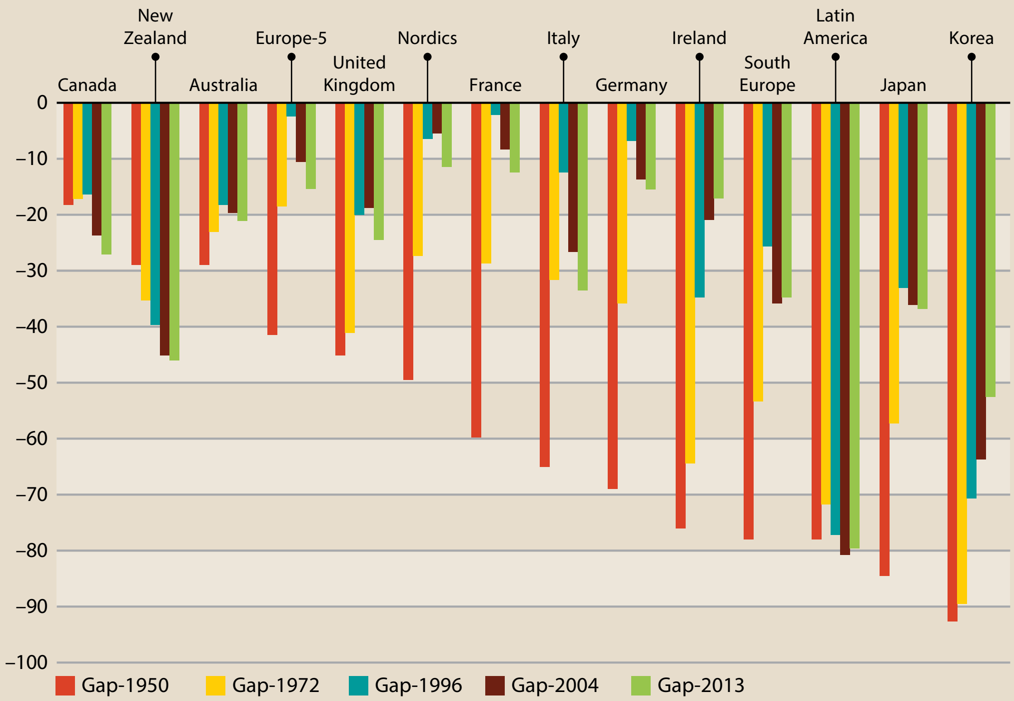
TREND OF CAPITAL DEEPENING.



Source: Author's calculation based on Conference Board [52] data.

FIGURE 6

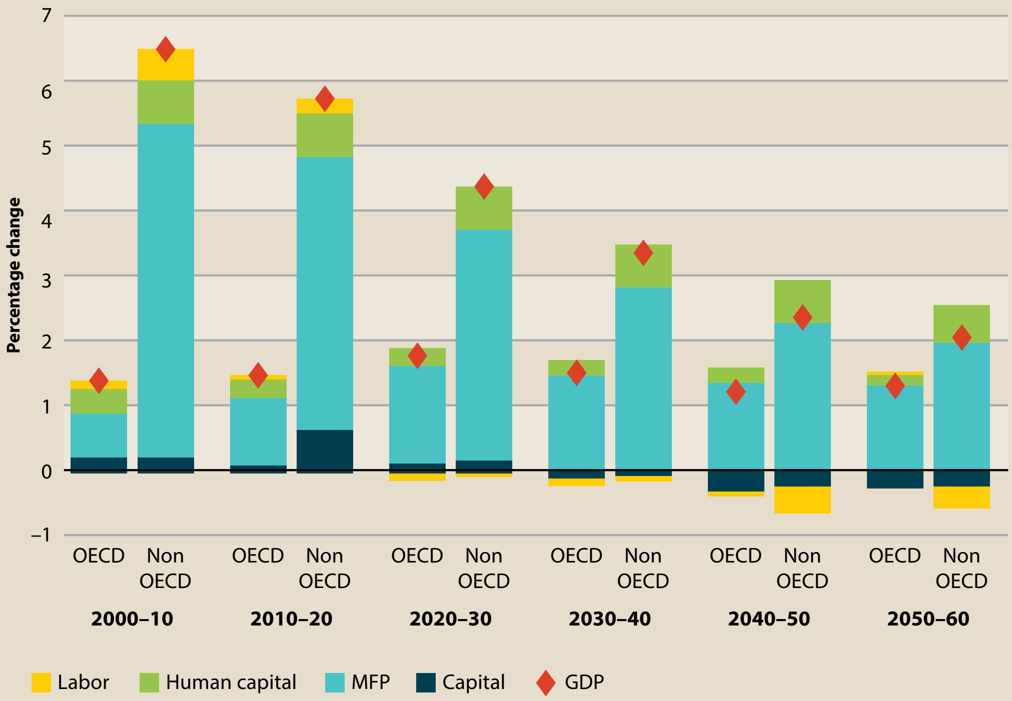
PERCENT GAP IN GDP PER HOUR WORKED WITH THE USA.



Source: OECD [55].

FIGURE 7

CONTRIBUTION TO GDP PER CAPITA: 2000–60 (ANNUAL AVERAGE).



Source: OECD [53].

The OECD projects that through 2060, global productivity growth will slow down (see Figure 7) and become more dependent on MFP growth [53]. In turn, MFP will be affected by investments in knowledge-based capital as well as pro-competition reforms and continued dissemination of new innovations made at the technological frontier. Therefore, it is important to analyze the determinants of MFP to not only attain, but also to sustain, a high level of productivity growth.

ANNEXURE B

IDENTIFICATION OF PRODUCTIVITY-ENHANCING FACTORS

Introduction

As a measure of production efficiency, productivity commonly refers to output per unit of productive input. The OECD defines productivity as the "ratio of a volume measure of output to a volume measure of input use" [56]; while the APO defines it as "gross domestic product (GDP) per unit of combined inputs" [57]. Productivity growth is closely related to real income and welfare and is a key indicator for analyzing economic growth.

Measuring productivity is important for several reasons. First, GDP per capita, which is a well-known measure of well-being, does not convey enough information regarding cross-country differences in productivity. Second, productivity is a key yardstick of economic performance and the key to sustainable economic growth. Third, productivity measurement is more complex. Industry sectors such as education, health, and government services have become major contributors with increasing shares to the national output, but the measurement of their outputs is particularly difficult. However, while the volumes of sectors such as agriculture, manufacturing, transport, and communication appear to be relatively easy to measure, their shares of national output have decreased.

For example, much of the economic growth has been driven by accumulation of knowledge, increasing the number of goods, and transforming the nature of others, thereby compounding measurement problems of productivity. "We are moving into a phase of development where small venture capital firms based in clusters for biotech and IT seem to be important sources for the creation of knowledge, and we do not fully understand these processes" [58]. Therefore, constructing accurate price and quantity indices of IT products that are internationally comparable is crucial to assessing the role of IT in economic growth.

This study has the following objectives: First, three different values of total factor productivity (TFP) are estimated and then compared with those estimated by the OECD, the APO, and the Penn World Table (PWT 9.1). Second, using dynamic panel system generalized method of moments (GMM) estimation, the determinants of TFP growth rate are investigated. Following Romer's [2] and Jones's [59] endogenous growth theories, the technological growth rate is assumed to be endogenous. The institutional determinants of technological growth are tested as well [25, 60, 61].

The explanatory variables are classified into four categories: traditional indicators, globalization, market regulations, and institutional quality. Traditional indicators include gross domestic expenditure on R&D (GERD) as a percentage of GDP; secondary school enrollment rate as a proxy for human capital; and energy use as a proxy for infrastructure. Globalization indicators include trade and FDI variables as a percentage of GDP. Market regulation indicators consist of the degree of regulation quality and the Labor Freedom Index. Lastly, institutional quality includes the Economic Freedom Index, Corruption Perception Index, Rule of Law Index, Political Rights Index, and a trust indicator.

The remainder of this study is structured as follows: The next section reviews previous studies to define productivity. The section after that explains the methodology and the estimation results for the determinants of TFP growth. The following section discusses the empirical model specification and provides the data sources and descriptive statistics for the variables. The last section presents and discusses the empirical results.

Definitions and Productivity Measures

Labor Productivity and Total Factor Productivity

Productivity can largely be classified into two types: single-factor productivity (SFP) and multifactor productivity (MFP). SFP, which is defined as labor productivity, is the ratio of the output to a single input; while MFP can be a single or aggregated output per aggregated inputs of all factors of production. Measuring MFP involves more measurement parameters than measuring labor productivity, e.g., weighting inputs/outputs; taking into account quality changes in inputs/outputs; treating investments in intangible assets; and so on.

Labor productivity (LP) is measured as output per unit of labor input. Labor is one of the most important factors of production, and it seems to be relatively easy to measure. However, there are various issues to consider when measuring labor productivity. Typically, either work hours or the number of employees is used as labor input. However, these variables do not include multiple-job holders, unpaid workers, or the quality of labor. Yet, work hours are recognized as the most appropriate measure of labor input. Additionally, we consider whether the gross or net approach will be used in measuring the output as follows:

$$\textit{Labor productivity}\ (LP) = \frac{Q}{L}\text{; where Q is output, and L is labor}$$

In general, LP depends on the investments in capital, technology, and human capital. MFP, as another measure of productivity, is also known as total factor productivity (TFP). This is derived by isolating the contribution of production inputs such as physical capital, human capital, and labor from the total amount of outputs (goods and services). By computing the contributions of labor and capital to output, MFP measures the residual growth that cannot be explained by the rate of change in the services of labor, capital, and intermediate outputs. The estimated residual is often interpreted as the technical and organizational innovation.

$$\textit{Multifactor productivity}\ (MFP) = \frac{Q}{F(L,K)}\text{ , where K is capital}$$

The modern approach to MFP measurement is based on Solow's growth model and its growth accounting technique. As one of the MFP measures, growth accounting is based on neoclassical assumptions: factors of productions are paid their marginal products (r $= MP_k$; w $= MP_L$) and are entirely consumed (Y = wL + rK) in a competitive market system. However, since original neoclassical assumptions do not hold in reality, some studies have improved the model by assuming various possibilities such as non-constant returns to scale, markups, refinements, and so on. Toward the end of the 1980s, as endogenous growth models arose, many studies were conducted on the magnitude of impact of capital accumulation, including clarification of the role of human capital and understanding of the processes of endogenous technological changes [58].

Estimating productivity starts with defining outputs and inputs. The most recognized and widely used productivity measures by the OECD and the APO provide thorough insights into the productivity concept and comparable measurements. Capital inputs are estimated by cumulating and depreciating past investments such as machinery and equipment because capital stock data are not available.

OECD's Total Factor Productivity

The OECD productivity database provides a wide range of data, from GDP growth and capital services to labor productivity levels and MFP growth. The OECD classifies output measures into gross and value added and classifies input measures into labor, capital, and intermediate inputs [62]. When measuring labor productivity, GDP is measured as gross value added in market prices. An ideal measure of labor input is the total number of hours worked, differentiated by the type of labor input, and this includes not only employees' hours but also the hours of self-employed and unpaid workers. The OECD uses the OECD Annual National Accounts database for measures of labor input, while the household-based labor force surveys (LFS) and the firm-based employee surveys (ES) are used to construct the national accounts (NA). Typically, labor productivity measured by total work hours shows a faster increasing trend than other employment measures in country panel research [63].

Capital input is measured as the volume of capital services, which is the flow of productive services that capital delivers in production. According to the OECD Compendium of Productivity Indicators 2019, capital services are broken down into six or seven assets, depending on data availability. These can be IT equipment, communication equipment, other machinery and equipment, non-residential construction, transport equipment, software, and other intangibles, as well as three aggregates, i.e., total information and communication technology (ICT), total non-ICT, and total products of agriculture; metal products; and machinery.

The OECD assumes capital services to be in fixed proportion to capital stock ($S_t = \lambda K_t$). Capital services are estimated by using the rate of change in the 'productive capital stock' that takes into account the wear and tear, retirements, and other sources of reduction in the productive capacity of fixed capital assets [64]. The Törnqvist Index is used for calculating aggregate assets. Rental price, which is the price of capital services per asset, is imputed to user cost that is measured as

$$u_t = (r_t + \delta_t - i_t)p_t,$$

where r_t is the required rate or return; δ_t is the rate of depreciation; and i_t is the rate of asset price change.

The OECD assumes the country-specific ex-ante real rate of return, r^*, to be constant for the whole period while defining $r_t = (1 + r^*)(1 + \rho_t) - 1$, where ρ_t is the expected overall inflation rate, determined by a five-year centered moving average of the rate of change of the consumer price index (CPI).

After aggregating the volume change of weighted capital and labor inputs using the Törnqvist Index, the TFP growth is measured as follows:

$$\ln\left(\frac{TFP^t}{TFP^{t-1}}\right) = \ln\left(\frac{Q^t}{Q^{t-1}}\right) - \ln\left(\frac{X^t}{X^{t-1}}\right),$$

where Q is the GDP at constant market prices, and X is the weighted average of the rate of change of labor and capital inputs, with the respective cost shares as weights.

Productivity is usually measured as the ratio of a quantity index of output to a quantity index of inputs. The Fisher Index and the Törnqvist Index are the two most commonly used indices. Labor and capital productivity are SFP measures, while capital–labor and capital–labor–energy–materials–services (KLEMS) are MFP measures. They can be based on either value added or gross output. Labor productivity based on a value-added approach is the most frequently computed productivity measure.

Other than input and output measures, an international comparison of productivity requires conversion factors or purchasing power parity (PPP) to translate outputs and inputs from national currencies to a common currency. The OECD uses current-price PPPs in USD to eliminate the differences in price levels across countries. While the System of National Accounts 2008 (SNA 2008) recommends countries to construct national balance sheet accounts, the assumptions and methodologies differ by countries.

APO's Total Factor Productivity

The APO provides baseline indicators on productivity estimated for 30 Asian economies, including per-worker labor productivity, per-hour labor productivity, TFP, and energy productivity [57]. Per capita GDP is composed of labor productivity (real GDP per worker) and employment. Using the Törnqvist Index, the 2019 APO Productivity Databook aggregates 15 types of capital inputs (11 types of produced assets and four types of land, while inventory stocks and natural resources are not considered).

However, the weights used to aggregate labor and capital can differ between the APO and the OECD, as the APO defines compensation of capital as a residual of the value added and the compensation of labor (compensation for employees and self-employed persons, and the contributions of family workers). The user cost of capital of a new asset (with the type of asset denoted by k of the period t) is measured as

$$u_{t,0}^{k} = q_{t-1,0}^{k}\{r_t + (1+\pi_t^{k})\delta_{P,t,0}^{k} - \pi_t^{k}\},$$

where $\pi_t^k = \frac{q_{t,0}^k}{q_{t-1,0}^k} - 1$; r_t is the expected nominal rate of return; $\delta_{P,t,0}^k$ is the cross-section depreciation rate; $q_{t,0}^k$ is the asset price; and π_t^k is the asset-specific inflation rate.

While the OECD defines compensation of capital as the imputed value of capital services based on the assumptions of an ex-ante rate of return on capital, the APO uses ex-post real rate of return based on $r_t^* = (1+r_t)/(1+\rho_t) - 1$. Then, TFP growth is estimated as follows:

$$TFPG_t = (\ln TFP_t - \ln TFP_{t-1})$$

$$= (\ln Q_t - \ln Q_{t-1}) - \frac{1}{2}(S_{kt} + S_{kt-1})(\ln K_t - \ln K_{t-1}) - \frac{1}{2}(S_{lt} + S_{lt-1})(\ln L_t - \ln L_{t-1})$$

$$= Q_t - \tfrac{1}{2}(S_{kt} + S_{kt-1})K_t - \tfrac{1}{2}(S_{lt} + S_{lt-1})L_t\,,$$

where TFPG is TFP growth; Q_t is output; K_t is capital; L_t is labor; and S_k and S_l are relative shares of the income of capital $(\frac{rK_t}{Q_t})$ and labor $(\frac{wL_t}{Q_t})$, respectively [83].

Moreover, the APO [57] includes the capital services of residential buildings in the capital input to be consistent with the output that includes the imputed cost of owner-occupied housing. The APO also derives a quality adjusted labor input (QALI) that consists of the number of workers, hours worked per worker, and hourly wages, which are cross-classified by gender, educational attainment, age, and employment status.

Literature Review

Färe, et al. [65] estimate the TFP of 17 OECD countries using Penn World Table (PWT) data and the Malmquist Productivity Index, where aggregate output is measured by gross GDP, labor input by real GDP per worker, and capital input by capital stock per worker. The study compares the result of TFP growth between the traditional growth accounting approach and the Malmquist Index approach. The two approaches yield different results because the growth accounting approach measures and compares TFP growth only for the focal country during a given period, while the Malmquist index approach makes a direct multilateral comparison among countries. Moreover, as mentioned above, one of the assumptions of growth accounting is that the factors of production are paid by their marginal products. However, if the factors are not paid by their marginal products and cause inefficiency, the measure of TFP growth will be biased, resulting in different estimations between the two approaches.

Maudos, et al. [66] also use the Malmquist Productivity Index to estimate TFP in OECD countries, but they consider human capital in measuring labor input. Total output is measured by real GDP, labor input by total employment, capital input by non-residential capital, and human capital by years of schooling for the population aged above 25 years and the number of workers. The study shows that including or excluding human capital can cause a notable difference in productivity growth, thus emphasizing the importance of human capital in measuring TFP growth. Therefore, our study estimates and compares TFPs with and without consideration of human capital.

Inklaar and Timmer [67] use the PWT (version 8.0) to measure TFP across countries. TFP is estimated using GDP as the measure of output, and labor and capital as inputs. While they use the standard approach in measuring labor input (number of employees and average years of schooling), the labor share and capital depreciation rate vary across countries and periods. The study shows that labor share varies across countries and that it is declining in most countries.

Kim, et al. [49] construct a multidimensional productivity index (MPI) that considers not only the economic variables but also institutional variables and the market environment. Economic variables consist of labor and energy input. Using the labor survey, labor productivity is measured by GDP per employee, and energy productivity is measured by GDP per energy consumption.

Derivation of Total Factor Productivity and Capital Stock

Derivation of Total Factor Productivity

TFP is an important determinant of economic growth because of its effect on increasing the production of technological growth. We begin by defining the production function as follows:

$$Y_t = f(A_t, K_t, L_t) \tag{1}$$

where Y_t is the country-level aggregate output consisting of A_t (technology) and input factors such as L_t (quantity of labor) and K_t (capital stock) in time period t. Here, A_t is known as TFP.

Productivity, in general, is derived as a residual of the production function, which consists of physical and labor inputs. For TFP estimation, the Cobb–Douglas production function is assumed in Equation (2) below

$$Y_t = A_t(K_t^{\alpha} L_t^{1-\alpha})^{\gamma},\ 0 < \alpha < 1 \tag{2},$$

where α indicates the importance of physical capital in output. Assuming that equation (2) is a constant return to scale (CRS), i.e., $\gamma = 1$, and taking the natural logarithm of both sides, it can also be expressed as equations (3) and (4) as follows:

$$lnY_t = lnA_t + \alpha lnK_t + (1-\alpha)lnL_t \tag{3}$$

$$lnA_t = lnY_t - \alpha lnK_t - (1-\alpha)lnL_t \tag{4}$$

Equation (4) is a simple TFP equation. Previous studies have assumed that the marginal return on physical capital, α is 0.35 [68–71].

Derivation of Physical Capital

The physical capital stock of time period t is defined by the equation,

$$K_t = I_t + (1-\delta)K_{t-1} \tag{5},$$

where I_t is investment in time t, and δ is the depreciation rate of the capital stock. Since physical capital stock is not available, it is derived using the perpetual inventory method (PIM). This study uses PIM with a depreciation rate of 6%. Related studies assume various values such as 6%, 8%, and 10% [71–74]. Thus, PIM calculates physical capital stock by adding this year's gross capital formation, I_t, to the previous year's capital stock with a 6% depreciation rate $(1-0.06)K_{t-1}$.

Estimation of Total Factor Productivity

Assumptions

This study estimates TFP results using data from various sources for the period 1991–2018. To derive the results, assumptions are added to the methodology introduced above. In addition, the variables and limitations of the derivation are presented.

Assumption 1: As a basic assumption for deriving a simple TFP, an equation is derived from Equation (4) by assuming a CRS and a marginal return on physical capital, i.e., $\alpha = 0.35$, as follows:

$$lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t) \tag{6}$$

Assumption 2: Another basic assumption to derive the physical capital stock by using the PIM methodology is to assume that depreciation rate, δ, is 6% in Equation (5):

$$K_t = I_t + (0.94 * K_{t-1}) \tag{7}$$

Assumption 3: In addition to the basic assumptions used to estimate TFP empirically, specific assumptions are added. GDP is produced by using two capital factors, physical and labor, and assuming the Cobb–Douglas production function as in Equation (2). Labor can be estimated in two ways: with or without consideration of human capital. Another method is to divide labor by type, for instance, based on quantity or quality. Labor as a human-capital-adjusted labor input is defined as follows:

$$\widehat{L_t} = H_t L_t = h(\epsilon_t) L_t = e^{\phi(\epsilon_t)} L_t \qquad (8)$$

$$ln\widehat{L_t} = lnL_t + \phi(\epsilon_t) \qquad (9),$$

where L_t is the quantity of labor, while $e^{\phi(\epsilon_t)}$ reflects the quality of labor. Additionally, the number of workers is adjusted for their years of schooling (ϵ_t) by assuming that each additional year of schooling raises workers' productivity by a given percentage, and various estimates suggest that the rate of return of education is about 10% [69, 75]. Henderson and Russell [75] present ϕ as a piecewise linear function, with a zero intercept and a slope of 0.134 through the fourth year of education, 0.101 for the next four years, and 0.068 for education beyond the eighth year. Clearly, the rate of return to education (where ϕ is differentiable) is (dlnh(ϵ_it))/(dϵ_it)= 〖ϕ^' (ϵ〗 _it) and h(0)=1.

In this study, we assume that $\phi(\epsilon_t)$ is in a linear equation with ϵ_t, yielding an average marginal return (increase) of 10% on an additional year of education. Finally, by taking the logarithm, Equation (8) can be rewritten as Equation (9).

Data and Imputation

Table 1 provides information on the sources and availability of data to derive TFP. The data for the estimation consists of 217 countries, including 20 APO countries for the period 1991–2018, from the World Bank World Development Indicators (WDI) database [76]; International Labour Organization (ILO) database [77]; Barro and Lee [78]; Lee and Lee [79]; and PWT 9.1 [80]. It may be noted that out of the 21 APO member countries, the Republic of China (ROC) is not included in the World Bank WDI.

The variables are: (1) two output indicators, namely, aggregate GDP, expressed in constant 2010 USD from WDI, and, output-side real GDP at chained PPPs, expressed in constant 2011 USD from PWT 9.1; (2) human capital variables such as labor force participation and average years of schooling attained, based on the population aged 15–64 years, and the number of persons engaged (in millions); and (3) capital stock, obtained by gross fixed capital formation and expressed in constant 2010 USD, and, capital stock at current PPPs, expressed in 2011 USD from PWT 9.1.

The data has the following limitations. First, the availability of data per year varies by specific variables. This study uses overlapping years, covering the period from 1991 to 2018. Second, data of average years of schooling attained, which is one of the human capital variables, is provided at an interval of five years. Therefore, missing values are replaced by the nearest year's value by imputation. Third, the number of countries available changes by variables. For example, the ratios of the number of countries available to the number of countries available in GDP based on 2010 data are 90.7% (labor force participation); 42.9% (average years of schooling attained); and 85.9% (gross capital formation). Moreover, in PWT 9.1, the country ratios to output-side real GDP are 94.0% (number of persons engaged); 98.9% (capital stock in current PPPs); and 48.4% (average years of schooling attained). Therefore, to minimize missing data, they are replaced by values using linear interpolation and nearest neighbor interpolation methods.

First, the linear interpolation method to obtain missing TFP values after TFP estimated using original raw data is presented. This estimates missing values based on the linear relationship with other raw data. This study assumes that the variable y is fully unknown, but x in $(x,\ y)$, x_0, and x_1

are known. The missing value (y) at x can be found by the close points (x_0, y_0) and (x_1, y_1), such that $x_0 < x$ and $x_1 > x$ where y_0 and y_1 are observed [81] by:

$$y = \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) + y_0 \quad (10).$$

Second, missing variables that are not between known values are replaced by the nearest neighbor values.

TABLE 1

DATA AVAILABILITY AND SOURCES.

	Availability								Sources
	Number of countries by year							period	
	1991	1995	2000	2005	2010	2015	2018		
GDP (constant 2010 USD)	171	185	194	200	205	200	193	1960–2018	WDI [76]
Labor force participation (age 15–64)	186	186	186	186	186	186	186	1990–2030	ILO [77]
Average years of schooling attained (age 15–64)	88	88	88	88	88	144	144	1870–2010 2015–40 (five-year interval)	Barro and Lee [78], Lee and Lee [79]
Gross capital formation (constant 2010 USD)	105	122	133	144	176	157	142	1960–2018	WDI [76]
Output-side real GDP at chained PPPs (2011 USD)	180	180	180	182	182	182	–	1950–2017	PWT 9.1 [80]
Number of persons engaged	176	175	175	175	171	172	–	1950–2017	
Capital stock at current PPPs (2011 USD)	180	180	180	180	180	180	–	1950–2017	

Notes: (1) Labor force participation and average years of schooling attained are based on population aged 15–64 years. (2) PWT 9.1 is available from 1950 to 2017.

Tables 2 and 3 show summary statistics of the variables included in equations (6) to (9) for the groups of APO and non-APO countries for the period 1991–2018. As of 2021, APO has 21 members. They are Bangladesh, Cambodia, the ROC, Fiji, Hong Kong, India, Indonesia, IR Iran, Japan, the ROK, Lao PDR, Malaysia, Mongolia, Nepal, Pakistan, the Philippines, Singapore, Sri Lanka, Thailand, Turkey, and Vietnam. First, all variables except for the average years of schooling are expressed in million USD. In addition, in deriving the physical capital stock by PIM, the gross capital formation (GCF) and GDP from WDI are taken at constant 2010 USD. The PWT 9.1 data are expressed in terms of PPP at 2010 USD.

For the estimation of TFPs, this study uses the logarithmic form of the TFP components given in Table 3. They are compared with those estimated by the APO, the OECD, and the PWT 9.1. Figures 1–4 compare the raw and imputed values of various TFP components. The TFPs show similar trends, but the average values show a monotonous trend after imputing. Thus, the use of imputed TFP component values may cause the TFP value to deteriorate. Therefore, the TFP is imputed after estimation with the raw data. It may be noted that throughout this report, TFP means natural log of TFP, that is, Ln(A), if not specified otherwise.

TABLE 2

SUMMARY STATISTICS (1991–2018) USING RAW AND IMPUTED DATA.

		Original raw data									
		APO member					Non-APO country				
		Obs.	Mean	S.D.	Min	Max	Obs.	Mean	S.D.	Min	Max
Y_t	GDP	557	548,284	1,212,840	2,052	6,189,778	4,871	266,692	1,192,368	22	17,900,000
	Output-side real GDP	567	794,314	1,282,356	4,071	8,599,774	4,319	339,628	1,416,962	20	18,400,000
L_t	Labor force participation	588	42.978	85.942	0.266	470.967	4,648	11.731	58.931	0.031	777.409
	Number of persons engaged	567	44.591	95.673	0.258	537.835	4,131	12.221	61.628	0.004	792.575
ϵ_t	Average years of schooling	420	8.607	2.634	3.200	13.331	2,264	8.140	2.944	0.951	13.570
K_t	GCF stock	489	4,306,300	9,790,118	326	57,600,000	3,440	1,653,684	6,361,250	26	96,900,000
	Capital stock at current PPPs	567	2,879,317	5,270,197	5,090	33,400,000	4,293	1,265,644	5,365,043	167	106,000,000

		Imputed raw data									
		APO member					Non-APO country				
		Obs.	Mean	S.D.	Min	Max	Obs.	Mean	S.D.	Min	Max
Y_t	GDP	560	546,367	1,210,016	2,052	6,189,778	5,180	251,375	1,157,872	22	17,900,000
	Output-side real GDP	588	815,013	1,319,204	4,071	8,599,774	4,507	343,766	1,441,620	20	18,400,000
L_t	Labor force participation	588	42.978	85.942	0.266	470.967	4,648	11.731	58.931	0.031	777.409
	Number of persons engaged	588	44.925	96.328	0.258	537.835	4,451	11.834	60.651	0.004	792.575
ϵ_t	Average years of schooling	588	8.346	2.615	3.200	13.331	3,416	8.321	2.939	0.951	13.570
K_t	GCF stock	532	4,574,554	12,100,000	12,893	71,200,000	4,368	2,105,339	7,793,642	–3,942	112,000,000
	Capital stock at current PPPs	588	2,986,326	5,444,220	5,090	33,400,000	4,451	1,308,875	5,604,205	167	106,000,000

Notes: (1) Labor force participation and average years of schooling attained are based on the population aged 15-64 years. (2) PWT 9.1 is available from 1950 to 2017. (3) Obs.=Observations; S.D.=Standard deviation; Min.=Minimum; Max.=Maximum.
Source: authors estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79] and PWT 9.1 [80] data.

TABLE 3

SUMMARY STATISTICS (1991–2018) USING LOG TRANSFORMED DATA.

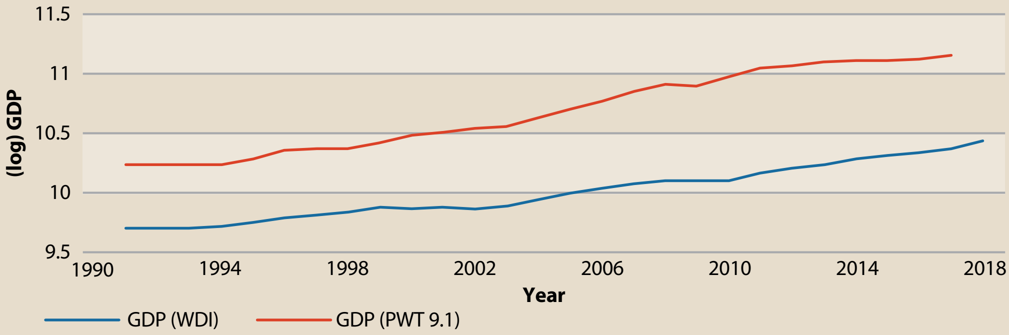
		Original raw data									
		APO member					Non-APO country				
		Obs.	Mean	S.D.	Min	Max	Obs.	Mean	S.D.	Min	Max
lnY_t	(log) GDP	557	11.621	2.019	7.627	15.638	4,871	9.817	2.360	3.145	16.698
	(log) Output-side real GDP	567	12.388	1.851	8.312	15.967	4,319	10.456	2.188	3.034	16.727
lnL_t	(log) Labor force participation	588	2.828	1.366	0.235	6.157	4,648	1.455	1.123	0.031	6.657
	(log) Number of persons engaged	567	2.801	1.383	0.230	6.289	4,131	1.449	1.143	0.004	6.677
ϵ_t	Average years of schooling	420	8.607	2.634	3.200	13.331	2,264	8.140	2.944	0.951	13.570
lnK_t	(log) GCF stock	489	13.423	2.294	5.790	17.869	3,440	11.582	2.537	3.282	18.389
	(log) Capital stock at current PPPs	567	13.423	2.032	8.535	17.324	4,293	11.545	2.346	5.122	18.478

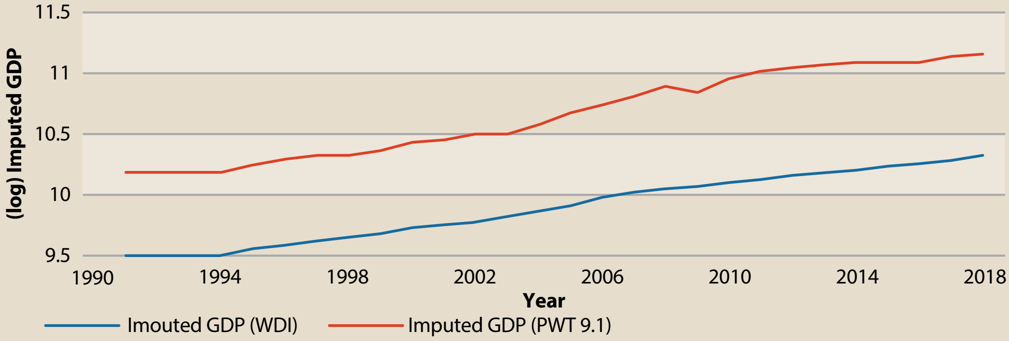
		Imputed raw data									
		APO member					Non-APO country				
		Obs.	Mean	S.D.	Min	Max	Obs.	Mean	S.D.	Min	Max
lnY_t	(log) GDP	560	11.612	2.023	7.627	15.638	5,180	9.698	2.375	3.145	16.698
	(log) Output-side real GDP	588	12.413	1.852	8.312	15.967	4,507	10.456	2.197	3.034	16.727
lnL_t	(log) Labor force participation	588	2.828	1.366	0.235	6.157	4,648	1.455	1.123	0.031	6.657
	(log) Number of persons engaged	588	2.808	1.384	0.230	6.289	4,451	1.402	1.156	0.004	6.677
ϵ_t	Average years of schooling	588	8.346	2.615	3.200	13.331	3,416	8.321	2.939	0.951	13.570
lnK_t	(log) GCF stock	532	13.584	1.914	9.464	18.082	4,361	12.098	2.213	6.511	18.533
	(log) Capital stock at current PPPs	588	13.459	2.034	8.535	17.324	4,451	11.580	2.346	5.122	18.478

Note: (1) Labor force participation and average years of schooling attained are based on the population aged 15–64 years. (2) PWT 9.1 is available from 1950 to 2017. (3) Obs.=Observations; S.D.=Standard deviation; Min.=Minimum; Max.=Maximum.
Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 1

COMPARISON OF THE GDP COMPONENT OF TFP.

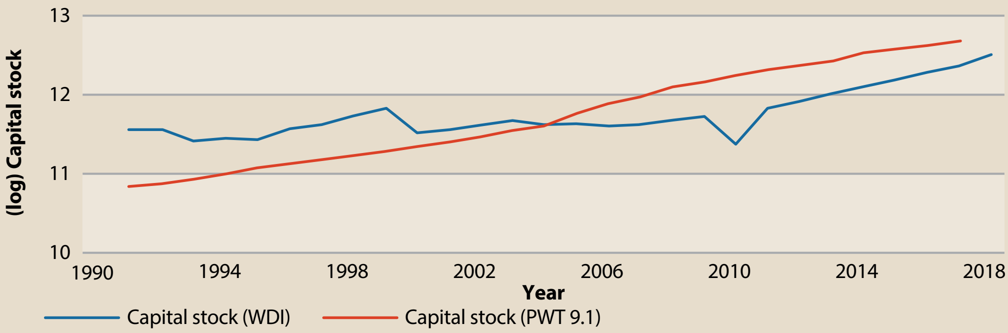


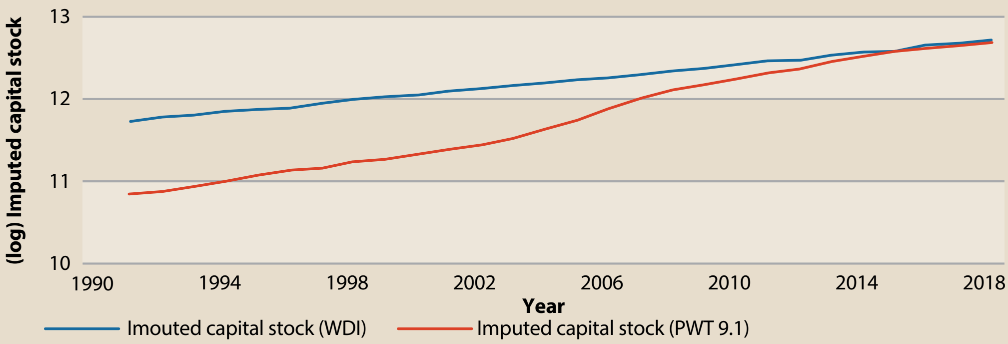


Source: Authors' estimation based on the WDI [76] and PWT 9.1 [80] data.

FIGURE 2

COMPARISON OF THE CAPITAL STOCK COMPONENT OF TFP.

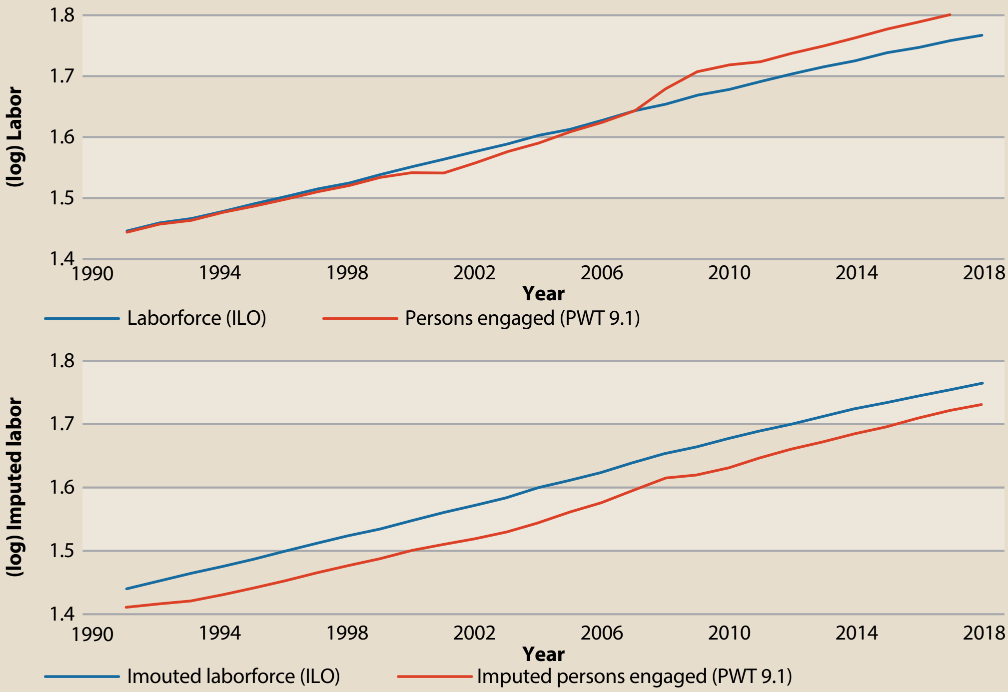




Source: Authors' estimation based on the WDI [76] and PWT 9.1 [80] data.

FIGURE 3

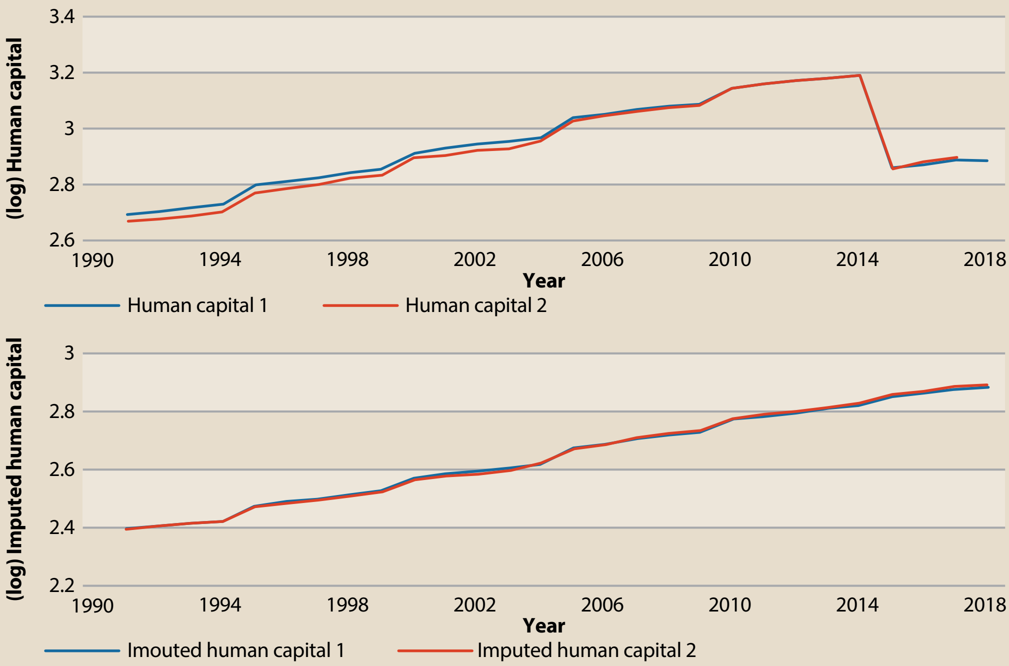
COMPARISON OF THE LABOR PARTICIPATION COMPONENT OF TFP.



Source: Authors' estimation based on the WDI [76] and PWT 9.1 [80] data.

FIGURE 4

COMPARISON OF THE HUMAN CAPITAL COMPONENT OF TFP.



Note: Authors' estimation of Human capital 1 is based on labor force participation data from the ILO [77],]; and years of schooling data from Barro and Lee [78] and Lee and Lee [79]. Authors' estimation of Human capital 2 is based on data on number of persons engaged from the PWT 9.1 [80] and data on years of schooling from Barro and Lee [78] and Lee and Lee [79].

Estimated TFPs and Comparison with OECD, APO, and PWT TFPs

Tables 5–8 show the simple TFPs estimated considering the number of workers and human capital defined in Equation (6). In addition, the results are explained using two criteria, namely, the original raw data, and the imputed values. Moreover, two additional TFPs are estimated using the PWT 9.1 data to consider the PPP values in GDP and capital stock. Furthermore, TFPs are presented for the 21 APO member countries and the top 10 non-APO countries with the highest TFP values in 2017 (PWT) and 2018 (WDI).

There are advantages and disadvantages of using the PWT 9.1 data [80]. Specifically, it shows PPP-based data for GDP and estimated capital stock. However, it has data only until 2017. So, the study cannot extend the coverage of years until the new version is available. Further, even if it is quite useful, PPP-based data cannot be compared with non-PPP based data. Lastly, data on human capital are expressed in an index form rather than as values.

Table 4 describes how this study uses different ways of TFP estimation. Largely, TFP1 only considers the quantity of labor input, which is labor participation in millions of workers aged 15–64 years, while TFP2 considers both labor quantity and quality, which includes labor participation and years of schooling. The number of countries included in computing TFP1 and TFP2 are 167 and 130, respectively, and those from PWT 9.1 are 178 and 137, respectively.

TABLE 4

DEFINITION OF TFP.

	TFP 1	TFP 2
Basic equation	$lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t)$	
Human capital	lnL_t where L_t is labor force participation	$ln\widehat{L_t} = lnL_t + \phi(\epsilon_t)$ where $\widehat{L_t} = H_t L_t = h(\epsilon_t) L_t = e^{\phi(\epsilon_t)} L_t$, L_t is la or force participation and ϵ_t is average years of schooling

Table 5 presents the TFPs of the 21 APO and 148 non-APO countries without considering human capital. In this case, lnL_t simply uses the quantity of labor, which is the natural log of the labor force participation variable. In other words, Table 5 shows the results of Equation (6): $lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t)$.

According to the results of the 21 APO countries (except for four missing countries in 2018), the economies with the highest TFP values in 2018 were Singapore (6.7), Japan (6.7), and Hong Kong (6.6), having shown the highest TFP values since 1991. Meanwhile, the country with the lowest value in 2018 was Nepal (4.2), and its imputed TFP value also ranks the lowest.

In addition, among the 146 non-APO countries (see bottom of Table 5), the three countries with the highest TFP values in 2018 were Ireland (7.1), the USA (7.0), and Norway (7.0). Meanwhile, for the imputed TFP values, the top countries were Ireland (7.1), the USA (7.0), Iraq (7.0), and Norway (7.0). This indicates that the result changes because the values fluctuate after the imputation. For example, oil-exporting countries, such as Iraq, might be reconsidered.

Table 6 presents the TFP results based on PWT 9.1 data from 1991 to 2017 using the same method for TFP1, as shown in Table 5. Unlike the previous results, all APO countries' TFPs (including those of Fiji and the ROC) were estimated. Based on the results of the 21 APO countries for both

TABLE 5

TFP1 WITHOUT HUMAN CAPITAL (WDI).

Original raw data								Imputed data							
APO countries															
	1991	1995	2000	2005	2010	2015	2018		1991	1995	2000	2005	2010	2015	2018
Bangladesh	4.4	4.4	4.4	4.5	4.6	4.7	4.7	Bangladesh	4.4	4.4	4.4	4.5	4.6	4.7	4.7
Cambodia	-	4.7	4.5	4.5	4.5	4.6	4.7	Cambodia	5.4	4.7	4.5	4.5	4.5	4.6	4.7
ROC	-	-	-	-	-	-	-	ROC	-	-	-	-	-	-	-
Fiji	-	-	-	-	-	-	-	Fiji	-	-	-	-	-	-	-
Hong Kong	6.3	6.4	6.3	6.4	6.5	6.5	6.6	Hong Kong	6.3	6.4	6.3	6.4	6.5	6.5	6.6
India	4.4	4.5	4.6	4.7	4.9	5.0	5.1	India	4.4	4.5	4.6	4.7	4.9	5.0	5.1
Indonesia	4.4	4.5	4.4	4.5	4.7	4.9	4.9	Indonesia	4.4	4.5	4.4	4.5	4.7	4.9	4.9
IR Iran	5.6	5.6	5.5	5.6	5.7	5.6	-	IR Iran	5.6	5.6	5.5	5.6	5.7	5.6	5.7
Japan	6.8	6.7	6.7	6.7	6.7	6.7	6.7	Japan	6.8	6.7	6.7	6.7	6.7	6.7	6.7
ROK	6.0	6.1	6.2	6.3	6.4	6.4	6.4	ROK	6.0	6.1	6.2	6.3	6.4	6.4	6.4
Lao PDR	-	-	5.1	4.6	4.6	4.7	-	Lao PDR	5.1	5.1	5.1	4.6	4.6	4.7	4.7
Malaysia	5.7	5.8	5.8	5.9	5.9	6.0	6.0	Malaysia	5.7	5.8	5.8	5.9	5.9	6.0	6.0
Mongolia	-	-	-	-	5.6	5.3	5.3	Mongolia	5.6	5.6	5.6	5.6	5.6	5.3	5.3
Nepal	-	-	-	4.5	4.3	4.3	4.2	Nepal	4.9	4.9	4.9	4.5	4.3	4.3	4.2
Pakistan	4.7	4.7	4.7	4.8	4.7	4.8	4.9	Pakistan	4.7	4.7	4.7	4.8	4.7	4.8	4.9
Philippines	4.9	4.8	4.9	4.9	5.0	5.2	5.3	Philippines	4.9	4.8	4.9	4.9	5.0	5.2	5.3
Singapore	6.1	6.3	6.4	6.5	6.6	6.7	6.7	Singapore	6.1	6.3	6.4	6.5	6.6	6.7	6.7
Sri Lanka	4.6	4.8	4.9	5.0	5.2	5.3	5.4	Sri Lanka	4.6	4.8	4.9	5.0	5.2	5.3	5.4
Thailand	5.0	5.2	5.0	5.2	5.3	5.4	5.5	Thailand	5.0	5.2	5.0	5.2	5.3	5.4	5.5
Turkey	6.4	6.3	6.3	6.3	6.3	6.4	6.4	Turkey	6.4	6.3	6.3	6.3	6.3	6.4	6.4
Vietnam	4.9	4.7	4.6	4.6	4.6	4.7	4.8	Vietnam	4.9	4.7	4.6	4.6	4.6	4.7	4.8
Non-APO countries															
	1991	1995	2000	2005	2010	2015	2018		1991	1995	2000	2005	2010	2015	2018
Ireland	6.4	6.5	6.8	6.8	6.7	7.0	7.1	Ireland	6.4	6.5	6.8	6.8	6.7	7.0	7.1
USA	6.9	6.9	7.0	7.0	6.9	7.0	7.0	USA	6.9	6.9	7.0	7.0	6.9	7.0	7.0
Norway	6.9	6.9	7.0	7.0	7.0	7.0	7.0	Iraq	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Australia	6.8	6.8	6.9	6.9	6.9	6.9	6.9	Norway	6.9	6.9	7.0	7.0	7.0	7.0	7.0
Switzerland	6.9	6.9	6.9	6.9	6.9	6.9	6.9	Australia	6.8	6.8	6.9	6.9	6.9	6.9	6.9
Canada	6.7	6.7	6.8	6.8	6.8	6.8	6.8	Switzerland	6.9	6.9	6.9	6.9	6.9	6.9	6.9
UK	6.8	6.8	6.8	6.9	6.8	6.8	6.8	Canada	6.7	6.7	6.8	6.8	6.8	6.8	6.8
Netherlands	6.8	6.8	6.8	6.8	6.8	6.8	6.8	UK	6.8	6.8	6.8	6.9	6.8	6.8	6.8
Denmark	6.7	6.8	6.8	6.8	6.8	6.8	6.8	Netherlands	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Sweden	6.6	6.6	6.7	6.8	6.7	6.8	6.8	Denmark	6.7	6.8	6.8	6.8	6.8	6.8	6.8

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78] and Lee and Lee [79] data.

TABLE 6

TFP1 WITHOUT HUMAN CAPITAL (PWT 9.1).

Original raw data								Imputed data							
APO countries															
	1991	1995	2000	2005	2010	2015	2017		1991	1995	2000	2005	2010	2015	2017
Bangladesh	5.4	5.3	5.2	5.1	5.3	5.4	5.4	Bangladesh	5.4	5.3	5.2	5.1	5.3	5.4	5.4
Cambodia	4.7	5.0	4.8	5.0	5.1	5.2	5.2	Cambodia	4.7	5.0	4.8	5.0	5.1	5.2	5.2
ROC	6.8	6.8	6.9	6.9	6.8	6.8	6.8	ROC	6.8	6.8	6.9	6.9	6.8	6.8	6.8
Fiji	5.2	5.2	5.3	5.1	5.2	5.2	5.1	Fiji	5.2	5.2	5.3	5.1	5.2	5.2	5.1
Hong Kong	6.6	6.7	6.6	6.8	6.6	6.5	6.5	Hong Kong	6.6	6.7	6.6	6.8	6.6	6.5	6.5
India	5.0	5.1	5.3	5.4	5.6	5.7	5.8	India	5.0	5.1	5.3	5.4	5.6	5.7	5.8
Indonesia	5.7	5.9	5.6	5.6	5.7	5.8	5.9	Indonesia	5.7	5.9	5.6	5.6	5.7	5.8	5.9
IR Iran	5.7	5.9	6.2	6.6	6.7	6.5	6.6	IR Iran	5.7	5.9	6.2	6.6	6.7	6.5	6.6
Japan	6.7	6.7	6.7	6.7	6.7	6.8	6.8	Japan	6.7	6.7	6.7	6.7	6.7	6.8	6.8
ROK	6.4	6.5	6.6	6.6	6.7	6.7	6.7	ROK	6.4	6.5	6.6	6.6	6.7	6.7	6.7
Lao PDR	4.8	4.8	4.9	5.0	5.4	5.5	5.5	Lao PDR	4.8	4.8	4.9	5.0	5.4	5.5	5.5
Malaysia	6.2	6.3	6.2	6.4	6.4	6.5	6.5	Malaysia	6.2	6.3	6.2	6.4	6.4	6.5	6.5
Mongolia	4.9	4.8	4.8	5.0	5.4	5.7	5.7	Mongolia	4.9	4.8	4.8	5.0	5.4	5.7	5.7
Nepal	4.9	4.8	4.8	4.7	4.9	5.0	5.1	Nepal	4.9	4.8	4.8	4.7	4.9	5.0	5.1
Pakistan	5.9	5.9	5.9	5.9	6.0	6.1	6.1	Pakistan	5.9	5.9	5.9	5.9	6.0	6.1	6.1
Philippines	5.8	5.9	5.7	5.7	5.8	5.9	6.0	Philippines	5.8	5.9	5.7	5.7	5.8	5.9	6.0
Singapore	6.4	6.2	6.6	6.7	6.7	6.7	6.8	Singapore	6.4	6.2	6.6	6.7	6.7	6.7	6.8
Sri Lanka	5.7	5.9	5.9	5.9	6.1	6.3	6.3	Sri Lanka	5.7	5.9	5.9	5.9	6.1	6.3	6.3
Thailand	5.7	5.7	5.5	5.8	5.9	6.0	6.1	Thailand	5.7	5.7	5.5	5.8	5.9	6.0	6.1
Turkey	6.5	6.5	6.6	6.7	6.7	6.8	6.9	Turkey	6.5	6.5	6.6	6.7	6.7	6.8	6.9
Vietnam	5.2	5.3	5.2	5.2	5.5	5.6	5.6	Vietnam	5.2	5.3	5.2	5.2	5.5	5.6	5.6
Non-APO countries															
	1991	1995	2000	2005	2010	2015	2017		1991	1995	2000	2005	2010	2015	2017
USA	6.9	7.0	7.1	7.1	7.1	7.1	7.1	USA	6.9	7.0	7.1	7.1	7.1	7.1	7.1
Ireland	6.3	6.5	6.8	7.0	6.8	7.1	7.1	Ireland	6.3	6.5	6.8	7.0	6.8	7.1	7.1
UAE	7.0	6.8	7.0	7.1	7.0	7.1	7.1	UAE	7.0	6.8	7.0	7.1	7.0	7.1	7.1
Iraq	5.2	5.5	6.3	6.2	6.6	6.9	6.9	Iraq	5.2	5.5	6.3	6.2	6.6	6.9	6.9
Switzerland	6.5	6.6	6.7	6.8	6.9	6.9	6.9	Switzerland	6.5	6.6	6.7	6.8	6.9	6.9	6.9
Saudi Arabia	6.6	6.6	6.7	7.0	7.2	7.0	6.9	Saudi Arabia	6.6	6.6	6.7	7.0	7.2	7.0	6.9
Australia	6.7	6.7	6.8	6.9	6.9	6.8	6.9	Australia	6.7	6.7	6.8	6.9	6.9	6.8	6.9
Germany	6.6	6.7	6.8	6.9	6.8	6.8	6.8	Germany	6.6	6.7	6.8	6.9	6.8	6.8	6.8
France	6.7	6.7	6.9	6.9	6.8	6.8	6.8	France	6.7	6.7	6.9	6.9	6.8	6.8	6.8
Norway	6.4	6.5	6.9	7.1	7.1	6.9	6.8	Norway	6.4	6.5	6.9	7.1	7.1	6.9	6.8

Source: Authors' estimation based on Barro and Lee [78], Lee and Lee [79], PWT 9.1 [80] data.

the data sets, the countries with the highest TFPs in 2017 were Turkey (6.9), the ROC (6.8), Japan (6.8), and Singapore (6.8). Meanwhile, the countries with the lowest TFP values in 2017 were Nepal and Fiji (5.1). In addition, the top 10 countries among 156 non-APO countries in 2018 were the USA, Ireland, United Arab Emirates, Iraq, and so on. TFPs with imputed values showed the same results.

Table 7 shows the results that consider human capital, as defined in an earlier section. Labor input consists of the quantity and quality of human capital, and lnL_t is defined as $ln\widehat{L_t} = lnL_t + \phi(\epsilon_t)$. Table 7 presents the TFPs with original raw and imputed data that replaced the labor input in Equation (6), $lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t)$, with human capital.

The TFP results with consideration of human capital are as follows: From the results of the 2018 original raw and imputed data in Table 7, the countries with the highest TFP values among 19 APO countries were Singapore (5.9), Japan (5.9), and Hong Kong (5.8); while the country with the lowest TFP value was Nepal (3.8). The bottom of the table shows the TFPs of the top 10 countries of non-APO countries in 2018, with their average TFP values in 2015 and 2018 being 6.11 and 6.10, respectively. After imputation, the average TFP values in 2015 and 2018 were 6.17 and 6.16, respectively. It is notable that the TFP values of APO countries were similar before and after imputation, while those of non-APO countries showed larger fluctuation after imputation.

The TFP values of 136 countries using PWT 9.1 were derived by considering both Equation (6) and human capital (see Table 8). The TFP values differ from the estimated TFP values in Table 7 because the TFP component values of the PWT 9.1 are different from other databases. From the values derived using the original raw data, as of 2017, the APO country with the highest TFP value was Turkey (6.3), while the country with the lowest TFP value was Fiji (4.4). In addition, among the 115 non-APO countries, the average TFP of top-scoring countries (United Arab Emirates, Iraq, the USA, Saudi Arabia, Ireland, Egypt, Qatar, Kuwait, France, and Switzerland) was 6.25 in 2017. The imputed values on the right side of the table show the same results because PWT 9.1 has only a few missing variables in the raw data.

Tables 5 and 8 show that Singapore, Japan, and Hong Kong are among the APO countries with the highest TFPs, while Nepal has the lowest TFP value. For non-APO countries, the rankings differ by estimations, but the top 10 countries are quite similar. In addition, inclusion of human capital influences TFP values more than other TFP components do. As in Figures 5–7, the fitted value lines of the TFP values in 2017 for PWT 9.1 and in 2018 for WDI show that all components and TFPs have a positive correlation. In Figure 7, consideration of the quality of labor force might decrease the degree of fitting.

Table 9 shows the correlation coefficients among various estimated TFPs with the raw data. The correlation coefficients among TFPs show a very high positive (+) correlation, at an average of 0.816. For example, the correlation between two TFP1s is 0.8901. Thus, the two TFPs for both the data sets tend to be similar over years.

Table 10 shows descriptive statistics of the estimated TFPs by country groups. The mean values are measured as a simple average, and imputed values are used for group comparison. The simple mean of TFP values for each group, TFP1 (WDI), TFP2 (WDI), TFP1 (PWT), and TFP2 (PWT), are as follows. First, the mean values of TFPs for all countries are 5.474, 5.149, 5.640, and 5.437, respectively. Looking at the TFP of APO countries, the mean values are 5.353, 4.949, 5.870, and 5.502, respectively. Lastly, for non-APO countries, the mean values are 5.492, 5.187, 5.609, and 5.425, respectively. Moreover, TFP1, based on PWT 9.1, has the largest standard deviation among

TABLE 7

TFP2 WITH HUMAN CAPITAL (WDI).

Original raw data								Imputed data							
APO countries															
	1991	1995	2000	2005	2010	2015	2018		1991	1995	2000	2005	2010	2015	2018
Bangladesh	-	-	-	-	-	4.2	4.3	Bangladesh	4.2	4.2	4.2	4.2	4.2	4.2	4.3
Cambodia		4.4	4.2	4.3	4.2	4.3	4.3	Cambodia	5.2	4.4	4.2	4.3	4.2	4.3	4.3
ROC	-	-	-	-	-	-	-	ROC	-	-	-	-	-	-	-
Fiji	-	-	-	-	-	-	-	Fiji	-	-	-	-	-	-	-
Hong Kong	5.6	5.7	5.6	5.6	5.7	5.7	5.8	Hong Kong	5.6	5.7	5.6	5.6	5.7	5.7	5.8
India	4.2	4.2	4.2	4.3	4.4	4.5	4.6	India	4.2	4.2	4.2	4.3	4.4	4.5	4.6
Indonesia	4.1	4.2	4.0	4.1	4.1	4.3	4.4	Indonesia	4.1	4.2	4.0	4.1	4.1	4.3	4.4
IR Iran	5.2	5.1	5.0	5.0	5.1	5.0	-	IR Iran	5.2	5.1	5.0	5.0	5.1	5.0	5.0
Japan	6.1	6.0	6.0	5.9	5.9	5.9	5.9	Japan	6.1	6.0	6.0	5.9	5.9	5.9	5.9
ROK	5.3	5.4	5.4	5.5	5.5	5.5	5.5	ROK	5.3	5.4	5.4	5.5	5.5	5.5	5.5
Lao PDR	-	-	-	-	-	4.3	-	Lao PDR	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Malaysia	5.1	5.2	5.2	5.2	5.2	5.2	5.3	Malaysia	5.1	5.2	5.2	5.2	5.2	5.2	5.3
Mongolia	-	-	-	-	-	4.6	4.6	Mongolia	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Nepal	-	-	-	-	-	3.9	3.8	Nepal	3.9	3.9	3.9	3.9	3.9	3.9	3.8
Pakistan	-	-	-	-	-	4.4	4.5	Pakistan	4.4	4.4	4.4	4.4	4.4	4.4	4.5
Philippines	4.4	4.3	4.3	4.4	4.5	4.6	4.7	Philippines	4.4	4.3	4.3	4.4	4.5	4.6	4.7
Singapore	-	-	-	-	-	5.9	5.9	Singapore	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Sri Lanka	4.1	4.1	4.2	4.3	4.5	4.7	4.7	Sri Lanka	4.1	4.1	4.2	4.3	4.5	4.7	4.7
Thailand	4.7	4.8	4.7	4.7	4.7	4.8	4.9	Thailand	4.7	4.8	4.7	4.7	4.7	4.8	4.9
Turkey	6.1	5.9	5.9	5.9	5.8	5.8	5.8	Turkey	6.1	5.9	5.9	5.9	5.8	5.8	5.8
Vietnam	-	-	-	-	-	4.2	4.3	Vietnam	4.2	4.2	4.2	4.2	4.2	4.2	4.3
Non-APO countries															
	1991	1995	2000	2005	2010	2015	2018		1991	1995	2000	2005	2010	2015	2018
Kuwait	-	-	-	-	-	6.5	6.3	Iraq	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Ireland	5.7	5.8	6.0	6.1	5.9	6.1	6.2	Kuwait	6.5	6.5	6.5	6.5	6.5	6.5	6.3
Norway	6.2	6.2	6.2	6.3	6.2	6.2	6.2	Ireland	5.7	5.8	6.0	6.1	5.9	6.1	6.2
USA	6.1	6.1	6.1	6.1	6.1	6.1	6.1	Norway	6.2	6.2	6.2	6.3	6.2	6.2	6.2
Australia	6.0	6.0	6.1	6.1	6.1	6.0	6.1	Qatar	6.2	6.2	6.2	6.2	6.2	6.2	6.1
Denmark	6.0	6.1	6.1	6.0	6.0	6.0	6.0	USA	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Netherlands	6.1	6.1	6.1	6.1	6.0	6.0	6.0	Australia	6.0	6.0	6.1	6.1	6.1	6.0	6.1
Switzerland	6.2	6.2	6.2	6.2	6.0	6.0	6.0	Denmark	6.0	6.1	6.1	6.0	6.0	6.0	6.0
UAE	-	-	-	-	-	6.1	6.0	Netherlands	6.1	6.1	6.1	6.1	6.0	6.0	6.0
Sweden	5.9	5.9	6.0	6.0	6.0	6.0	6.0	Switzerland	6.2	6.2	6.2	6.2	6.0	6.0	6.0

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78] and Lee and Lee [79] data.

TABLE 8

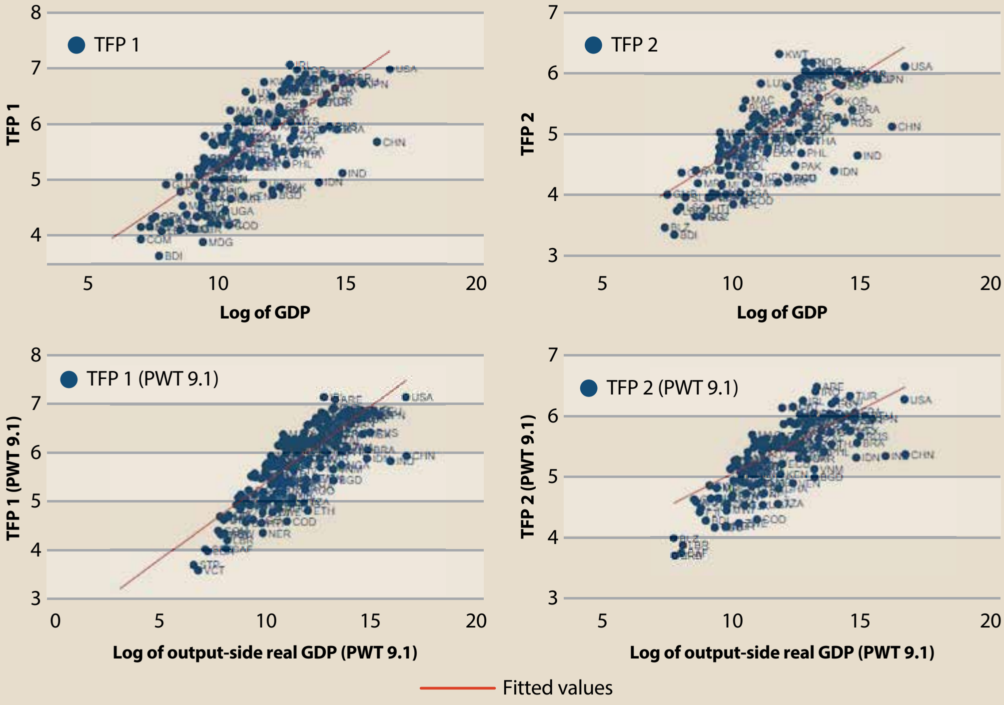
TFP2 WITH HUMAN CAPITAL (PWT 9.1).

Original raw data								Imputed data							
APO countries															
	1991	1995	2000	2005	2010	2015	2017		1991	1995	2000	2005	2010	2015	2017
Bangladesh	-	-	-	-	-	5.0	5.0	Bangladesh	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Cambodia	4.5	4.8	4.6	4.7	4.7	4.9	4.8	Cambodia	4.5	4.8	4.6	4.7	4.7	4.9	4.8
ROC	6.2	6.2	6.3	6.2	6.0	6.0	6.0	ROC	6.2	6.2	6.3	6.2	6.0	6.0	6.0
Fiji	4.6	4.6	4.6	4.4	4.5	4.5	4.4	Fiji	4.6	4.6	4.6	4.4	4.5	4.5	4.4
Hong Kong	6.0	6.0	5.9	6.0	5.8	5.7	5.7	Hong Kong	6.0	6.0	5.9	6.0	5.8	5.7	5.7
India	4.8	4.9	4.9	5.0	5.2	5.3	5.3	India	4.8	4.9	4.9	5.0	5.2	5.3	5.3
Indonesia	5.4	5.6	5.2	5.1	5.2	5.3	5.3	Indonesia	5.4	5.6	5.2	5.1	5.2	5.3	5.3
IR Iran	5.4	5.5	5.7	6.0	6.1	5.9	6.0	IR Iran	5.4	5.5	5.7	6.0	6.1	5.9	6.0
Japan	6.0	6.0	6.0	5.9	5.9	5.9	5.9	Japan	6.0	6.0	6.0	5.9	5.9	5.9	5.9
ROK	5.7	5.8	5.9	5.8	5.9	5.8	5.8	ROK	5.7	5.8	5.9	5.8	5.9	5.8	5.8
Lao PDR	-	-	-	-	-	5.1	5.2	Lao PDR	5.1	5.1	5.1	5.1	5.1	5.1	5.2
Malaysia	5.6	5.7	5.6	5.7	5.7	5.7	5.7	Malaysia	5.6	5.7	5.6	5.7	5.7	5.7	5.7
Mongolia	-	-	-	-	-	5.0	5.1	Mongolia	5.0	5.0	5.0	5.0	5.0	5.0	5.1
Nepal	-	-	-	-	-	4.7	4.7	Nepal	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Pakistan	-	-	-	-	-	5.7	5.7	Pakistan	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Philippines	5.3	5.4	5.2	5.1	5.2	5.3	5.4	Philippines	5.3	5.4	5.2	5.1	5.2	5.3	5.4
Singapore	-	-	-	-	-	5.9	6.0	Singapore	5.9	5.9	5.9	5.9	5.9	5.9	6.0
Sri Lanka	5.1	5.3	5.2	5.2	5.4	5.6	5.6	Sri Lanka	5.1	5.3	5.2	5.2	5.4	5.6	5.6
Thailand	5.3	5.3	5.1	5.3	5.4	5.5	5.5	Thailand	5.3	5.3	5.1	5.3	5.4	5.5	5.5
Turkey	6.1	6.2	6.2	6.2	6.2	6.3	6.3	Turkey	6.1	6.2	6.2	6.2	6.2	6.3	6.3
Vietnam	-	-	-	-	-	5.1	5.1	Vietnam	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Non-APO countries															
	1991	1995	2000	2005	2010	2015	2017		1991	1995	2000	2005	2010	2015	2017
UAE	-	-	-	-	-	6.5	6.5	UAE	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Iraq	4.8	5.1	5.9	5.8	6.2	6.4	6.4	Iraq	4.8	5.1	5.9	5.8	6.2	6.4	6.4
Ireland	5.6	5.8	6.1	6.2	6.0	6.2	6.3	USA	6.1	6.1	6.2	6.2	6.2	6.3	6.3
Saudi Arabia	-	-	-	-	-	6.4	6.3	Saudi Arabia	6.4	6.4	6.4	6.4	6.4	6.4	6.3
USA	6.1	6.1	6.2	6.2	6.2	6.3	6.3	Ireland	5.6	5.8	6.1	6.2	6.0	6.2	6.3
Egypt	5.8	6.0	5.9	5.9	6.0	6.2	6.2	Egypt	5.8	6.0	5.9	5.9	6.0	6.2	6.2
Qatar	-	-	-	-	-	6.3	6.2	Qatar	6.3	6.3	6.3	6.3	6.3	6.3	6.2
France	6.2	6.1	6.2	6.2	6.1	6.1	6.1	Kuwait	6.3	6.3	6.3	6.3	6.3	6.3	6.1
Kuwait	-	-	-	-	-	6.3	6.1	France	6.2	6.1	6.2	6.2	6.1	6.1	6.1
Switzerland	5.9	5.9	6.0	6.1	6.0	6.1	6.1	Switzerland	5.9	5.9	6.0	6.1	6.0	6.1	6.1

Source: Authors' estimation based on Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 5

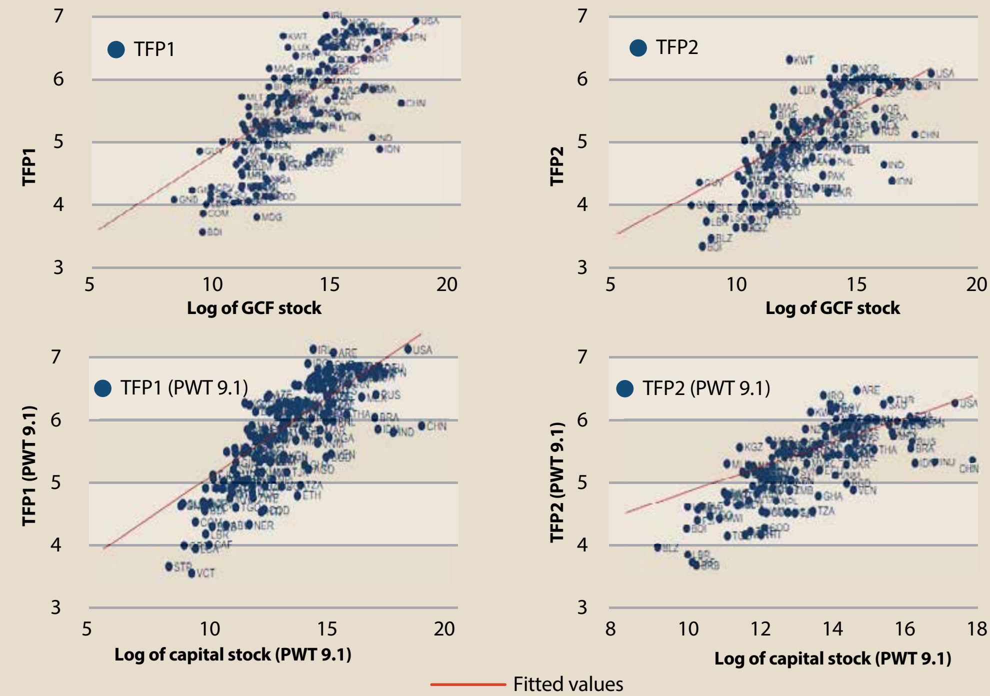
VARIOUS TFPs AND GDP.



Source: Authors' estimation based on the WDI [76] and PWT 9.1 [80] data.

FIGURE 6

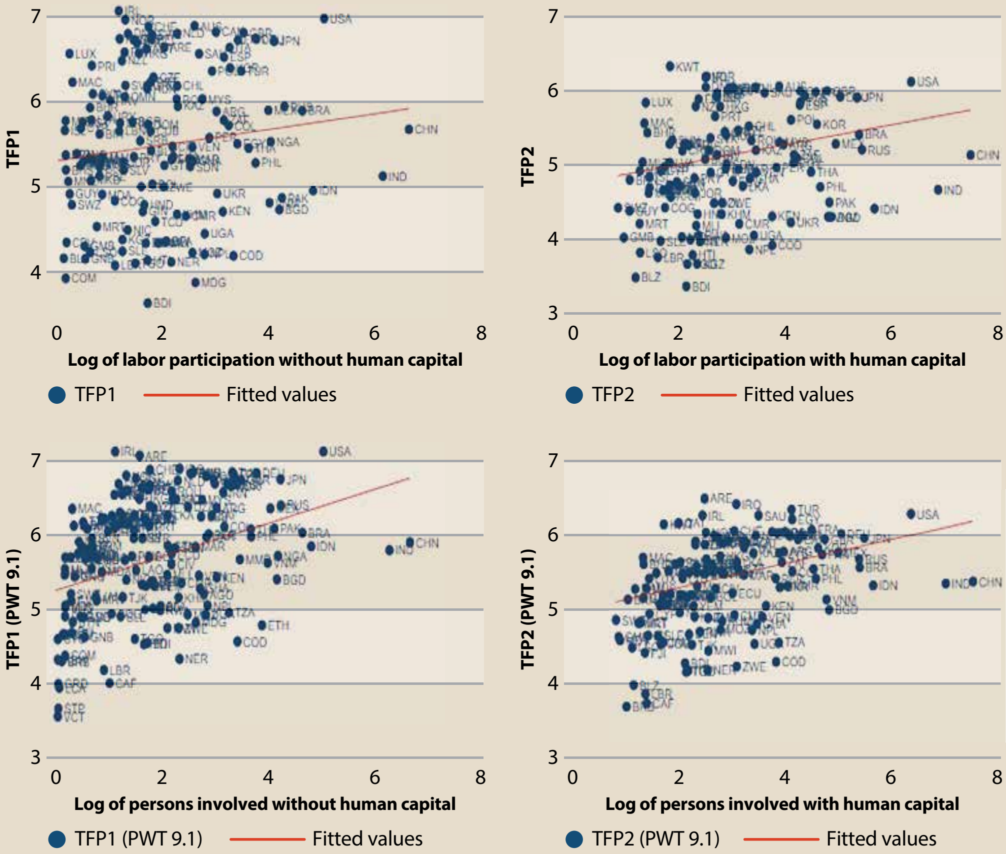
VARIOUS TFPS AND CAPITAL STOCK.



Source: Authors' estimation based on the WDI [76] and PWT 9.1 [80] data.

FIGURE 7

VARIOUS TFPS AND HUMAN CAPITAL.



Source: Authors' estimation based on the ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

TABLE 9

CORRELATION MATRIX OF ESTIMATED TFPs.

	TFP1	TFP2	TFP1 (PWT)	TFP2 (PWT)
TFP1	1.000			
TFP2	0.9859	1.000		
TFP1 (PWT)	0.8901	0.8683	1.000	
TFP2 (PWT)	0.8111	0.8272	0.9668	1.000

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

all groups. Using PWT 9.1 data, the average for TFP2 is higher than that for TFP1, which implies that human capital lowers the TFP value.

In Figure 8, the TFPs show an increasing trend over time, and a difference in values appears depending on whether human capital is considered or not. Figures 9–11 present TFP indices and TFP components, with 2010 as the base year (2010 = 100). Figure 9 shows that starting with 2010, TFP2 increases faster than TFP1. The growth of TFP1 tends to slow down after 2010, and the growth of TFP2 appears to speed up after 2014. Meanwhile, the TFPs derived based on PWT 9.1

TABLE 10

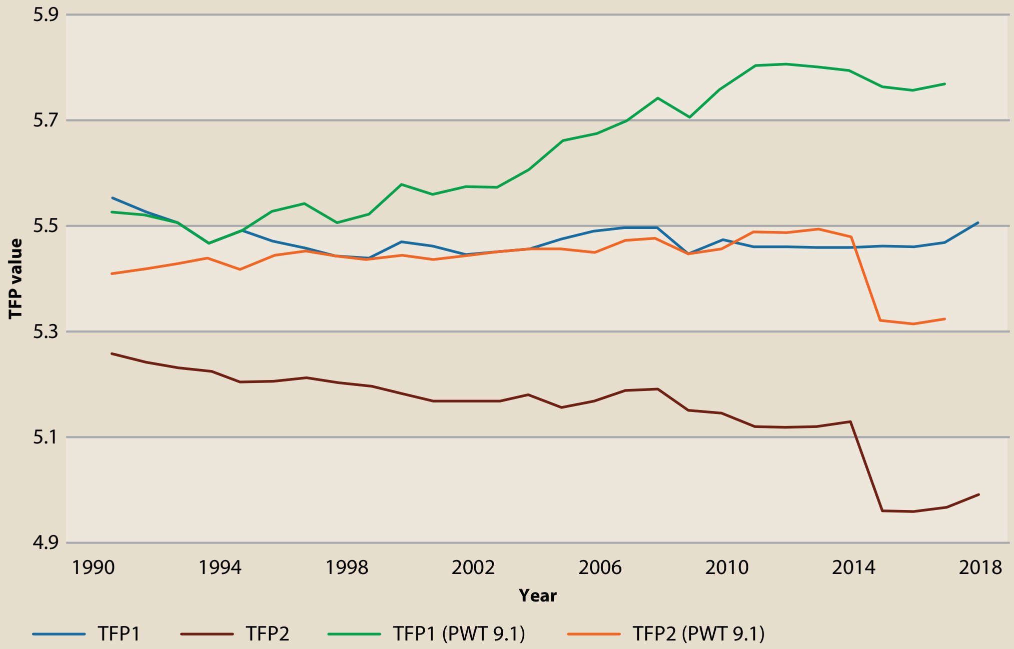
A COMPARISON OF THE ESTIMATED TFPS BY COUNTRY GROUPS.

Country	TFP	Mean	SD	Minimum	Maximum
Total	TFP1 (WDI)	5.474	0.026	5.431	5.552
	TFP2 (WDI)	5.149	0.082	4.956	5.257
	TFP1 (PWT)	5.640	0.115	5.474	5.810
	TFP2 (PWT)	5.437	0.047	5.315	5.492
APO	TFP1(WDI)	5.353	0.059	5.258	5.501
	TFP2(WDI)	4.949	0.053	4.835	5.041
	TFP1 (PWT)	5.870	0.118	5.712	6.067
	TFP2 (PWT)	5.502	0.042	5.435	5.594
non-APO	TFP1(WDI)	5.492	0.029	5.450	5.584
	TFP2(WDI)	5.187	0.094	4.975	5.306
	TFP1 (PWT)	5.609	0.115	5.437	5.779
	TFP2 (PWT)	5.425	0.050	5.291	5.475

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 8

A COMPARISON OF ESTIMATED TFP.

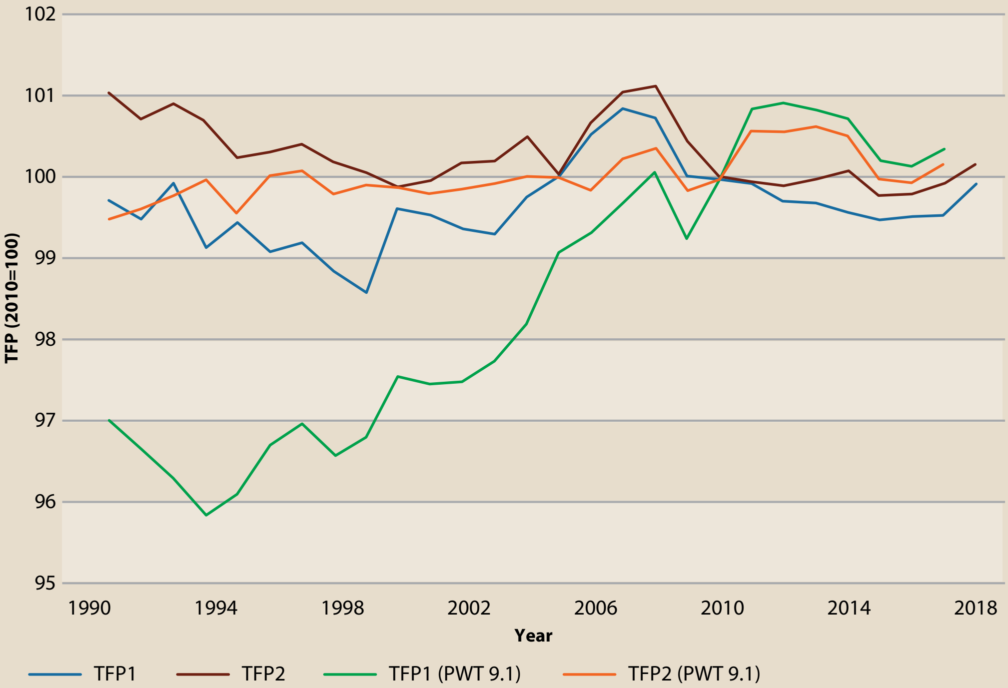


Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79] and PWT 9.1 [80] data.

data, with the base year being 2010 (2010=100) show a huge fall in 2009 but recover after 2014. Moreover, an expansion of labor with consideration of human capital since 2010 is shown in Figures 10 and 11. In other words, labor factor is overestimated without considering human capital. Therefore, the empirical estimation in this Annexure uses TFP 2 as a dependent variable.

FIGURE 9

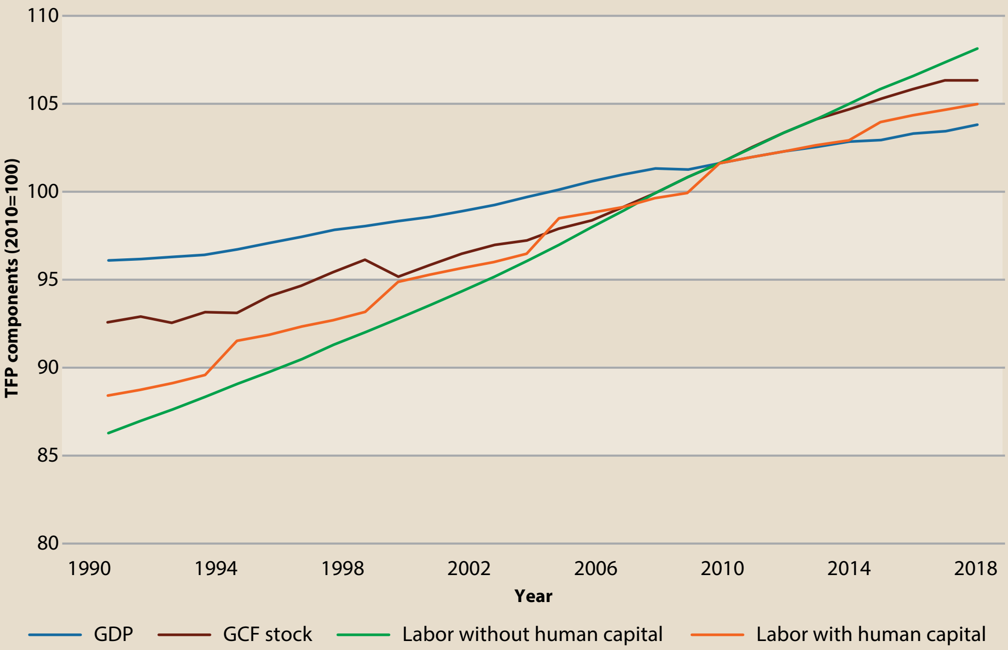
A COMPARISON OF ESTIMATED TFPs TAKING BASE YEAR.



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 10

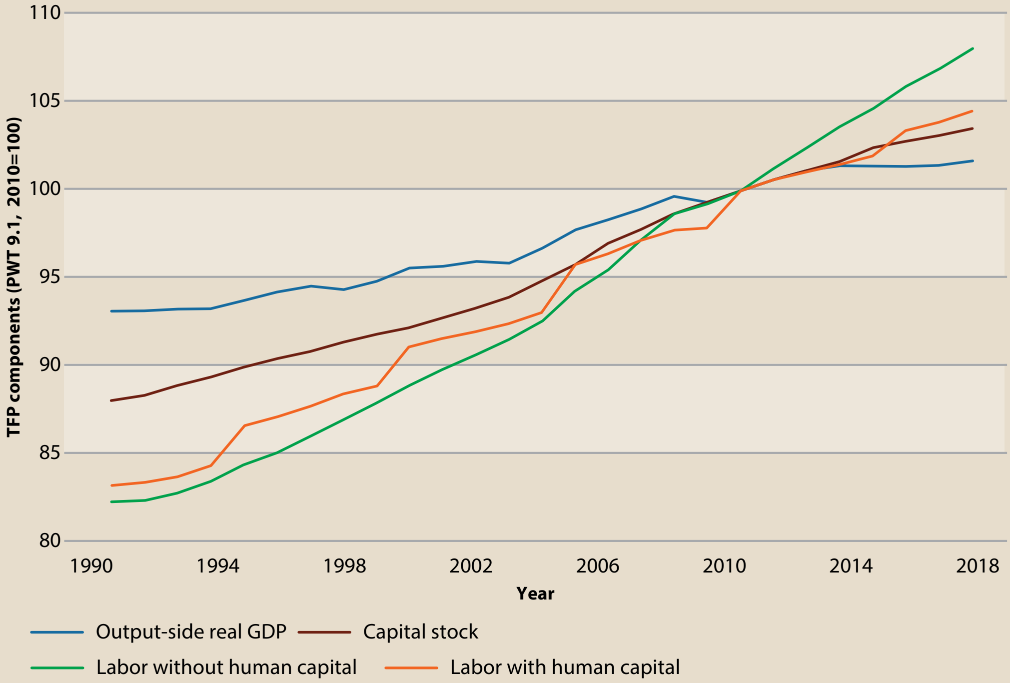
THE TRENDS OF TFP COMPONENTS.



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], and Lee and Lee [79] data.

FIGURE 11

THE TRENDS OF TFP COMPONENTS (PWT 9.1).



Source: Authors' estimation based on the PWT 9.1 [80], Barro and Lee [78], and Lee and Lee [79] data.

The components used in the TFP estimation are compared in Table 11. First, there is a difference in defining the capital stock. In this study, GCF from WDI is used, but the APO and the OECD define it by the subdivided components, using volumes of the types of capital services, which are aggregated using the Törnqvist Index. Second, in defining the labor inputs, this study considers both quantity and quality of labor by combining variables such as labor participation and years of schooling. By contrast, the APO and the OECD use total number of hours worked and do not consider the quality of labor force. Although the APO measures labor quality as QALI, which consists of the number of workers, hours worked per worker, and hourly wages, the total number of worked hours is used in the TFP estimation. Third, the shares of capital and labor are also assumed differently. In this study, the marginal return on physical capital is assumed to be 0.35 which is based on previous studies. Meanwhile, the APO and the OECD calculate their own versions of capital share by estimating the user cost of capital using ex-post and ex-ante approaches, respectively.

PWT 9.1 is the most recent version of the PWT, which consists of data such as TFP, GDP, and income for 182 countries for the period 1950–2017. According to Feenstra, et al. [80], TFP is estimated using real GDP at constant PPP 2011 national prices (in 2011 million USD) as a measure of output; employment; average years of schooling as a measure of labor input; and capital services at constant 2011 national prices (2011=1) as a measure of capital input. The equation for TFP estimation is as follows:

$$\frac{TFP_t}{TFP_{t-1}} = \frac{GDP_t}{GDP_{t-1}} / Q_{t,t-1} \, ,$$

where $Q_{t,t-1}$ is the Törnqvist Index of factor inputs.

$Q_{t,t-1}$ is derived by using the formula

$$Q_{t,t-1} = \frac{1}{2}(LABSH_t + LABSH_{t-1})\left(\frac{EMP_t}{EMP_{t-1}}\frac{HC_t}{HC_{t-1}}\right) + \left[1 - \frac{1}{2}(LABSH_t + LABSH_{t-1})\right]\left(\frac{RK_t}{RK_{t-1}}\right)$$

where $LABSH$ is labor share; EMP is employment; HC is the human capital variable; and RK is capital services.

PWT 9.1 differs from PWT 9.0 in that it includes new PPP data for the range of countries from ICP benchmarks for 2011; revised GDP data from the national accounts (NA) data of countries; and estimated capital services using the rate of change of the productive capital stock, which is the same as the OECD estimation [82]. In contrast with APO and OECD data, the PWT uses the number of employees instead of the number of hours worked as a measure of labor input and also takes into account labor quality by considering average years of schooling.

TABLE 11

COMPARISON OF ESTIMATED TFPs BY STATISTICS.

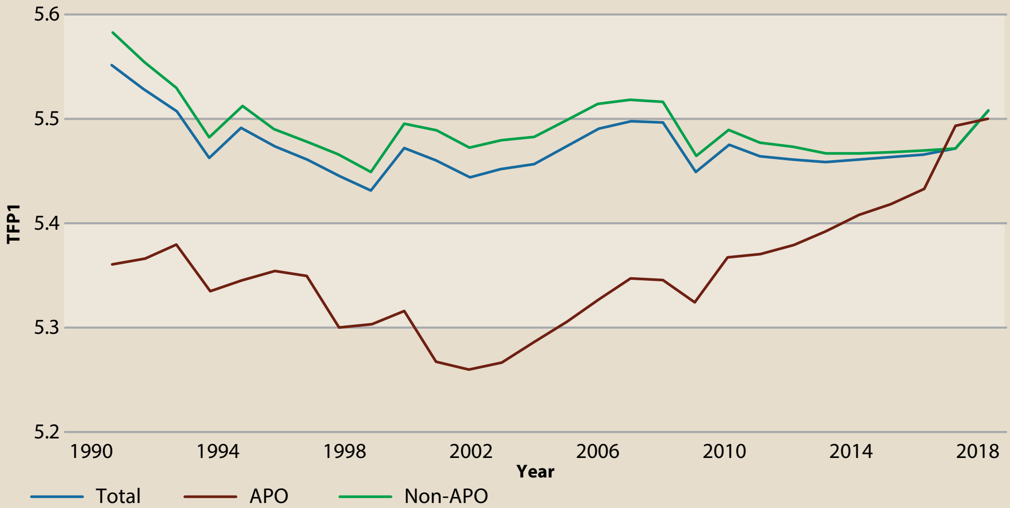
	TFP equation	Capital inputs	Capital share	Labor input	Labor share	Labor quality	GDP
TFP 1	$lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t)$ where L_t is labor force participation	GCF stock (WDI)	0.35	Labor participation in thousands of workers aged 15–64	0.65	x	Market price (WDI)
TFP 2	$lnA_t = lnY_t - (0.35 * lnK_t) - (0.65 * lnL_t)$ where $L_t = N_t P_t e^{0.1S}$	GCF stock (WDI)	0.35	Labor participation, years of schooling	0.65	o	Market price (WDI)
OECD Compendium of Productivity Indicators 2019	$\ln\left(\frac{TFP^t}{TFP^{t-1}}\right) = \ln\left(\frac{Q^t}{Q^{t-1}}\right) - \ln\left(\frac{X^t}{X^{t-1}}\right)$	Volume of 6–7 types of capital services aggregated by Törnqvist Index	Ex-ante approach	Total number of hours worked	The ratio of compensation of employees to the market-price GDP	x	Market price
APO Productivity Databook 2019	$(\ln TFP_t - \ln TFP_{t-1}) = Q_t - \frac{1}{2}(S_{kt} + S_{kt-1})K_t - \frac{1}{2}(S_{lt} + S_{lt-1})L_t$	Volume of 15 types of capital services aggregated by Törnqvist index	Ex-post approach	Total number of hours worked	The ratio of compensation of employees to the basic-price GDP	o / x	Basic price (market price minus–net indirect taxes on products)
PWT 9.1	$\frac{TFP_t}{TFP_{t-1}} = \frac{GDP_t}{GDP_{t-1}} / Q_{t,t-1}$	Volume of nine types of capital services aggregated by Törnqvist Index	Ex-ante approach	Number of employees, average years of schooling	The ratio of labor compensation of employees to the basic-price GDP	o	Real GDP at current PPPs (in million 2011 USD)

Note: Although APO [57] measures labor quality as QALI measure, APO TFP Index doesn't consider labor quality in the estimation.
Source: APO [83], APO [57], OECD [62,64], and Feenstra, et al. [80].

Figures 12–15 show the TFP trends by country groups, i.e., total, APO, and non-APO countries. All graphs reflect raw data. In Figure 12, all three TFP values show different trends. The values of APO countries increase most rapidly after switching in 2002, while the values of total and non-APO countries show similar trends over years. In other words, their TFP values show opposite trends compared with the TFPs of APO countries after 2002. Moreover, the TFPs that consider human capital show similar trends for each dataset, with the TFPs of APO countries showing the most similar pattern over years. This is one of the reasons why this study uses TFP2 as a dependent variable in Annexure C.

FIGURE 12

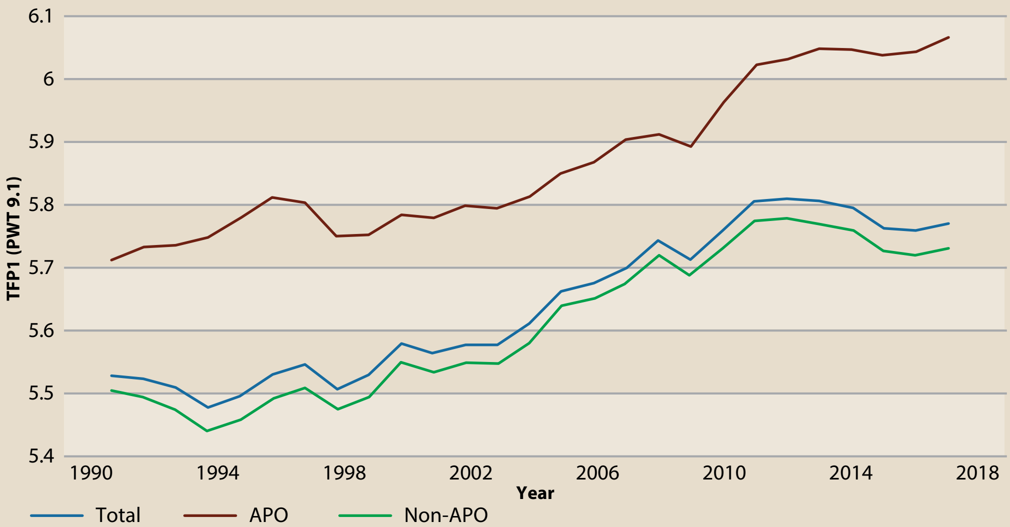
COMPARISON OF ESTIMATED TFP1 (WDI).



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 13

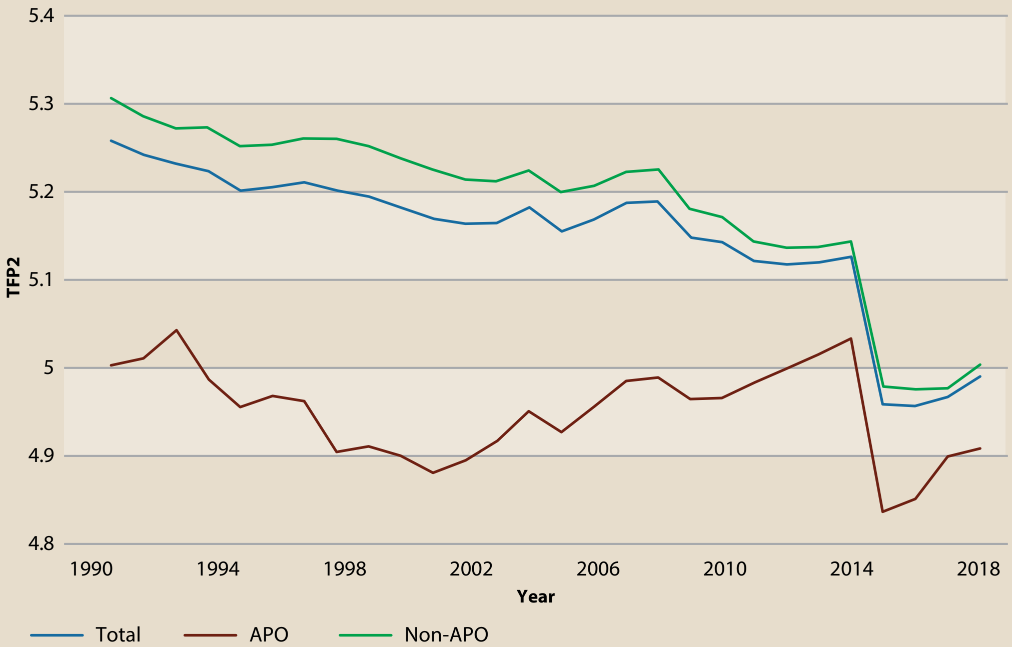
COMPARISON OF ESTIMATED TFP1 (PWT 9.1).



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 14

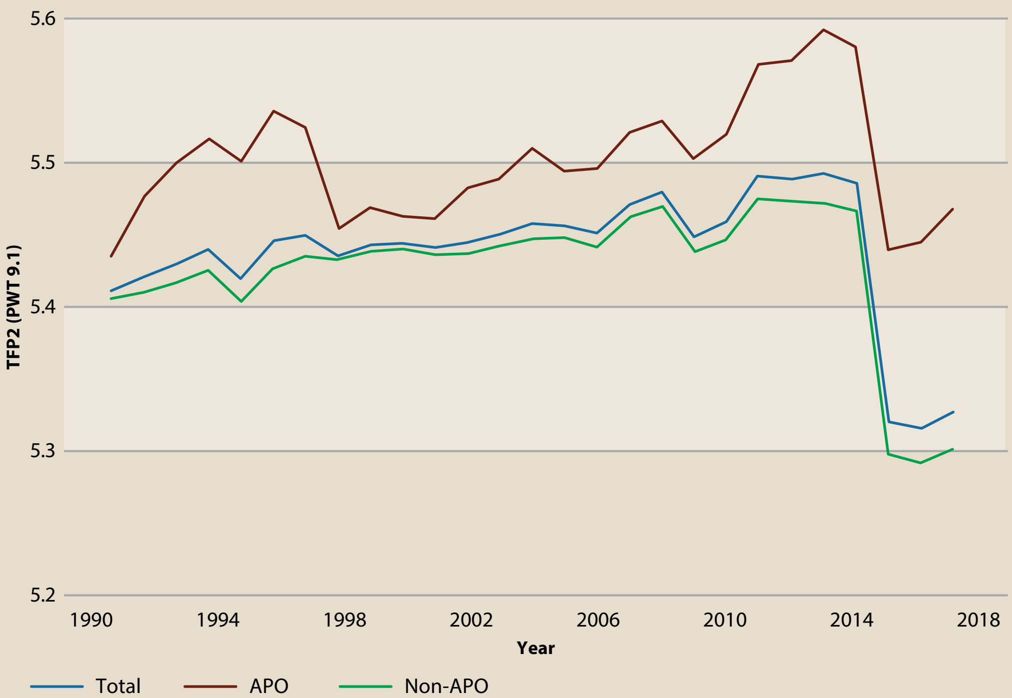
COMPARISON OF ESTIMATED TFP2 (WDI).



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 15

COMPARISON OF ESTIMATED TFP2 (PWT 9.1).



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

Next, the TFPs estimated in this study are compared with those estimated by the APO for APO countries and by the OECD for OECD countries.

First, Table 12 and Figure 16 compare the TFPs for APO countries. The APO provides historical TFP values (1970 to 2017) for 20 member countries (excluding Turkey, for which historical data is not available) and four non-member countries (Bhutan, Brunei, PR China, and Myanmar). Table 12 summarizes the descriptive statistics of the TFPs for APO countries. The values are a minimum of 98.419 and a maximum of 100.075. For the TFPs estimated by the APO, there are 540 observations, where the mean is 95.028 and the minimum and maximum values are 57.740 and 125.600, respectively.

Figure 16 shows an increasing trend for the period 1991–2018, even though absolute values are different. All values are indexed by 2010=100. Moreover, all estimated TFPs show similar increasing trends. APO TFPs show an increasing trend with a higher increasing rate. While the TFPs estimated in this study consider improvement in labor quality, the APO only uses total worked hours as labor input. This may have contributed to an overestimation of the APO's TFPs. While our TFP estimates do not consider user cost of capital, the APO uses different user costs of capital for different capital sectors, which may have led to some differences in the trends shown in Figure 16.

TABLE 12

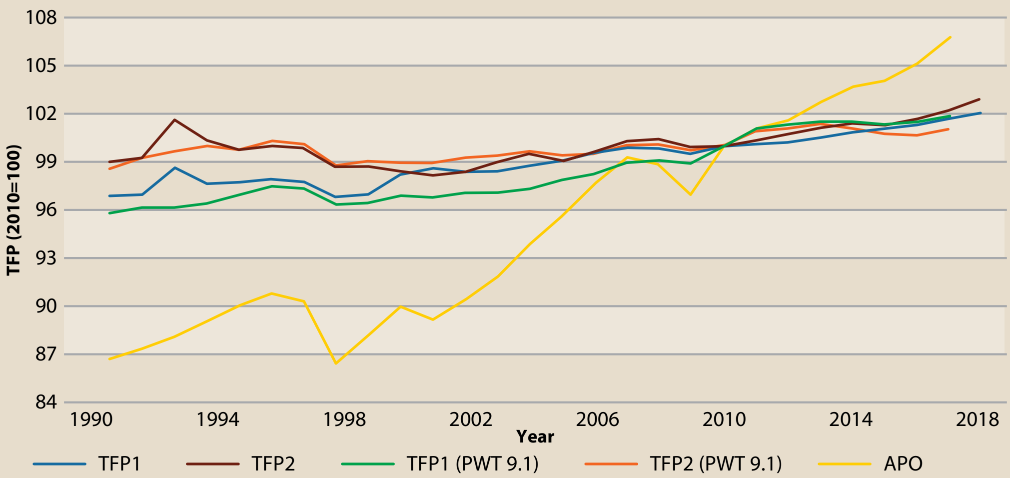
COMPARISON OF TFPS AND APO'S TFP FOR APO COUNTRIES (2010 = 100).

	Countries	Obs.	Mean	S.D.	Min	Max
TFP1 (WDI)	19	489	99.192	3.158	90.005	121.042
TFP2 (WDI)	19	333	100.075	2.910	91.033	125.380
TFP1 (PWT)	21	567	98.419	3.562	84.549	106.219
TFP2 (PWT)	21	378	99.917	2.837	87.388	107.680
APO	20	540	95.028	10.776	57.740	125.600

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], PWT 9.1 [80], and APO [57, 83, 84] data.

FIGURE 16

COMPARISON OF ESTIMATED TFPS AND APO TFPS.



Source: Authors' estimations based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], PWT 9.1 [80], and APO [57, 83, 84] data.

Second, Table 13 and Figure 17 compare the TFPs estimated in this study and the TFPs estimated by the OECD for OECD countries. The OECD estimated TFPs for only 23 countries out of 37 OECD member countries. They are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, the ROK, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK, and the USA.

The OECD measures TFP values as the ratio of a volume of output to a volume of input used, not only for OECD countries but also for some non-OECD countries (e.g., Brazil, PR China, India, Indonesia, Russia, and South Africa) after 1970. Like the APO, the OECD uses the total worked hours of employees as labor input. It derives capital input by aggregating the volume changes in capital services of all individual assets using asset-specific user cost shares as weights.

Table 13 presents summary statistics of the various TFPs. There are 644 TFP observations for WDI data and 621 TFP observations for the PWT data of 23 countries. All values are indexed by 2010 = 100. For example, the mean of TFP1 based on WDI data is 99.963, and the minimum and maximum of TFP2 with 100.21 of mean value are 95.980 and 106.06, respectively. In case of OECD Index, there are 622 observations, where the mean is 96.892 and the minimum and maximum values are 54.412 and 114.91, respectively.

Figure 17 presents the trends of the estimated TFPs and the OECD's TFP. From 1991 to 2017, other TFPs and the OECD's TFP show an improving trend, even though it differs from that of the APO's TFP. Meanwhile, the trend of the estimated TFPs relative to the OECD's TFPs seems to be flat. Like the APO, the difference in trends between our TFPs and that of the OECD's TFP could be due to the consideration of labor quality factors in our estimation (but not in the OECD); the user cost of capital in OECD estimation (but not in ours); and the use of different estimation methods in calculating a TFP.

TABLE 13

DESCRIPTIVE STATISTICS OF VARIOUS TFPS FOR OECD COUNTRIES (2010 = 100).

	Countries	Observations	Mean	Standard deviation	Minimum	Maximum
TFP1 (WDI)	23	644	99.963	1.195	94.749	105.166
TFP2 (WDI)	23	644	100.721	1.604	95.980	106.076
TFP1 (PWT)	23	621	99.170	1.828	90.985	104.731
TFP2 (PWT)	23	621	99.867	2.007	90.788	104.877
OECD	23	622	96.892	7.889	54.412	114.917

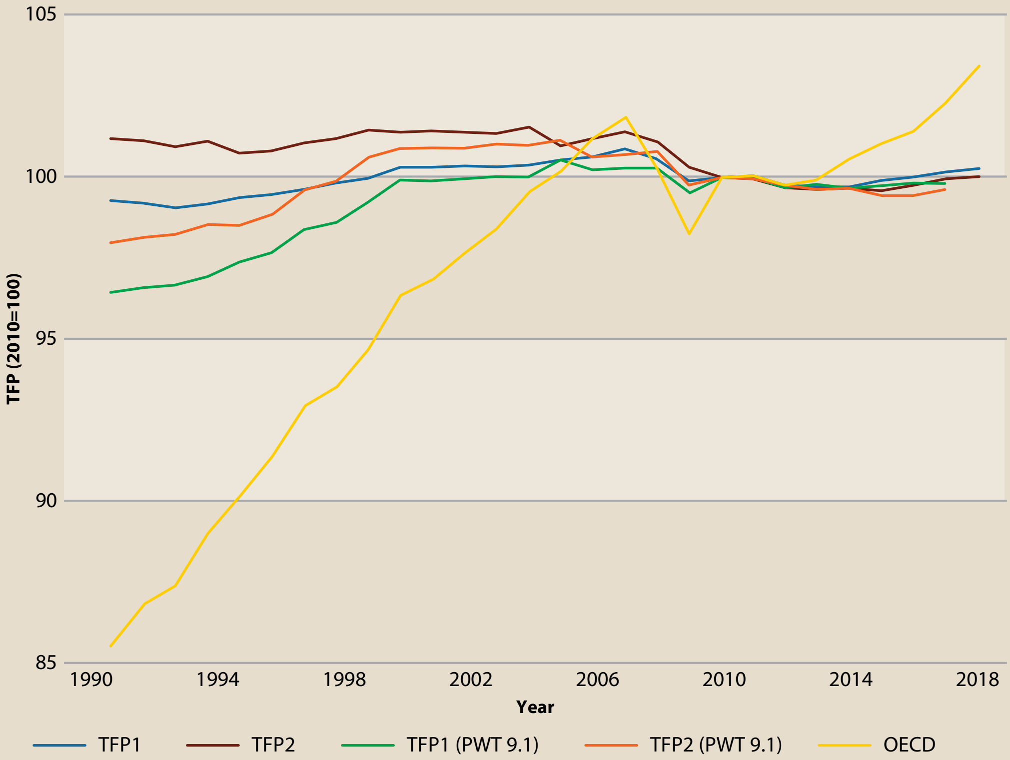
Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], PWT 9.1 [80], and OECD [55, 85] data.

Finally, Table 14 and Figure 18 compare the TFPs for 117 countries. Here, the values are indexed by the year 2011 = 100, while OECD and APO values are indexed in the year 2010. The mean of TFP2 (WDI) is 100.292 with a minimum of 88.282 and a maximum of 118.699. For the TFPs with PWT 9.1, 3,159 for TFP1 and 2,052 for TFP2 are observed.

Figure 18 shows the trends of five different TFPs. For the period 1991–2017, they show similar trends, though the gap among the values tends to decrease over the years. To be specific, starting

FIGURE 17

COMPARISON OF ESTIMATED TFPs AND OECD.



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], PWT 9.1 [80], and OECD [55, 85] data.

from a lower value than TFP1 when applying PWT 9.1, after 2010, the TFP1 based on WDI surpasses the TFP1 based on PWT9.1. The two TFP2 indices show more similar trends, as compared with the TFP1 indices. Both TFP2 indices reach the highest point in 2008 and show similar fluctuation over time. Furthermore, the index based on PWT 9.1 shows a noticeable fall in 1993 but recovers quickly from 2003 and reaches the highest point in 2007.

TABLE 14

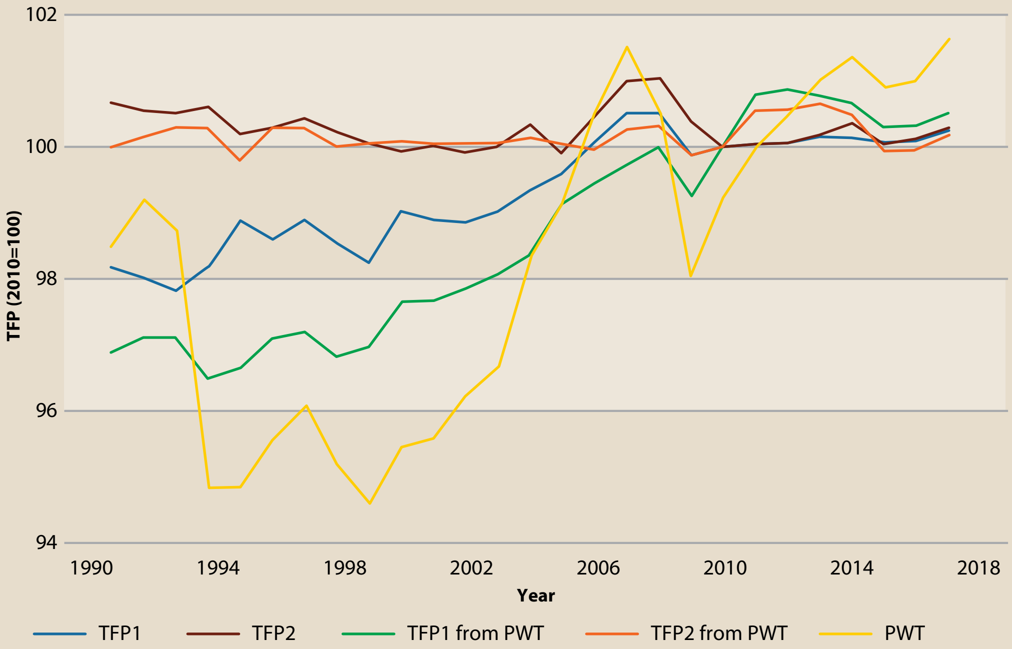
COMPARISON OF THE TWO TFPS AND PWT 9.1 TFP FOR 117 COUNTRIES (2011 = 100).

	Countries	Observations	Mean	Standard deviation	Minimum	Maximum
TFP1 (WDI)	114	2,887	99.485	3.084	76.911	126.632
TFP2 (WDI)	73	1,890	100.292	2.490	88.282	118.699
TFP 1 (PWT)	117	3,159	98.652	4.805	71.392	137.068
TFP 2 (PWT)	76	2,052	100.185	4.493	78.552	144.742
PWT	117	3,114	98.331	17.512	28.903	220.005

Note: The PWT9.1 reports the human capital data by index with 2011=100.
Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

FIGURE 18

COMPARISON OF THE ESTIMATED TFPs AND OECD'S TFP.



Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

Empirical Model Specification and Data

Empirical Model Specification

The empirical model specification is derived from the endogenous growth model by Romer [2] and Jones [59] and extended to a broader version with consideration of institutions [61]. The two models assume a Cobb–Douglas production function for country i in year t as in Equation (11):

$$Y_{it} = (A_{it}K_{it})^{\alpha}L_{Yit}^{1-\alpha} \quad (11).$$

Here, Y_{it}, A_{it}, K_{it},, and L_{Yit} are total value added (production), technology, capital, and labor of country i in year t, respectively, while α is the income share attributed to capital.

Unlike the neoclassical growth model of the Solow–Swan type, which assumes that technology is exogenously given and growing at a constant rate, Romer and Jones assume that technological growth depends on various factors such as the accumulated technology level, human capital, and innovation capacity. Since technology holds the properties of non-rivalry and non-excludability, innovation cannot occur and become profitable without appropriate institutional protection [61]. Therefore, we consider various institutional factors as determinants of innovation as shown in Equation (12) below:

$$A_{it} - A_{it-1} = A_{it-1}^{\beta_1}L_{Ait}^{\beta_2}\Theta_{it}^{\beta_3} \quad (12).$$

Here, Θ_{it} reflects various institutions that affect the innovation process for country i in year t. L_{Ait} is labor input contributed to innovation, which is a part of total labor, given by $L_{it} = L_{Ait} + L_{Yit}$.

The labor force decides whether it will work for output production or for an innovation process.

Equation (12) can be rewritten as Equation (13) given below:

$$\frac{A_{it}-A_{it-1}}{A_{it-1}} = A_{it-1}^{\beta_1} L_{Ait}^{\beta_2} \Theta_{it}^{\beta_3} \quad (13).$$

The first-order Taylor series expansion around 0 leads to the following equation [61]:

$$ln\, A_{it} - ln\, A_{it-1} = \beta_1\, ln\, A_{it-1} + \beta_2\, ln\, L_{Ait} + \beta_3\, ln\, \Theta_{it} + \omega_{it} \quad (14).$$

This study investigates the determinants of TFP for 135 countries for the period 1981–2018. Following Equation (14), TFP growth becomes a function of previous TFP level, labor input, and other institutional variables. With $ln\, A_{it} = lnTFP_{it}$, Equation (14) can be rewritten as an estimation Equation (15) given below:

$$lnTFP_{i,t} - lnTFP_{i,t-1} = \alpha + \beta lnTFP_{i,t-1} + \gamma X'_{i,t} + \eta_i + \xi_t + \epsilon_{i,t} \quad (15),$$

where α is a constant term; β and γ are the coefficients to be estimated;

$i = 1, 2, \cdots, N;\; t = 1, 2, \cdots, T;\; \eta_i = iid(0, \sigma_\eta^2);\; \xi_t = iid(0, \sigma_\xi^2)$; and $\epsilon_{i,t} = iid(0, \sigma_\epsilon^2)$.

The dependent variable, $TFP_{i,t}$, is a value derived as the natural log of TFP at time t of country i, and $TFP_{i,t-1}$ is TFP at time (t – 1) of country i. $X'_{i,t}$ is a row vector consisting of a total of four categories ($Y_{i,t}, G_{i,t}\, M_{i,t}$, and $I_{i,t}$), while $Y_{i,t}$ is a row vector of indicators that affect TFP growth in the traditional growth theory. They include gross domestic expenditure on R&D (GERD) as a percentage of GDP, which is an R&D investment variable; secondary school enrollment (% net), which is a variable of education and human capital; and energy use (kg of oil equivalent per capita), which reflects infrastructure. $G_{i,t}$ is a row vector of globalization that includes trade (% of GDP) and net FDI inflow (% of GDP). $M_{i,t}$ is a row vector of market regulation that consists of the regulation quality and the labor freedom index. Lastly, $I_{i,t}$ is a row vector of institutional quality that includes CPI and indices of economic freedom and rule of law, which are sourced from the World Bank Governance Indicators (WGI) [37]. Others refer to the political rights index from Freedom House [41], and the "share of most people can be trusted" from the World Value Survey (WVS) [86].

Here, $\omega_{it} = \eta_i + \upsilon_t + \varepsilon_{it}$, where η_i is an unobserved, time-invariant, country-specific term; υ_t is a year-specific term; and ε_{it} is white noise, respectively, for country i at time t. However, $lnTFP_{i,t-1}$ in Equation (15) is on both the left- and right-hand sides, which may cause endogeneity problems due to the lagged dependent variable in the dynamic panel model. In other words, it is difficult to obtain a consistent estimator via a general regression analysis. To avoid this problem, Equation (15) can be rewritten as Equation (16) by moving the lagging TFP to the right-hand side as follows:

$$lnTFP_{i,t} = \alpha + (1+\beta) lnTFP_{i,t-1} + \gamma X'_{i,t} + \eta_i + \xi_t + \epsilon_{i,t} \quad (16).$$

To remove the unobserved country-specific effect, the equation is converted to the first-difference equation as in Equation (17) below:

$$\Delta lnTFP_{i,t} = \alpha + (1+\beta)\Delta lnTFP_{i,t-1} + \gamma \Delta X'_{i,t} + \Delta\epsilon_{i,t} \quad (17).$$

Dynamic panel system Generalized Method of Moments (GMM) is used to solve this problem. The system GMM proposed by Arellano and Bover [87] and Blundell and Bond [88] estimates level Equation (16) and first-differenced Equation (17) simultaneously. At this point, both level-lagged and differenced-lagged variables of the explanatory variable are used as instrumental variables. That is, in the level equation, differenced variables that do not correlate with the error term $(\eta_i + \epsilon_{i,t})$ are used as instrumental variables, and in the first-differenced equation, lagged variables are used as instrumental variables.

In addition, since an overidentification problem of an instrumental variable can occur, the Sargan test is conducted to test the validity of the instrumental variables used in the estimation. In the Sargan test, the null hypothesis that the overidentifying restrictions are valid should not be rejected so that the instrumental variable used in the estimation can be validated. Moreover, as lagged dependent variables are used as instrumental variables of the first-differenced equation, serial correlation of error terms should be tested by the autocorrelation (AR) test of Arellano and Bond [89]. That is, both AR(1) and AR(2) should have a distribution of N(0, 1) and satisfy the following conditions: in AR(1), the statistical value should be a statistically significant negative number (i.e., rejecting the null hypothesis); and in AR(2), the null hypothesis that the correlation coefficient is 1 should be accepted to confirm that there is no serial correlation in the error term.

The difference from existing studies is that this study derives TFP values and presents determinants that can affect TFP into four categories. In existing studies, after specifying the specific variables that can affect TFP, explanatory variables are added. Generally, the variables suggested as determinants of TFP include FDI, R&D, human capital, income, trade, openness, labor regulation, and such others [90–94].

Data

To conduct an empirical analysis on the determinants of TFP, a panel dataset is constructed. The data are provided by the World Bank's World Development Indicators, World Bank Governance Indicators, UNESCO, ILO, Heritage Foundation, Transparency International, Freedom House, and World Values Survey, among others [37–41, 76, 77, 86]. The imputed TFP 2 is used as a dependent variable because it is derived by controlling human capital. The explanatory variables are composed of four categories based on the determinants affecting TFP. These are (1) *traditional input,* which is formally used in related literature as factors of production; (2) *globalization*, which reflects the degree of movement of resources; (3) *market regulation*; and (4) *institution* variables, which reflect the institutional aspects of the market and the overall society. To replace the missing values for all variables, the same imputation method that was mentioned above is used.

The sources and details of variables used in the analysis are shown in Table 15. The expected signs are the direction of the estimated coefficient expected from empirical analysis. The specific variables used in the estimation are as follows.

First, GERD per capita, the share of a country's total R&D expenditure, is used as the *traditional input*, where a higher value of GERD per capita is expected to have a positive impact on a country's TFP. Second, secondary school enrollment (% net), is a variable used to indicate the level of human capital quality, and is also expected to have a positive impact on TFP. Moreover, since energy consumption increases along with economic growth, energy use is used as a variable to represent the general economic performance of a country.

To represent the second category, *globalization*, as numerous previous studies have used, trade (% of GDP), FDI, and net inflow (% of GDP) are considered. They allow examining how the expansion of goods through trade affects economic growth, and a country's external dependence can be tested by resource inflow from the abroad.

For the third category, *market regulation*, a regulation quality indicator and the labor freedom index are used to reflect the degree of regulation in the market. The regulation quality indicator measures the degree of regulation that positively affects the development of the private sector, while the labor freedom index measures the degree of regulation on labor. Both variables are predicted to have a positive impact on TFP.

Lastly, to represent *institutional quality*, five variables (the indices of Economic Freedom, Corruption, Rule of Law, Political Rights, and the share of most people can be trusted) are used. The index of economic freedom indicates that the higher the score, the freer the legal system is. High freedom of the legal system means that there is a low degree of conflict with the input of resources in the production process. Economic freedom is predicted to have a positive correlation with TFP. Moreover, the CPI of Transparency International estimates how the public feels about the degree of corruption in the public sector. The lower the value, the greater the degree of corruption is. A high corruption index can have a negative impact on TFP, as investment that is not related to domestic productivity can occur. In addition, the rule of law variable is evaluated based on eight items, including restriction in government power, integrity, government openness, and basic rights, among others. This variable allows examining the level of the judicial system of a country and is expected to have a positive effect on TFP. Furthermore, the political rights variable is measured on a range of 1 to 7, where higher values mean fewer rights for the citizens. It measures political rights based on the electoral process, political pluralism and participation, and the function of the government. A country with fewer political rights is expected to have a higher TFP. Lastly, the "share of most people can be trusted" is a variable based on respondents' answers to the World Values Survey (WVS) [86]. In this study, the number of respondents who answered yes is expressed in percentage, and it is predicted to have a positive correlation with TFP.

Tables 16–18 show the summary statistics of imputed raw data according to the scope of the country (all, APO, and non-APO countries). For Table 16, 130 countries were analyzed, including 19 APO countries. However, the number of countries varied depending on the estimated model. Table 17 classified a total of 21 APO countries, excluding the analyses for Fiji and the ROC because their TFPs were not derived.

First, looking at the two TFPs with and without human capital as a dependent variable, the means of the TFPs of APO countries are 5.3 and 4.8, respectively, which are lower than those of all countries and non-APO countries (5.5 and 5.0). Moreover, for TFP1, the standard deviation for all and non-APO countries is 0.9, which is higher than the APO countries' standard deviation (0.8). For TFP2, the standard deviation of the non-APO countries is 0.8, which is also higher than the standard deviation of 0.7 for all and non-APO countries. This shows that there is a difference in the size of standard deviation by country group.

Next, the results for the four categories of explanatory variables are analyzed. GERD per capita, which represents *traditional input* (first category), has an average of 0.7 for all, APO, and non-APO countries, and has a standard deviation of 0.8 for all and non-APO countries, which is lower than the APO countries' standard deviation of 1.0. Secondary school enrollment (% net), which represents

TABLE 15

DEFINITION OF THE VARIABLES AND DATA SOURCES.

Variable	Definition	Expected sign	Source
(log) TFP	TFP estimated in previous section as a measure of the country's overall productivity.	Dependent variable	Author estimated
GERD (% of GDP)	Total intramural expenditure on R&D performed in the national territory during a specific reference period expressed as a percentage of GDP of the national territory.	+	UNESCO [38]
School enrollment, secondary (% net)	Ratio of children of official school age who are enrolled in school to the population of the corresponding official school age.	+	World Bank World Development Indicators [76]
Energy use (kg of oil equivalent per capita)	Equivalent to the approximate amount of energy that can be extracted from one kilogram of crude oil (41,868 kilojoules)	+/−	World Bank World Development Indicators [76]
Trade (% of GDP)	Sum of exports and imports of goods and services measured as a share of GDP	+	World Bank World Development Indicators [76]
FDI, net inflows (% of GDP)	Foreign direct investment is the net inflows of investment to acquire a lasting management interest (10% or more of voting stock) in an enterprise operating in an economy other than that of the investor.	+/−	World Bank World Development Indicators [76]
Regulation Quality	Perceived ability of government to formulate and implement sound policies and regulations. index distributed between −2.5 and 2.5	+	World Bank Governance Indicators [37]
Labor Freedom Index	The labor freedom component is a quantitative measure that considers various aspects of the legal and regulatory framework of a country's labor market, including regulations concerning minimum wages, laws inhibiting layoffs, severance requirements, and measurable regulatory restraints on hiring and hours worked.	+	The Heritage Foundation [39]
Economic freedom, overall score	The extent to which a legal system protects property rights in such areas as judicial independence, integrity of the legal system, and legal enforcement of contracts. Legal structure index ranges from 1 (no security of property rights) to 10 (full security of property rights)	+	The Heritage Foundation [39]
Corruption	The extent to which corruption is perceived to exist among public officials and politicians. The Index is distributed between 0 (highly corrupt) to 100 (very clean).	+	Transparency International [40]
Rule of Law	The extent to which people have confidence in and abide by the rules of the society. The Index distributed between −2.5 and 2.5.	+	World Bank Governance Indicators [37]
Political Rights	The extent to which people are allowed to participate freely and effectively in choosing their leaders or in voting directly on legislation. Gastil Index of political rights. It ranges from 1 (full rights) to 7 (no rights).	−	Freedom House [41]
Share of most people can be trusted	Share of respondents who believe that most people can be trusted	+/−	World Values Survey [86], various waves

human capital, shows an average of 62.7 for APO countries, which is higher than the average for all countries (61.5) and non-APO countries (61.4). This seems to be due to the large range of differences in the standard deviation and the minimum–maximum values for all and non-APO countries, which leads to various values when comparing between countries. The average of the energy-use variable is 2,164.5 for all countries; 1,485.0 for APO countries; and 2,248.4 for non-APO countries, with the non-APO countries' average being much higher than the other two categories. The standard deviation for the energy use of non-APO countries is also the highest at 2,887.1.

Looking at the average values of trade and FDI, which represent *globalization* (second category), the numbers indicate that APO countries tend to be more dependent on trade, having 100.4% share of trade to GDP, whereas non-APO countries have a value of 89.2%. For FDI (net inflows, % of GDP), APO countries have a lower value (4.3%) than non-APO countries (11.1%), which indicates that countries classified as APO countries have lesser average inflows than non-APO countries.

The summary statistics of the Regulation Quality and Labor Freedom indices represent *market regulation* (third category). The average of Regulation Quality is 0.0 for all categories, while the standard deviation for APO countries is 0.9, which is relatively lower than those for the other two categories. Moreover, regarding the range of the minimum–maximum values, non-APO countries show a larger difference than APO countries do. Meanwhile, the average of the Labor Freedom Index is 61.9, 63.9, and 61.6 for all, APO, and non-APO countries, respectively, which indicates that APO countries have a lower average level of labor restrictions than non-APO countries.

Lastly, the summary statistics of *institutional quality* (fourth category) are discussed. First, the Economic Freedom Index, which indicates the degree of freedom of the legal system, shows an average of 60.5 for APO countries, which is higher than the average for non-APO countries (57.6). This suggests that the legal systems of APO countries are relatively freer than those of non-APO countries. For the corruption variable, which quantifies the degree of corruption in the public sector, the averages for all, APO, and non-APO countries are 40.9, 40.2, and 41.0, respectively. This indicates that corruption in APO countries is relatively more prevalent than in non-APO countries. The average value of the rule-of-law variable is 0.0 for all categories. The average value of Political Rights is 3.8 for APO countries, which is higher than that for all countries (3.5), and non-APO countries (3.4). This implies that it is relatively more difficult to uphold political rights in APO countries. Looking at the "share of most people can be trusted" variable, the averages are 25.1%, 28.0%, and 28.0% for all, APO, and non-APO countries. The APO countries show relatively higher response rates, suggesting that more citizens feel that people in the society are trustworthy.

In addition, this study adjusts some variables for the convenience of analysis. First, considering that transforming variables into logarithms can omit negative values, the analysis is adjusted by adding the minimum value plus 1 to the variable. Moreover, some index variables are multiplied by a certain value to adjust the scale of the value. For example, in the case of the rule-of-law variable, the value is adjusted by multiplying the range by 10 and adding the minimum value. As a result, the summary statistics used in the analysis are as given in Table 19.

In addition, Tables 20 and 21 show the correlation coefficient values of all variables used in this study, with the number of observations used in each analysis being 2,436 and 2,204, respectively. For TFP 1 (Table 20) except for the political rights variable, all other variables show a positive (+) relationship with TFPs. Specifically, the variables GERD, education, energy, regulatory quality, corruption, and rule of law have correlation coefficients that are higher than 0.5. Moreover, the

TABLE 16

SUMMARY STATISTICS FOR ALL COUNTRIES.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
(log) TFP 1	4,843	5.5	0.9	3.2	7.8
(log) TFP 2	3,799	5.0	0.7	3.4	6.5
GERD (% of GDP)	4,263	0.7	0.8	0.0	4.6
School enrollment, secondary (% net)	5,423	61.5	27.5	0.2	99.9
Energy use (kg of oil equivalent per capita)	5,017	2,164.5	2,777.3	0.0	22,120.4
Trade (% of GDP)	5,800	90.3	58.1	0.0	860.8
FDI, net inflows (% of GDP)	5,771	10.4	70.5	–58.3	1,846.6
Regulation Quality	5,945	0.0	1.0	–2.6	2.3
Labor Freedom Index	5,394	61.9	16.8	0.0	100.0
Economic freedom overall score	5,336	57.9	12.2	1.0	90.5
Corruption	5,191	40.9	20.9	4.0	100.0
Rule of Law	4,080	0.0	1.0	–2.6	2.1
Political Rights	5,655	3.5	2.2	1.0	7.0
Share of most people can be trusted	3,161	25.1	14.6	2.8	75.0

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom house [41], and WVS [86] data.

TABLE 17

SUMMARY STATISTICS FOR APO COUNTRIES.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
(log) TFP 1	551	5.3	0.8	4.2	6.8
(log) TFP 2	551	4.8	0.7	3.8	6.2
GERD (% of GDP)	522	0.7	1.0	0.0	4.6
School enrollment, secondary (% net)	551	62.7	22.0	13.9	99.8
Energy use (kg of oil equivalent per capita)	551	1,485.0	1,469.1	118.9	7,370.7
Trade (% of GDP)	551	100.4	92.6	15.5	442.6
FDI, net inflows (% of GDP)	580	4.3	7.4	–37.2	58.5
Regulatory Quality	609	0.0	0.9	–1.7	2.3
Labor Freedom Index	609	63.9	15.2	37.8	98.9
Economic freedom overall score	609	60.5	13.0	33.5	90.5
Corruption	580	40.2	19.6	4.0	94.0
Rule of Law	420	0.0	0.8	–1.3	1.9
Political Rights	580	3.8	1.9	1.0	7.0
Share of most people can be trusted	435	28.0	13.9	2.8	50.9

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

TABLE 18

SUMMARY STATISTICS FOR NON-APO COUNTRIES.

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
(log) TFP 1	4,292	5.5	0.9	3.2	7.8
(log) TFP 2	3,248	5.0	0.8	3.4	6.5
GERD (% of GDP)	3,741	0.7	0.8	0.0	4.5
School enrollment, secondary (% net)	4,872	61.4	28.1	0.2	99.9
Energy use (kg of oil equivalent per capita)	4,466	2,248.4	2,887.1	0.0	22,120.4
Trade (% of GDP)	5,249	89.2	53.1	0.0	860.8
FDI, net inflows (% of GDP)	5,191	11.1	74.3	–58.3	1,846.6
Regulatory Quality	5,336	0.0	1.0	–2.6	2.1
Labor Freedom Index	4,785	61.6	17.0	0.0	100.0
Economic freedom overall score	4,727	57.6	12.1	1.0	84.2
Corruption	4,611	41.0	21.0	6.9	100.0
Rule of Law	3,660	0.0	1.0	–2.6	2.1
Political Rights	5,075	3.4	2.2	1.0	7.0
Share of most people can be trusted	2,726	24.6	14.7	2.8	75.0

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

political rights variable has a negative (–) correlation, with a coefficient of –0.395. Meanwhile, TFP2, shown in Table 20, has a higher positive (+) relationship with the variables GERD, education, energy, regulatory quality, corruption, and rule of law. However, the variables FDI and political rights show negative (–) values in Table 21.

Estimation Results

The empirical analysis presents the results of combining different sets of independent variables. Table 22 shows the estimation results for all countries, while Table 23 shows the estimation results when dividing them into APO and non-APO countries. The estimation periods are the same, from 1991 to 2018.

First, Models 1 to 3 present two-step estimators by adding more independent variables. Additional independent variables represent the four categories of *traditional inputs, Globalization, Market Regulation*, and *Institutional Quality*. A lagged TFP variable is used as a common endogenous variable, while 'energy use' is used as an exogenous variable. Specifically, GMM-type instrumental variables are the first-differenced variables of the lagged dependent variable from period t-3 to t-4. The number of countries analyzed is 102, 101, and 101 for Models 1, 2, and 3, respectively. The specification test statistics show that all model specifications are statistically valid. The p-values of AR(1) are significant at the 1% level; the p-values of AR(2) are insignificant; and the p-values of the Sargan test are not statistically significant. In the Sargan test, the hypothesis is rejected after estimating the one-step system GMM, but the two-step system GMM is not rejected. Thus, Models 1 to 3 present results from two-step system GMM with standard errors, adjusted for clustering by countries.

TABLE 19

DESCRIPTIVE STATISTICS.

	Variable	Observations	Mean	Standard deviation	Minimum	Maximum
		APO				
TFP	(log) TFP 1	551	5.3	0.8	4.2	6.8
	(log) TFP 2	551	4.8	0.7	3.8	6.2
Traditional input	GERD (% of GDP)	522	0.7	1.0	0.0	4.6
	School enrollment, secondary (% net)	551	62.7	22.0	13.9	99.8
	(log) Energy use (kg of oil equivalent per capita)	551	6.8	1.0	4.8	8.9
Globalization	Trade (% of GDP)	551	100.4	92.6	15.5	442.6
	FDI, net inflows (% of GDP)	580	4.3	7.4	–37.2	58.5
Market Regulation	Regulatory quality	609	2.7	0.9	0.9	4.9
	Labor freedom index	609	63.9	15.2	37.8	98.9
Institutional Quality	Economic freedom overall score	609	60.5	13.0	33.5	90.5
	Corruption	580	40.2	19.6	4.0	94.0
	Rule of law	609	26.2	8.1	13.3	44.7
	Political rights	580	3.8	1.9	1.0	7.0
	Share of most people can be trusted	435	28.0	13.9	2.8	50.9
		Non-APO				
TFP	(log) TFP 1	4,292	5.5	0.9	3.2	7.8
	(log) TFP 2	3,248	5.0	0.8	3.4	6.5
Traditional input	GERD (% of GDP)	3,741	0.7	0.8	0.0	4.5
	School enrollment, secondary (% net)	4,872	61.4	28.1	0.2	99.9
	(log) Energy use (kg of oil equivalent per capita)	4,466	7.0	1.3	0.0	10.0
Globalization	Trade (% of GDP)	5,249	89.2	53.1	0.0	860.8
	FDI, net inflows (% of GDP)	5,191	11.1	74.3	–58.3	1,846.6
Market Regulation	Regulatory quality	5,336	2.6	1.0	0.0	4.7
	Labor freedom index	4,785	61.6	17.0	0.0	100.0
Institutional Quality	Economic freedom overall score	4,727	57.6	12.1	1.0	84.2
	Corruption	4,611	41.0	21.0	6.9	100.0
	Rule of law	5,394	26.0	10.2	0.0	47.1
	Political rights	5,075	3.4	2.2	1.0	7.0
	Share of most people can be trusted	2,726	24.6	14.7	2.8	75.0

Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom house [41], and WVS [86] data.

TABLE 20

CORRELATION MATRIX (OBSERVATIONS = 2,436).

	TFP1	GERD	Education	Energy	Trade	FDI	Regulatory	Labor freedom	Economic freedom	Corruption	Rule of law	Political rights	Trust
TFP1	1.000												
GERD	0.529	1.000											
Education	0.547	0.511	1.000										
Energy	0.757	0.605	0.711	1.000									
Trade	0.091	0.122	0.230	0.247	1.000								
FDI	0.007	0.004	0.089	0.046	0.302	1.000							
Regulatory	0.592	0.634	0.516	0.577	0.302	0.117	1.000						
Labor Freedom	0.277	0.158	0.256	0.302	0.175	0.028	0.258	1.000					
Economic Freedom	0.378	0.457	0.357	0.405	0.270	0.100	0.822	0.308	1.000				
Corruption	0.627	0.720	0.489	0.658	0.276	0.093	0.873	0.303	0.724	1.000			
Rule of Law	0.629	0.712	0.505	0.634	0.268	0.116	0.924	0.234	0.736	0.922	1.000		
Political Rights	−0.395	−0.501	−0.425	−0.336	−0.033	−0.074	−0.728	0.010	−0.527	−0.596	−0.689	1.000	
Trust	0.441	0.503	0.298	0.494	0.026	−0.015	0.373	0.342	0.209	0.517	0.487	−0.160	1.000

Note: (1) Education=secondary school enrollments (% net); (2) Energy=log of energy use (kg of oil equivalent per capita); (3) Regulatory=regulatory quality; and (4) Trust=share of most people can be trusted.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

TABLE 21

CORRELATION MATRIX (OBSERVATIONS = 2,204).

	TFP2	GERD	Education	Energy	Trade	FDI	Regulatory	Labor freedon	Economic freedom	Corruption	Rule of law	Political rights	Trust
TFP2	1.000												
GERD	0.504	1.000											
Education	0.515	0.553	1.000										
Energy	0.697	0.605	0.736	1.000									
Trade	0.062	0.126	0.232	0.254	1.000								
FDI	−0.003	0.010	0.086	0.051	0.304	1.000							
Regulatory	0.553	0.648	0.644	0.629	0.335	0.132	1.000						
Labor Freedom	0.288	0.181	0.246	0.315	0.177	0.026	0.317	1.000					
Economic Freedom	0.340	0.467	0.455	0.449	0.301	0.111	0.807	0.357	1.000				
Corruption	0.614	0.718	0.564	0.676	0.293	0.106	0.877	0.341	0.718	1.000			
Rule of Law	0.604	0.717	0.610	0.669	0.289	0.131	0.922	0.286	0.720	0.922	1.000		
Political Rights	−0.352	−0.497	−0.514	−0.360	−0.041	−0.085	−0.706	−0.021	−0.494	−0.576	−0.670	1.000	
Trust	0.413	0.492	0.325	0.491	0.022	−0.012	0.374	0.365	0.205	0.513	0.490	−0.144	1.000

Note: (1) Education=secondary school enrollments (% net); (2) Energy=log of energy use (kg of oil equivalent per capita); (3) Regulatory=regulatory quality; and (4) Trust=share of most people can be trusted.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

For all model specifications, the lagged dependent variable is shown to be positive and significant. From Equation (15), the estimated coefficient is $(1+\beta)$. Thus, β can be calculated by subtracting 1 from the estimated coefficient. For example, since $1+\beta = 0.89$, β is –0.11. Thus, the lagged TFP has a negative correlation with its growth rate. The countries with lower initial value of TFP tend to have a higher growth rate.

GERD, which represents R&D expenditure, is positive (+) and significant. This indicates that investments in the R&D sector help in enhancing TFP. Meanwhile, 'school enrollment of secondary education,' which represents human capital in the *traditional input* category is positive (+) but not statistically significant in all models. Moreover, although the log of 'energy use,' which helps to enhance TFP, is positive (+), it is not statistically significant.

Next, among the variables for the *globalization* category, trade and FDI have negative (–) but not statistically significant coefficients in all models. In addition, Regulatory Quality, in the *Market regulation* category, is significant in Model 3. However, Labor Freedom Index has a negative (–) coefficient and is not significant.

Lastly, *institutional quality* was included in Model 4. The estimation results by the one-step system GMM estimator are as follows: Model 4 includes 76 countries. A lagged dependent variable is endogenous, while 'energy use' is considered to be exogenous. In the estimation of the first-differenced equation, the lagged dependent variable from t-3 is used as the instrumental variable. Moreover, for the level equation, the difference of the lagged dependent variables is used as a GMM-type instrumental variable. Furthermore, the constants are used as standard instrumental variables in estimating the level equation. Regarding the validity of the model by the Arellano and Bond [89] test, AR(1) is rejected at the 1% significance level, which shows autocorrelation; while the p-value of AR(2) is not rejected at the 1% significance level, which signifies no autocorrelation. In addition, the p-value of the Sargan overidentification test is 0.799, which is so sufficiently large that the hypothesis of the validity of overidentifying restrictions cannot be rejected. Therefore, the instrumental variables used in the estimation are deemed valid.

The estimated coefficient of TFP at period t-1 is shown to be significant and positive (+). The sign or significance of the coefficients of some variables is changed in Model 4. Corruption and political rights variables are shown to be positive and statistically significant. This implies that a lower degree of corruption contributes to an improvement of TFP, and the participation of legislation negatively affects TFP, even though by a small value.

In conclusion, the results for all countries are summarized as follows: First, the estimated coefficient of TFP at period t-1 is positive and significant in all models. Further, in Model 4, which considers all institutional indicators, Corruption and Political Rights are shown to be positive and statistically significant. This implies that anticorruption efforts pertaining to public officials and politicians are important in promoting TFP growth. However, the political rights indicator is shown to be positive, which implies a negative relation with TFP growth. This is inconsistent with our expectation. Thus, even though the coefficient is very small and reflects minor effects on TFP growth, it requires further investigation.

In the Appendix, Table 5 presents the system GMM results using the difference of the log of TFP 2 as a dependent variable described above in this section. All models satisfied the three types of system GMM model diagnostic tests. The p-value in the Sargan test is about 1, which means that there are too many instrumental variables included in all models. The log of energy use shows negative (–) values for the non-APO model, as expected. Meanwhile, trade shows a positive (+) and significant coefficient for the non-APO countries, and FDI shows positive (+) and significant values for the APO countries, which implies the importance of trade openness in driving productivity growth. Moreover, in the total and non-APO models, corruption and political rights have positive (+) but small coefficients that are significant at the 5% and 10% significance levels, respectively.

The empirical analysis presents the results by combining different sets of independent variables. Table 22 shows the estimation results for all countries, and Table 23 shows the estimation results by dividing countries into APO and non-APO groups. The estimation periods are same (from 1991 to 2018).

First of all, Model 1 to Model 3 present two-step estimators by adding more independent variables. Additional independent variables represent four categories of *traditional inputs, Globalization, Market Regulation*, and *Institutional Quality*. TFP lagged variable is used as an endogenous variable in common, and 'energy use' is used as an exogenous variable. So GMM-type instrument variables are the first-differenced variable of lagged dependent variable from period t-3 to t-4. The number of countries analyzed is 102 countries for Model 1 and 101 countries for Model 2 and Model 3. The specification test statistics show that all model specifications are statistically valid. The p-values of AR(1) are significant at the 1% level, the p-values of AR(2) are insignificant, and the p-values of Sargan test are not statistically significant. In the Sargan test, the hypothesis is rejected after estimating the one-step system GMM, but the two-step system GMM is not rejected. So, Models 1 to 3 present results from two-step system GMM with standard errors adjusted for clustering by countries.

For all model specifications, lagged dependent variable is shown to be positive and significant. Since the estimated coefficient is (1+β) from Equation (15), β can be calculated by subtracting 1 from the estimated coefficient. For example, since 1+β=0.89, β is –0.11 so that the lagged TFP has negative correlation with its growth rate. The countries with lower initial value of TFP tend to have higher growth.

The GERD that represents R&D expenditure is positive (+) and significant. It indicates that investments for R&D sector help to enhance TFP. The 'school enrollment of secondary education,' which represents human capital of the *traditional input* category is shown to be positive (+) but is not statistically significant in all models. Moreover, although 'the log of energy use,' which helps to enhance TFP is shown to be positive (+), it is not statistically significant.

Next, among the variables in the *globalization* category, trade and FDI show negative (–) coefficients in all models but are not statistically significant. In addition, the regulatory quality variable in *market regulation* category is significant in Model 3. However, the labor freedom variable shows a negative (–) coefficient and is not significant.

Lastly, *institutional quality* was included in Model 4. The estimation results by the one-step system GMM estimator are as follows. Model 4 includes 76 countries. A lagged dependent variable is endogenous, while the 'energy use' is considered to be exogenous. In the estimation of the first-differenced equation, the lagged dependent variable from t-3 is used as an instrument variable. For the level equation, the difference of lagged dependent variables is used as a GMM-type instrumental variable. Moreover, the constants are used as standard instrument variables in estimating the level equation. Regarding the validity of the model by the Arellano and Bond [89] test, AR(1) is rejected at a 1% significance level that shows autocorrelation. The p-value of AR(2) is not rejected at a 1% significance level and thus there is no autocorrelation. In addition, the p-value of the Sargan overidentification test is 0.799, which is so sufficiently large that the hypothesis of the validity of overidentifying restrictions cannot be rejected. Therefore, the instrument variables used in the estimation are valid.

The estimated coefficient of TFP at period t-1 is shown to be significant and positive (+), and the signs or significance of some variables' coefficients are changed in Model 4. As a result, corruption and political rights are shown to be positive and statistically significant. This implies that the lower degree of corruption contributes to an improvement in TFP, while the participation of legislation negatively affects TFP even if by a small value.

In conclusion, the results of total countries are summarized as follows: First, estimated coefficient of TFP at period t-1 showed positive and significant in all models. Further, in Model 4 that considers all institutional indicators, 'corruption' and 'political rights' are shown to be significant and statistically significant. This implies that anticorruption among public officials and politicians is an important factor in promoting TFP growth. However, the political rights indicator is shown to be positive, implying negative relation with TFP growth, which is at odds with the expectation. So even though the coefficient is very small and reflects minor effects on TFP growth, it requires further studies.

In the Appendix, Table 5 presents the system GMM results by using difference of log of TFP 2 as a dependent variable. All models are satisfied by three types of system GMM model diagnostic tests. The p-value in Sargan test is about 1, which means too many instrument variables are included in all models. The log of 'energy use' shows negative (–) values for non-APO countries as per the expectation. On the other hand, 'trade' shows positive (+) and significant coefficients for non-APO countries, while 'FDI' shows positive (+) and significant coefficients for APO countries, implying the importance of openness in driving productivity growth. Moreover, in total and non-APO model, 'corruption' and 'political rights' have positive (+) but small coefficients which are significant at the 5% and 10% significance levels, respectively.

Table 22: System GMM estimation results using baseline model.

Table 23 uses the same model specification as in Model 4, dividing the sample into all, APO, and non-APO countries. Model 5 considers 76 countries. Model 5 and Model 7 analyze 11 and 65 countries, respectively, due to missing institution variables in some countries.

In the estimation, a lagged dependent variable is used as an endogenous variable, while GMM-type instrumental variables in the first-differenced equation are used as lagged dependent variables from period t-3 in the total and non-APO country models, and from period t-3 to t-6 in the APO country model. Moreover, 'energy use' is used as a standard instrumental variable for the differenced equation as an exogenous variable, and the instrument for the level equation is the lagged dependent variable and some constants.

Regarding the specification validity of the model, the Arellano and Bond [89] test statistics show that the models are valid. AR(1) is rejected at the 1% and 5% significance levels, as it presents autocorrelation. The p-values of AR(2) are so sufficiently large that the model cannot be rejected.

TABLE 22

SYSTEM GMM ESTIMATION RESULTS USING BASELINE MODEL.

Model	(1)	(2)	(3)	(4)
(log) (t-1) TFP2	0.879***	0.874***	0.879***	0.879***
	(0.033)	(0.041)	(0.029)	(0.037)
GERD	0.056***	0.061**	0.046**	−0.029
	(0.018)	(0.027)	(0.023)	(0.048)
Education/100	0.075	0.103	0.053	−0.069
	(0.071)	(0.074)	(0.111)	(0.225)
(log) Energy use	0.006	0.009	0.008	0.048
	(0.008)	(0.011)	(0.011)	(0.056)
Trade/100		-0.005	−0.042	−0.031
		(0.024)	(0.027)	(0.035)
FDI/100		-0.021	−0.007	−0.026
		(0.024)	(0.029)	(0.053)
Regulatory quality			0.036*	0.074
			(0.022)	(0.094)
Labor freedom/100			−0.014	−0.067
			(0.088)	(0.187)
Economic freedom/100				−0.406
				(0.487)
Corruption/100				0.350**
				(0.175)
Rule of law/100				−0.065
				(0.614)
Political rights/100				0.358**
				(0.183)
Trust/100				−0.052
				(0.233)
Constant	0.354	0.342	0.410***	0.226
	(0.313)	(0.364)	(0.146)	(0.311)
Observations	2,856	2,828	2,828	2,128
Number of countries	102	101	101	76
AR(1)	0.001	0.001	0.001	0.000
AR(2)	0.494	0.385	0.165	0.766
Sargan	0.312	0.225	0.119	0.799

Notes: (1) Model 1, Model 2, and Model 3 were estimated by two-step system GMM, while Model 4 was estimated by one-step GMM with clustered standard errors (in parentheses). (2) *** represents significant at 1%, ** represents significant at 5%, and * represents significant at 10%. (3) All models include year dummies. (4) AR(1) and AR(2) are the test results for auto-regressive processes of order 1 and order 2, respectively. Sargan test reports the p-values for the overidentification restrictions.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

Thus, there is no autocorrelation. In addition, the p-values of the Sargan overidentification test are also large that the hypothesis of the validity of overidentifying restrictions cannot be rejected. Therefore, the instrumental variables used in the estimation are deemed valid.

As a result, in every model, the estimated coefficient of TFP at period t-1 shows a significant positive (+) value. This implies that when other variables are controlled, the countries with lower initial TFP values tend to grow faster. Moreover, 'political rights' is significant and positive (+) with a small coefficient in every model, which is an unexpected result. This implies that TFP can improve, even if political freedom is not guaranteed.

In the *market regulation* category, 'regulatory quality' is shown to have a positive (+) value for APO countries, which is not significant in Models 5 and 7. Meanwhile, the coefficient for the 'rule of law' is significant (+) for APO countries. In Models 5 and 7, 'corruption' in the *institutional quality* category is shown to be positive (+) and statistically significant, which implies that the eradication of corruption in a country is an important component of TFP growth.

TABLE 23

SYSTEM GMM ESTIMATION RESULTS: COUNTRY GROUP.

Model	(5) Total countries	(6) APO countries	(7) Non–APO countries
(log) (t–1) TFP2	0.879*** (0.037)	0.964*** (0.015)	0.867*** (0.062)
GERD	−0.029 (0.048)	−0.015 (0.031)	−0.007 (0.043)
Education/100	−0.069 (0.225)	−0.057 (0.104)	−0.116 (0.163)
(log) Energy use	0.048 (0.056)	0.024 (0.028)	0.066 (0.041)
Trade/100	−0.031 (0.035)	−0.027 (0.029)	−0.010 (0.037)
FDI/100	−0.026 (0.053)	−0.332 (0.285)	−0.031 (0.043)
Regulatory quality	0.074 (0.094)	0.047* (0.025)	0.058 (0.092)
Labor freedom/100	−0.067 (0.187)	0.004 (0.118)	−0.198 (0.151)
Economic freedom/100	−0.406 (0.487)	−0.123 (0.218)	−0.106 (0.515)
Corruption/100	0.350** (0.175)	−0.203 (0.225)	0.294* (0.160)
Rule of law/100	−0.065 (0.614)	0.451* (0.259)	−0.009 (0.483)

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Model	(5) Total countries	(6) APO countries	(7) Non–APO countries
Political rights/100	0.358**	0.123**	0.311*
	(0.183)	(0.060)	(0.163)
Trust/100	−0.052	0.026	−0.218
	(0.233)	(0.083)	(0.267)
Constant	0.226	−0.037	0.153
	(0.311)	(0.210)	(0.350)
Observations	2,128	308	1,820
Number of countries	76	11	65
AR(1)	0.000	0.017	0.000
AR(2)	0.776	0.446	0.531
Sargan	0.799	0.219	0.403

Notes: (1) The results are based on one-step system GMM with the clustered standard errors (in parentheses). (2) *** represents significant at 1%, ** represents significant at 5%, and * represents significant at 10%. (3) All models include year dummies. (4) AR(1) and AR(2) are the test results for auto-regressive processes of order 1 and order 2, respectively. Sargan test reports the p-values for the overidentification restrictions.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

Lastly, Table 24 shows the estimation results for all countries using TFP1 in Model 8 and TFP2 in Model 9, where TFP values are estimated. The results of Model 9 are from Model 4 of Table 22. First, the two models satisfy the three system GMM tests. TFP 1 in Model 8 shows that only 'political rights' is positive (+), which is an unexpected result, as more rights for the citizens (i.e., lower 'political rights' value) was predicted to contribute to TFP growth. In contrast with Model 8, the TFP2 results in Model 9, which considers human capital, shows that some coefficients have the opposite direction. For example, the value for 'corruption' is negative, but it is not shown to be significant in Model 8.

In the Appendix, Table 6 shows the system GMM results using the log of TFP from PWT 9.1 as a dependent variable. Two models satisfied three types of system GMM model diagnostic tests. As estimation results, in every model, the estimated coefficient of TFP at period (t–1) showed significant and positive (+) value. Also, 'labor freedom' is statistically significant and positive (+) in Model 1, implying higher labor rights have a positive correlation with TFP growth for total country. Moreover, when the human capital is considered, 'corruption' shows positive (+) coefficient at 5% significance level for total country. As a result, the estimation results of PWT 9.1 also have effective factors on TFP but show small coefficients.

TABLE 24

SYSTEM GMM ESTIMATION RESULTS FOR TFP1.

Model	(8) (log) TFP1	(9) (log) TFP2
(log) (t–1) TFP	0.854***	0.879***
	(0.060)	(0.037)
GERD	0.081	–0.029
	(0.096)	(0.048)
Education/100	0.305	–0.069
	(0.371)	(0.225)
(log) Energy use	–0.060	0.048
	(0.081)	(0.056)
Trade/100	–0.114	–0.031
	(0.073)	(0.035)
FDI/100	–0.037	–0.026
	(0.040)	(0.053)
Regulatory quality	0.058	0.074
	(0.096)	(0.094)
Labor freedom/100	–0.047	–0.067
	(0.200)	(0.187)
Economic Freedom/100	0.772	–0.406
	(0.500)	(0.487)
Corruption/100	–0.021	0.350**
	(0.242)	(0.175)
Rule of Law/100	0.901	–0.065
	(1.182)	(0.614)
Political rights/100	0.481*	0.358**
	(0.268)	(0.183)
Trust/100	–0.633	–0.052
	(0.442)	(0.233)
Constant	0.199	0.226
	(0.416)	(0.311)
Observations	2,352	2,128
Number of countries	84	76
AR(1)	0.001	0.000
AR(2)	0.351	0.776
Sargan	0.789	0.799

Notes: (1) The results are based on one-step system GMM with the clustered standard errors (in parentheses). (2) *** represents significant at 1%, ** represents significant at 5%, and * represents significant at 10%. (3) All models include year dummies. (4) AR(1) and AR(2) are test results for auto-regressive processes of order 1 and order 2, respectively. Sargan test reports the p-values for the overidentification restrictions.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

ANNEXURE C

PRODUCTIVITY AND PRODUCTION EFFICIENCY ESTIMATION

Introduction

In a nutshell, the notion of productivity typically refers to how much output is obtained for a given level of inputs. The notion of production (or productive) efficiency takes this notion of productivity into a relative perspective. It refers to how high the attained productivity level is relative to a reference or benchmark, e.g., relative to some optimal level. The next two subsections will discuss both these concepts and then provide a more formal treatment to them, while more details can be found in Sickles and Zelenyuk [95], which has been followed here among other sources cited therein and here.

The Notion of Productivity

By far the most commonly used (and the simplest) example of a measure designed to capture the notion of productivity is *labor productivity*, defined as a single-valued measure of output (e.g., GDP) divided by a single-valued measure representing labor as a key input that was used to produce that output.

While being both an intuitive and useful measure, labor productivity (and any other single-factor productivity measure) requires careful interpretation because it only uses a single input (labor) and ignores the other inputs that are perhaps as important or even more important in the production of the output (e.g., physical capital, human capital, and materials). As a result, when studying levels of or changes in labor productivity, it is also useful to look at the sources of those changes, e.g., whether they are due to a change in capital, a change in technology, or a change in the efficiency of using that technology.

Moreover, the use of labor productivity (or any other single-factor productivity measure) also requires a single output process or all outputs to be adequately aggregated into a single-valued aggregate output. Often, this is not an issue, as a researcher might be comfortable with focusing on some suitable and well-accepted aggregate measure of output, e.g., GDP for cross-country analysis or total sales for cross-firm analysis, etc.

On the other hand, when a researcher is interested in explicitly accounting for several outputs, other measures of productivity must be used. To wit, many sophisticated measures of productivity have been suggested in the literature to address various challenges of analyzing multi-output processes. These typically rely on finding adequate or appropriate ways of aggregating inputs and outputs, and are usually referred to as multifactor productivity indices. Indeed, the aggregation of many outputs into a single aggregate output and the aggregation of many inputs into a single aggregate input require careful selection of well-justified weights for aggregation because different weights can indeed imply different conclusions, which can potentially be very different (both quantitatively and qualitatively). Thus, for the contexts where a researcher is interested in explicitly accounting for several outputs, it is recommended that several well-justified approaches are used. This will be to either help obtain robust conclusions or to point out the differences in conclusions due to the use of different weights. It may also help explain the differences in conclusions and provide justifications for which of the possibly contradicting estimates should be regarded as more reliable. This in turn may depend on the data, the context, or the specific goals of the study[95].

The Notion of Production Efficiency

As mentioned above, the notion of production (or productive) *efficiency* typically refers to how high is the attained productivity level relative to some reference or benchmark, e.g., a theoretically known optimal or observed best practice. As a result, the notion of efficiency is what economists call a 'normative' concept, and, as with other normative concepts, it may be heavily dependent on the orientation (or the accepted criterion) taken by the researcher for measuring the efficiency that defines the benchmark.

For example, an output-oriented efficiency looks at how much output is produced relative to some reference level of output, i.e., the relevant criterion here is the maximization of output, given some inputs and technology. If one is more focused on the value of output, measured by revenue or sales or, in case of countries, by GDP, then the relevant criterion would be revenue or sales (or GDP) maximization, given some inputs, technology, and output prices (properly deflated to represent the real rather than nominal value).

On the other hand, an input-oriented efficiency looks at how much input is actually used relative to some reference level of inputs, i.e., the relevant criterion is input minimization, given some outputs and technology. If one is interested in the value of the inputs used, measured by the associated cost, then the relevant criterion would be the minimization of costs, given the desired outputs, technology, and input prices (again, properly deflated to represent the real rather than nominal value).

The reference or benchmark is chosen by the researcher and can be, for example, based on engineering specifications that define the maximum feasible output that can be produced with given inputs and given technology or the minimum inputs needed to produce a desired level of output with a given technology. Such engineering specifications are usually not available for complex processes, such as production of GDP, which may also widely vary across countries. So, usually a more feasible approach is to approximate or estimate such maxima or minima from the data, by identifying the observed best practice that would define the reference relative to which all other observations are benchmarked.

It is worth noting that there are many approaches for identifying the best practice, stemming from different paradigms or philosophies of measuring efficiency [95]. Moreover, there is also a myriad of approaches to statistically estimate efficiency and productivity [95, 96]. We will consider a few major approaches here that we recommend to be used, with further references to their details and alternatives.

Productivity Measures and Indices: Formal Definitions

Basic Definitions

As mentioned above, in the simplest case, when there is only one input (call it x) and only one output (call it y), a very natural and intuitive way of measuring productivity is the *single-factor productivity* (SFP) measure, defined as the ratio of output to input,

$$SFP = y/x. \tag{1}$$

Analogously, a *multifactor productivity* (MFP) measure, for a single (possibly aggregate) output, is defined as

$$MFP = y/Q_x, \tag{2}$$

where Q_x is some function (or a measure or index) that 'appropriately' aggregates the vector of inputs ($x \in \mathbb{R}_+^p$) into a positive scalar. A natural choice for Q_x is a production function that characterizes (at least approximately) the technology used in producing *y* from *x*, or its analogues (e.g., the so-called distance functions). For example, a very common assumption for the production function is,

$$y_t = f_t(x_t) = A_t f(x_t), \tag{3}$$

where the technological change is modeled as a scaling of some constant function *f* via the scalar factor A_t. For example, the Cobb–Douglas production functions we considered in Appendix B are special cases of this function. So, for the aggregator of inputs, here one can take $Q_x = f(x)$. As a result, A_t is sometimes referred to as a measure of *total factor productivity* (TFP) for this production relationship, because rearranging Equation (3) gives the ratio of output to the aggregate of all inputs (for the same period t, aggregated via the time independent part of the production function). So, $A_t = y_t/f(x_t)$ as a measure of productivity is well-justified when technology is described via this particular production function and with various economic theories developed for it that we briefly described in the previous sections. Some other 'appropriate' examples for Q_x will be considered in the next section.

Similarly, an MFP measure, for a multi-output case, can be defined as

$$MFP = Q_y/Q_x, \tag{4}$$

where Q_y is some function that 'appropriately' aggregates the vector of outputs ($y \in \mathbb{R}_+^q$) into a positive scalar. We will consider some 'appropriate' examples for Q_y in the next section.

A common way to define a productivity *index* is to take the ratio of two productivity measures. For the simplest case, it is the ratio of the SFP measures for different periods, say *s* and *t* (*s*<*t*), which provides the SFP index as given by Equation (5) below.

$$SFP\ Index = \frac{y_t/x_t}{y_s/x_s}, \tag{5}$$

which is also equivalent to the ratio of an output index to an input index, i.e.,

$$SFP\ Index = \frac{y_t/y_s}{x_t/x_s}\ . \tag{6}$$

The MFP *index* can thus be defined as a generalization of Equation (6), where y_t/y_s is replaced by an index representing the change of output and x_t/x_s is replaced by an index representing the change of input, i.e.,

$$MFP\ Index = \frac{Q_y^t/Q_y^s}{Q_x^t/Q_x^s}\ , \tag{7}$$

which is equivalent to the ratio of two MFP measures in different periods, i.e.,

$$MFP\ Index = \frac{Q_y^t/Q_x^t}{Q_y^s/Q_x^s}\ . \tag{8}$$

A key question is what should one choose for Q_y and Q_x. Many alternatives have been suggested in the literature on this topic [95]. In the case of single output (e.g., GDP) and when a researcher is comfortable using the time-independent part of the production function characterization of technology as the aggregator of inputs, i.e., $Q_x = f(x)$ as described above, we have

$$MFP\ Index = \frac{y_t/f(x_t)}{y_s/f(x_s)} = \frac{A_t f(x_t)/f(x_t)}{A_s f(x_s)/f(x_s)} = \frac{A_t}{A_s}\ . \tag{9}$$

In other words, MFP is simply the ratio of the factors that determine the level of the technology frontier at the periods of interest (e.g., s and t). Thus, in this simplified framework (with Hicks-neutral technological change), the MFP is a measure of technological change. Since A_t is often referred to as a measure of TFP, the MFP index in Equation (9) is also often referred to as TFP index or TFPI.

This latter approach is the basis for the so-called growth accounting approach to measuring productivity, which we will describe in the next section. Its generalization, which we will also discuss, among other things, allows for the existence of inefficiency and so is capable of decomposing MFP into several components, such as technological change, efficiency change, and capital deepening.

Growth Accounting Approach

The roots of the growth accounting approach go back to the classic work of Solow [97]. While it can be applied to any type of data (firm level, country level, etc.), to facilitate the description of this method for our study, we cast the model for the case when the goal is to analyze the productivity of countries $i = 1, \dots, n$. Let $x_t^i = (x_{1\,t}^i, \dots, x_{N\,t}^i)' \in \mathbb{R}_+^p$ denote the vector of p inputs that each country i uses in period t to produce a GDP, denoted with y_t^i.

Suppose the aggregate production function that characterizes how country i produces its GDP from its resources is given by

$$y_t^i \equiv f_t^i(x_t^i) = A_t^i f^i(x_t^i), i = 1, \dots, n, \tag{10}$$

where f^i is the part of country i's aggregate production function that is independent of time, while A_t^i is TFP.

Again, note that this formulation implies that technology changes only through the scaling of the frontier (via TFP factor A_t^i), while the functional form that aggregates inputs cannot change over time. This is a simplifying assumption that is sometimes reasonable, at least as the first step of the analysis and so is commonly used. It can be relaxed, with the addition of some complexity for modeling and estimation, and we will consider such approaches in the next sections.

The growth accounting method of Solow is leveraged, noticing that, assuming differentiability of Equation (10), the growth rate of GDP, which we denote with $growth(y_t^i) \equiv \frac{dy_t^i/dt}{y_t^i}$, can be mathematically written as

$$growth(y_t^i) \equiv \frac{dy_t^i/dt}{y_t^i}$$

$$= \frac{1}{y_t^i}\left(\left(\frac{\partial f^i(x_t^i)}{\partial x_{1,t}^i}\frac{dx_{1,t}^i}{dt} + \cdots + \frac{\partial f^i(x_t^i)}{\partial x_{p,t}^i}\frac{dx_{p,t}^i}{dt}\right)A_t^i + \frac{dA_t^i}{dt}f^i(x_t^i)\right). \quad (11)$$

Rearranging (after putting $(1/y_t^i)$ and A_t^i inside the parentheses and noticing that $A_t^i/y_t^i = 1/f^i(x_t^i)$ or $f^i(x_t^i)/y_t^i = 1/A_t^i$), we get,

$$growth(y_t^i) \equiv \left(\frac{\partial f^i(x_t^i)}{\partial x_{1,t}^i}\frac{x_{1,t}^i}{f^i(x_t^i)}\frac{1}{x_{1,t}^i}\frac{d(x_{1,t}^i)}{dt} + \cdots + \frac{\partial f^i(x_t^i)}{\partial x_{p,t}^i}\frac{x_{p,t}^i}{f^i(x_t^i)}\frac{1}{x_{p,t}^i}\frac{dx_{p,t}^i}{dt}\right) + \frac{dA_t^i}{dt}\frac{1}{A_t^i}. \quad (12)$$

After further rearrangements, an elegant expression for the growth rate of GDP appears as a decomposition into various sources,

$$growth(y_t^i) = \left(\sum_{j=1}^{p} e_{j,t}^i \times \frac{d\ln x_{j,t}^i}{dt}\right) + \frac{d\ln A_t^i}{dt}$$

$$= \left(\sum_{j=1}^{p} e_{j,t}^i \times growth(x_{j,t}^i)\right) + growth(A_t^i), i = 1, \dots, n., \quad (13)$$

where

$$e_{jt}^i \equiv \frac{\partial f_t^i(x_t^i)}{\partial x_{j,t}^i} \times \frac{x_{j,t}^i}{f^i\,(x_t^i)}, j = 1, \dots, p \quad (14)$$

is the so-called *partial scale elasticity* with respect to input j, which can also be understood as the weight of each input in the production technology, weighting the growth rate of the corresponding input $x_{t,j}$. Thus, in words, Equation (13) states that the growth rate of output (here GDP) is the weighted average of growth rates of each input $x_{j,t}^i$ weighted by the corresponding partial scale elasticity of that input, plus the growth rate of technology. In practice, these elasticities are often assumed to be constant across all or some countries as well as over some periods.

Moreover, if in addition we assume *constant returns to scale* (CRS), which is a common assumption for aggregate cross-country analyses, then we can normalize each variable by one of the input variables (e.g., labor); call it $x_{c,t}^i$. So, the decomposition of the growth rate of the single factor productivity is obtained for each $i = 1, \dots, n$.

$$growth(y_t^i/x_{c,t}^i) \equiv \sum_{\substack{j=1 \\ j\neq c}}^{p} e_{j,t}^i \frac{d\ln(x_{j,t}^i/x_{c,t}^i)}{dt} + \frac{d\ln A_t^i}{dt}$$

$$= \sum_{j=1, j\neq c}^{p} e_{j,t}^i \times growth(x_{j,t}^i/x_{c,t}^i) + growth(A_t^i). \quad (15)$$

Thus, when the normalizing variable in Equation (15) is labor, we obtain a decomposition of the growth rate of labor productivity into several sources: the growth in each input (capital per unit labor, human capital per unit labor, energy per unit labor, etc.) weighted by its shares, plus the growth in technology. Note that the increase in physical or human capital per unit of labor is often referred to as physical or human 'capital deepening.'

To estimate this equation, researchers usually use approximations for the growth rate, given by

$$growth(x_t) \equiv \frac{dx_t/dt}{x_t} = \frac{d\ln(x_t)}{dt} \approx \frac{x_{t+\triangle t}}{x_t} - 1 = \frac{x_{t+\triangle t} - x_t}{x_t}$$

along with some assumptions for the shares, which will yield estimates for each component of Equation (13) or Equation (15) except for the last term, $growth(A_t^i)$, which in turn is determined by those estimates as the residual of Equation (13) or Equation (15). For this reason, $growth(A_t^i)$ is referred to as Solow's residual, attributing the credit to the work of Solow [97]. Note that $growth(A_t^i)$ is closely related to the TFPI described in Equation (9). Indeed,

$$\begin{aligned} growth(A_t^i) &\equiv \frac{dA_t^i/dt}{A_t^i} = \frac{d\ln A_t^i}{dt} \\ &\approx \ln(A_t^i/A_s^i) \\ &\approx A_t^i/A_s^i - 1 \\ &= TFPI_{st}^i - 1. \end{aligned} \tag{16}$$

In practice, technological changes are often biased toward some inputs. For example, physical capital or human capital become more important than basic labor, thus leading to less labor-intensive and more capital-intensive technologies. This is especially the case for some industries, though it is less pronounced at the aggregate level.

Another important assumption made here is that all countries are assumed to be fully efficient (i.e., on the frontier of technology). On the other hand, note that this formulation allows each country to have its own technological change and own technology type, due to superscripts i for both A_t^i and f_t^i (at any time period t). In other words, each country is assumed efficient relative to its own technology frontier, and these frontiers may (or may not) vary widely across countries for various reasons. Another paradigm for addressing this heterogeneity is to take a step beyond the assumption of 'full self-efficiency' and instead benchmark everyone relative to the so-called overall or 'grand' frontier, sometimes called the 'observed best-practice' frontier, which we will consider in the next section.

Hicks–Moorsteen Productivity Indices

A natural way to define a productivity index is to use a generalization Equation (7) or Equation (8), where the so-called Malmquist input and output quantity indices are used in place of Q_x and Q_y. Early ideas of this approach go back to at least Hicks [98] and Moorsteen [99] and later to Caves, Christensen, and Diewert [100]. The approach is more formally outlined by Diewert [101] who called it the 'Hicks–Moorsteen Productivity Index,' and further refined by Bjurek [102] who called it the 'Malmquist Total Factor Productivity Index.' It is worth noting that in productivity literature, this index has also appeared under different names, e.g., Bjurek Index, Bjurek Productivity Index, Bjurek TFP Index, Hicks–Moorsteen TFP Index, or simply Hicks–Moorsteen Index or Malmquist–Hicks–Moorsteen–Diewert–Bjurek Productivity (or TFP) Index.

Formally, the Hicks–Moorsteen Productivity Index with respect to period s is defined as

$$HMPI^s \equiv HM^s(x_s, x_t, y_s, y_t|\mathcal{T}^s) \equiv \frac{Q_o^s(y_s, y_t, x_s|\mathcal{T}^s)}{Q_i^s(x_s, x_t, y_s|\mathcal{T}^s)}, \tag{17}$$

while the Hicks–Moorsteen Productivity Index with regard to period t is defined as

$$HMPI^t \equiv HM^t(x_s, x_t, y_s, y_t|\mathcal{T}^t) \equiv \frac{Q_o^t(y_s, y_t, x_t|\mathcal{T}^t)}{Q_i^t(x_s, x_t, y_t|\mathcal{T}^t)}, \tag{18}$$

where on the right side of Equations (17) and (18), the Malmquist output quantity indices and Malmquist input quantity indices are used, which are explained in the next subsections.

A natural and practical question here is which period, *s* or *t*, to choose as a reference. Should it be as in Equation (17) or as in Equation (18)? To avoid the dependency of results on such a choice, researchers often take the geometric mean of the two Hicks–Moorsteen productivity indices, i.e.,

$$HMPI_{st} \equiv HM(x_s, x_t, y_s, y_t | \mathcal{T}^s, \mathcal{T}^t)$$

$$\equiv \left[\frac{Q_o^t(y_s, y_t, x_t | \mathcal{T}^t)}{Q_i^t(x_s, x_t, y_t | \mathcal{T}^t)} \times \frac{Q_o^s(y_s, y_t, x_s | \mathcal{T}^s)}{Q_i^s(x_s, x_t, y_s | \mathcal{T}^s)}\right]^{\frac{1}{2}}. \tag{19}$$

More discussions on this index can be found in Nemoto and Goto [103], Epure, Kerstens, and Prior [104], and Sickles and Zelenyuk [95].

Economic Quantity Indices

A well-justified (from an economic theory perspective) way of constructing quantity indices is to use the *Malmquist quantity indices*. The idea goes back to Malmquist [105], and was formalized and theoretically justified in the seminal work by Caves, et al. [100]. It uses the Shephard's output distance functions (ODF) and Shephard's input distance functions (IDF) as building blocks to construct the output quantity indices and input quantity indices, respectively, as we detail in the next two subsections.

Output Quantity Indices

Specifically, the Malmquist output quantity index with respect to period *s* as the reference is defined as

$$Q_o^s(y_s, y_t, x_s | \mathcal{T}^s) \equiv \frac{ODF(x_s, y_t | \mathcal{T}^s)}{ODF(x_s, y_s | \mathcal{T}^s)}, \tag{20}$$

while the Malmquist output quantity index with respect to period *t* as the reference is defined as

$$Q_o^t(y_s, y_t, x_t | \mathcal{T}^t) \equiv \frac{ODF(x_t, y_t | \mathcal{T}^t)}{ODF(x_t, y_s | \mathcal{T}^t)}, \tag{21}$$

where $ODF(x_l, y_\tau | \mathcal{T}^l)$ is the Shephard's output distance function for the input level observed in the period l (l=s,t), with the technology available in the same period l, and the output level observed in the period τ, $(\tau = t, s)$, i.e.,

$$ODF(x_l, y_\tau | \mathcal{T}^l) = \inf\{\theta > 0 : (x_l, y_\tau/\theta) \in \mathcal{T}^l\}, (x_l, y_\tau) \in \mathbb{R}_+^p \times \mathbb{R}_+^q, \tag{22}$$

where $\mathcal{T}^l$ is the technology set describing all the input-output combinations (x,y) that are feasible with technologies (or knowledge) available in period l, and formally defined (in general terms) as

$$\mathcal{T}^l = \{(x, y) : x \text{ can produce } y \text{ with technologies in period } l\}. \tag{23}$$

Note that ODF is also a natural efficiency measure. When both x and y are for the same period, say t, and if ODF is defined with respect to the technology set in the same period $\mathcal{T}^t$, then the ODF measures the distance (or the gap) between a given input–output allocation and the frontier $\mathcal{T}^t$ and gives a value between 0 and 1 (or 0 and 100%). More formally, we have,

$$ODF(x_t, y_t|\mathcal{T}^t) \in [0,1].$$

Whenever $(x_t, y_t) \in \mathcal{T}^t$, i.e., whenever (x_t, y_t) is feasible with the technology characterized by $\mathcal{T}^t$, where $ODF(x_t, y_t|\mathcal{T}^t) = 1$, it implies that the allocation (x_t, y_t) is 100% efficient in the sense that it is on the output-oriented frontier of technology set $\mathcal{T}^t$, defined as

$$\partial_o \mathcal{T}^t \equiv \{(x, y) : (x, y) \in \mathcal{T}^t, (x, y\delta) \notin \mathcal{T}^t, \forall \delta > 1\}.$$

Meanwhile, the values $ODF(x_t, y_t|\mathcal{T}^t) < 1$ imply the allocation (x_t, y_t) is under the frontier of technology set $\mathcal{T}^t$ and the value of $ODF(x_t, y_t|\mathcal{T}^t)$ itself will indicate the level of inefficiency, while $1 - ODF(x_t, y_t|\mathcal{T}^t)$ indicates its inefficiency or gap between the allocation (x_t, y_t) and the frontier of $\mathcal{T}^t$ (in percentage terms, relative to the maximal possible output from the given level of input x_t).

In the case of a single output, the ODF can be characterized via the classical production function. Indeed,

$$f(x|\mathcal{T}^t) = \max\{y : (x, y) \in \mathcal{T}^t\}, (x, y) \in \mathbb{R}_+^p \times \mathbb{R}_+^q \tag{24}$$

Then we have,

$$ODF(x_t, y_t|\mathcal{T}^t) = \frac{y_t}{f(x_t|\mathcal{T}^t)}, \tag{25}$$

i.e., $ODF(x_t, y_t|\mathcal{T}^t)$ is the ratio of the actual level of output y_t to the maximal level of output given by the production function for the particular level of input x_t.

Input Quantity Indices

The Malmquist input quantity index with respect to period s as the reference is defined as

$$Q_i^s(x_s, x_t, y_s|\mathcal{T}^s) \equiv \frac{IDF(y_s, x_t|\mathcal{T}^s)}{IDF(y_s, x_s|\mathcal{T}^s)}, \tag{26}$$

while the Malmquist input quantity index with respect to period t as the reference is defined as

$$Q_i^t(x_s, x_t, y_t|\mathcal{T}^t) \equiv \frac{IDF(y_t, x_t|\mathcal{T}^t)}{IDF(y_t, x_s|\mathcal{T}^t)}, \tag{27}$$

where $IDF(x_l, y_\tau|\mathcal{T}^l)$ is the Shephard's input distance function for the output level observed in the period l $(l = s, t)$, with the technology available in the same period l, and the input level observed in the period τ, $(\tau = t, s)$, i.e.,

$$IDF(y_l, x_\tau|\mathcal{T}^t) = \sup\{\theta > 0 : (x_\tau/\theta, y_l) \in \mathcal{T}^l\}, (x_l, y_\tau) \in \mathbb{R}_+^p \times \mathbb{R}_+^q. \tag{28}$$

It should be noted that, similar (yet not the same) to the above, IDF is also a natural efficiency measure. When both x and y are for the same period, say t, and if IDF is defined with respect to the technology set in the same period $\mathcal{T}^t$, then the reciprocal of IDF gives a value between 0 and 1 (or 0 and 100%). More formally, we have

$$1/IDF(x_t, y_t|\mathcal{T}^t) \in [0,1],$$

Whenever $(x_t, y_t) \in \mathcal{T}^t$, i.e., whenever (x_t, y_t) is feasible with the technology characterized by $\mathcal{T}^t$, where $IDF(x_t, y_t|\mathcal{T}^t) = 1$, it implies that the allocation (x_t, y_t) is on the input-oriented frontier of the technology set $\mathcal{T}^t$, defined as

$$\partial_i \mathcal{T}^t \equiv \{(x, y) : (x, y) \in \mathcal{T}^t, (x/\delta, y) \notin \mathcal{T}^t, \forall \delta > 1\}.$$

The values $1/IDF(x_t, y_t|\mathcal{T}^t) < 1$ imply that the allocation (x_t, y_t) is not on the frontier of the technology set $\mathcal{T}^t$ and the value of $1/IDF(x_t, y_t|\mathcal{T}^t)$ itself will indicate the level of inefficiency, while $1 - 1/IDF(x_t, y_t|\mathcal{T}^t)$ indicates its inefficiency or the gap between the allocation (x_t, y_t) and the frontier of $\mathcal{T}^t$ in percentage terms, relative to the minimal possible input needed to produce the given level of output y_t.

A natural question is "When are the quantity indices with respect to different time periods equal?" The answer is, 'under very restrictive conditions,' and so for this reason, it is advised to take an equally weighted geometric average of the two. Färe and Zelenyuk [106] provide a closely related theoretical justification.

Malmquist Productivity Indices

Another, and much more popular measure, of change in productivity is based on the *Malmquist Productivity Indices* (MPIs), proposed by Caves, et al. [100], and so is sometimes referred to as Caves, Christensen, and Diewert (CCD) index approach.

Definitions of MPIs

For the output orientation, and when a researcher aims to measure all the quantities with respect to technology in period *s*, Caves, et al. [100] proposed using the output-oriented period-*s* MPI

$$MPI_o^s \equiv M_o(x_s, x_t, y_s, y_t|\mathcal{T}^s) \equiv \frac{ODF(x_t, y_t|\mathcal{T}^s)}{ODF(x_s, y_s|\mathcal{T}^s)}, \tag{29}$$

and when choosing technology in period *t* as the reference, they suggested the output-oriented period-*t* MPI

$$MPI_o^t \equiv M_o(x_s, x_t, y_s, y_t|\mathcal{T}^t) \equiv \frac{ODF(x_t, y_t|\mathcal{T}^t)}{ODF(x_s, y_s|\mathcal{T}^t)}. \tag{30}$$

Similarly, as for Hicks–Moorsteen indices for different periods, to avoid dependency on the choice of the time periods with respect to which productivity change is measured, researchers often take the *geometric* mean of the two MPIs, namely

$$MPI_o \equiv M_o(x_s, x_t, y_s, y_t|\mathcal{T}^s, \mathcal{T}^t) \equiv \left[\frac{ODF(x_t, y_t|\mathcal{T}^s)}{ODF(x_s, y_s|\mathcal{T}^s)} \times \frac{ODF(x_t, y_t|\mathcal{T}^t)}{ODF(x_s, y_s|\mathcal{T}^t)}\right]^{\frac{1}{2}}. \tag{31}$$

Further, it may be noted that an alternative to the output-oriented Shephard's distance function is the input-oriented Shephard's distance function, and so, in a similar way, one can define the input-oriented *s*-period MPI as

$$MPI_i^s \equiv M_i^s(y_s, y_t, x_s, x_t|\mathcal{T}^s) \equiv \frac{IDF(y_t, x_t|\mathcal{T}^s)}{IDF(y_s, x_s|\mathcal{T}^s)}, \tag{32}$$

and, the input-oriented t-period MPI as

$$MPI_i^t \equiv M_i(y_s, y_t, x_s, x_t | \mathcal{T}^t) \equiv \frac{IDF(y_t, x_t | \mathcal{T}^t)}{IDF(y_s, x_s | \mathcal{T}^t)}. \tag{33}$$

The geometric mean of the two input-oriented MPIs is given by

$$MPI_i \equiv M_i(y_s, y_t, x_s, x_t | \mathcal{T}^s, \mathcal{T}^t) \equiv \left[\frac{IDF(y_t, x_t | \mathcal{T}^s)}{IDF(y_s, x_s | \mathcal{T}^s)} \times \frac{IDF(y_t, x_t | \mathcal{T}^t)}{IDF(y_s, x_s | \mathcal{T}^t)}\right]^{\frac{1}{2}}. \tag{34}$$

It is important to note that under the assumption of CRS (which is very common for aggregate cross-country studies), we have an equivalence between the output-oriented MPI and the input-oriented MPI, in the sense that

$$M_o(x_s, x_t, y_s, y_t | \mathcal{T}^s, \mathcal{T}^t) = 1/M_i(y_s, y_t, x_s, x_t | \mathcal{T}^s, \mathcal{T}^t), \tag{35}$$

for any (x_s, y_s) and (x_t, y_t) in their allowed domains. For this reason, many researchers assume CRS and just focus on one of them, most frequently the output-oriented MPI, $M_o(x_s, x_t, y_s, y_t | \mathcal{T}^s, \mathcal{T}^t)$.

Decompositions of MPIs

One important reason for the high popularity of the MPIs is a convenient possibility of decomposing the (total) productivity change into several components representing different sources of the entire productivity change somewhat similar to growth accounting, yet allowing for the inefficiency and thus enabling to measure efficiency change as one of the sources of the total change in productivity.

Many decompositions of the MPIs were offered in the productivity literature, going back to at least Nishimizu and Page [107], and the most popular in practice being the decomposition proposed by Färe, et al. [108, 109], also usually referred to as Färe, Grosskopf, Norris and Zhang [65]. It is given by (for the output-oriented MPI),

$$M_o(x_s, x_t, y_s, y_t | \mathcal{T}^s, \mathcal{T}^t)$$

$$\equiv \left(M_o(x_s, x_t, y_s, y_t | \mathcal{T}^s) \times M_o(x_s, x_t, y_s, y_t | \mathcal{T}^t)\right)^{\frac{1}{2}} \tag{36}$$

$$= \left[\frac{ODF(x_t, y_t | \mathcal{T}^s)}{ODF(x_s, y_s | \mathcal{T}^s)} \times \frac{ODF(x_t, y_t | \mathcal{T}^t)}{ODF(x_s, y_s | \mathcal{T}^t)}\right]^{\frac{1}{2}}$$

$$= \frac{ODF(x_t, y_t | \mathcal{T}^t)}{ODF(x_s, y_s | \mathcal{T}^s)} \times \left[\frac{ODF(x_s, y_s | \mathcal{T}^s)}{ODF(x_s, y_s | \mathcal{T}^t)} \times \frac{ODF(x_t, y_t | \mathcal{T}^s)}{ODF(x_t, y_t | \mathcal{T}^t)}\right]^{\frac{1}{2}}$$

$$= \mathrm{Eff}\Delta_{st} \times [Tech\Delta_s \times Tech\Delta_t]^{\frac{1}{2}}$$

$$= \mathrm{Eff}\Delta_{st} \times Tech\Delta_{st}. \tag{37}$$

Expressed in words, Equation (37) states that we can decompose MPI into two sources of productivity change, namely, (1) *efficiency change*, defined as an efficiency index, i.e., the ratio of the technical efficiency measure in period t to the same technical efficiency measure for the same country in period s; and (2) *technology change*, defined as a geometric mean of two components that compare technologies between periods s and t, keeping the observations fixed at the periods and evaluated at (x_s, y_s) and (x_t, y_t). In case of Hicks-neutral technology change assumption, these two parts are equal, but not so in general.

For the first component, a score greater or smaller than unity implies an improvement or deterioration in efficiency over time and is sometimes referred to as the 'catching-up to the frontier' effect. Meanwhile, (EffΔ-1)% yields a percentage measure of such an improvement or deterioration. If the score is equal to unity, then there is no catching-up or lagging-behind for the particular observation, meaning thereby that the efficiency level (relative to the frontiers) in both the periods remains the same. Importantly, this does not mean it is good. In fact, the efficiency could be equally low in both the periods.

Similarly, the quantity given by (TechΔ-1)% yields a percentage change in the technological frontier, which is positive when there is technological improvement and negative when there is technological deterioration. Technological deterioration rarely happens in an absolute (and abstract) sense, i.e., in the sense of existence of knowledge in society. In practice, however, it is not uncommon to see the estimated best practice frontier in some future period being below that of some past periods, possibly due to some unaccounted factors, e.g., weather or climate change.

For more of related discussions, see a recent review of many applications of such methods in Badunenko, Henderson, and Zelenyuk [110].

MPI vs. Growth Accounting

It is worth clarifying here that the Malmquist Productivity Index (MPI) is indeed a generalization of the growth accounting approach that relaxes many of the restrictive assumptions of the latter. In particular, the MPI approach does not impose the assumption of full efficiency, while the Solow approach does. Moreover, the MPI allows for the multi-output case and does not assume that the production function follows a Hicks-neutral technological change pattern or any assumptions of the differentiability or elasticity weights. To see the linkage between the two, note that if we assume the technology assumption Equation (10), the Shephard's output distance function would then be,

$$ODF^{\tau}(x_l, y_l|\mathcal{T}^{\tau}) = y_l/(A_\tau\, f(x_l\ ))$$

where $l, \tau = s, t$. By plugging it into the MPI component of technological change, we get

$$Tech\ \Delta \equiv \left[\frac{ODF(x_s,y_s|\mathcal{T}^s)}{ODF(x_s,y_s|\mathcal{T}^t)} \times \frac{ODF(x_t,y_t|\mathcal{T}^s)}{ODF(x_t,y_t|\mathcal{T}^t)}\right]^{\frac{1}{2}}$$

$$= \left[\frac{y_s/(A_s f(y_s))}{y_s/(A_t f(y_s))} \times \frac{y_t/(A_s f(x_t))}{y_t/(A_t f(x_t))}\right]^{\frac{1}{2}}$$

$$= \left[\frac{A_t}{A_s} \times \frac{A_t}{A_s}\right]^{\frac{1}{2}} = \frac{A_t}{A_s}.$$

Thus, the component of MPI that measures technological change yields an index for Solow's TFP and its natural logarithm gives a discrete approximation to the theoretical (continuous) version of Solow's growth accounting, since we have,

$$\ln(Tech\ \Delta) = \ln(A_t/A_s) \approx A_t/A_s - 1$$

$$\approx g(A_t) \equiv \frac{d\ln A_t}{dt}\ .$$

The Kumar–Russell Approach

Another very interesting decomposition was proposed by Kumar and Russell [111]. They used essentially an MPI approach tailored for the case of single output (GDP), using relationships like Equation (10) and Equation (25) and thus appearing similar to the growth accounting approach, yet with an efficiency-change component as in the MPI decomposition Equation (36). This approach was applied to study labor productivity of a sample of about 50 major countries in the world and in this sense is very close to our goal. So, we briefly outline the essence of this approach here.

To simplify the formulations, we consider the case of two inputs, labor (L) and capital (K) used to produce GDP (Y) of a country, whose technology is characterized by the aggregate production function, $f(K_\tau, L_\tau|\mathcal{T}^\tau), \tau = s, t$. The output-oriented Shephard's distance function is then given by,

$$ODF(K_\tau, L_\tau, Y_\tau|\mathcal{T}^\tau) = \frac{Y_\tau}{f(K_\tau, L_\tau|\mathcal{T}^\tau)}. \tag{38}$$

It is important to note that Kumar and Russell [111] mainly focused on their reference or benchmark under the assumption of CRS, which is a common assumption for cross-country analysis, which in turn implies that

$$Y_\tau/L_\tau = ODF(K_\tau, L_\tau, Y_\tau|\mathcal{T}^\tau) f(K_\tau/L_\tau|\mathcal{T}^\tau) \tag{39}$$

and so, the index measuring the changes in labor productivity (LP) can then be represented as

$$\frac{Y_t/L_t}{Y_s/L_s} = \frac{ODF(K_t, L_t, Y_t|\mathcal{T}^t) f(K_t/L_t|\mathcal{T}^t)}{ODF(K_s, L_s, Y_s|\mathcal{T}^s) f(K_s/L_s|\mathcal{T}^s)}. \tag{40}$$

From this an interesting decomposition is given by

$$\frac{Y_t/L_t}{Y_s/L_s} = \frac{ODF(K_t, L_t, Y_t|\mathcal{T}^t)}{ODF(K_s, L_s, Y_s|\mathcal{T}^s)} \times \left[\frac{f(K_s/L_s|\mathcal{T}^t)}{f(K_s/L_s|\mathcal{T}^s)} \frac{f(K_t/L_t|\mathcal{T}^t)}{f(K_t/L_t|\mathcal{T}^s)}\right]^{\frac{1}{2}} \times \left[\frac{f(K_t/L_t|\mathcal{T}^s)}{f(K_s/L_s|\mathcal{T}^s)} \times \frac{f(K_t/L_t|\mathcal{T}^t)}{f(K_s/L_s|\mathcal{T}^t)}\right]^{\frac{1}{2}}$$

$$= \text{Eff}\Delta_{st} \times \text{Tech}\Delta_{st} \times \text{KLACC}\Delta_{st}. \tag{41}$$

Expressed in words, Equation (41) states that the index measuring labor productivity changes, or the labor productivity index (LPI), is decomposed into three components: (1) index of (technical) efficiency change (EffΔ_{st}); (2) index of technology change (TechΔ_{st}); and (3) index of capital (per labor) accumulation change (KLACCΔ_{st}).

In a sense, Equation (24) is an extension of the discrete version of the Solow [97] decomposition and is also a version of the Färe, Grosskopf, Lindgren, and Roos [108] decomposition that exploits the CRS and single-output case assumptions. Further extensions of this approach can also be found in Henderson and Russell [75]; Badunenko, Henderson, and Zelenyuk [112]; Zelenyuk [113]; and Trinh and Zelenyuk [114]; to mention a few, and the most recent overview by Badunenko, et al. [110], where more details and references can be found.

Estimation via DEA

In this section, we briefly describe a very popular method practiced for estimating efficiency and productivity indices. The method is referred to as Data Envelopment Analysis (DEA). The roots of this method originate from economic theory modeling, inspired by Leontief [115]; von Neumann

[116]; Debreu [117]; and Shephard [118]. It is based on the linear programming approach [119–123] and is most prominently influenced by Farrell [124]; Charnes, Cooper, and Rhodes [125]; and other works.

Intuitively, they all give the so-called 'piece-wise linear' approximation of the true technology by enveloping the observed data. For example, for a sample of observations on inputs and outputs $\{(x^k, y^k) : k = 1, \ldots, n\}$, the approximation of the technology set $\hat{\mathcal{T}}^{\tau}$ in any period τ can be given by,

$$\hat{\mathcal{T}}^{\tau} = \{(x, y) \colon \textstyle\sum_{k=1}^{n} z^k y_{m,\tau}^k \geq y_m, m = 1, \ldots, q;$$

$$\textstyle\sum_{k=1}^{n} z^k x_{l,\tau}^k \leq x_l \ , l = 1, \ldots, p;$$

$$z^k \geq 0, k = 1, \ldots, n; \ \delta_l \leq \textstyle\sum_{k=1}^{n} z^k \leq \delta_u\}$$

where $z^1, \ldots, z^n$ are usually referred to as 'intensity variables' while δ_l and δ_u are the constraints imposed on them to obtain various types of returns to scale. For example, when $\delta_l = 0$ and $\delta_u = +\infty$ (i.e., unbounded) the estimated technology will exhibit CRS; when $\delta_l = 0$ and $\delta_u = 1$ then the estimated technology will exhibit non-increasing returns to scale; and when $\delta_l = 1$ and $\delta_u = 1$ then the estimated technology will exhibit what is dubbed in the literature as variable returns to scale.

The corresponding estimates of the Shephard's distance functions (and related efficiency scores and indices they are used in) can then be obtained by replacing $\mathcal{T}^{\tau}$ in Equations (22) and (28) with its DEA estimate $\hat{\mathcal{T}}^{\tau}$.

More specifically, the estimate of $IDF(x_t^j, y_t^j | \mathcal{T}^{\tau})$, which we denoted as $\widehat{IDF}(x_t^j, y_t^j | \hat{\mathcal{T}}^{\tau})$, can be obtained as the reciprocal of the DEA-estimator of the so-called Farrell input-oriented technical efficiency score, which for an allocation (x_t^j, y_t^j) with respect to (or benchmarked relative to) technology $\hat{\mathcal{T}}^{\tau}$ can be formulated as

$$1/\widehat{IDF}(x_t^j, y_t^j | \hat{\mathcal{T}}^{\tau}) \equiv \min_{\theta, z^1, \ldots, z^n} \ \theta$$

such that

$$\sum_{k=1}^{n} z^k y_{m,\tau}^k \geq y_{m,t}^j, m = 1, \ldots, q,$$

$$\sum_{k=1}^{n} z^k x_{l,\tau}^k \leq \theta \ x_{l,t}^j, l = 1, \ldots, p,$$

$$\theta \geq 0, z^k \geq 0, k = 1, \ldots, n,$$

$$\delta_l \leq \sum_{k=1}^{n} z^k \leq \delta_u,$$

where θ is both the entire objective function and is the variable of primary interest over which the optimization is done, together with *n* intensity variables, $z^1, \ldots, z^n$.

Similarly, the estimate of $ODF(x_t^j, y_t^j|\mathcal{T}^\tau)$, denoted as $\widehat{ODF}(x_t^j, y_t^j|\hat{\mathcal{T}}^\tau)$, can be obtained as the reciprocal of the DEA-estimator of the Farrell output-oriented technical efficiency score, which for an allocation (x_t^j, y_t^j) with respect to (or benchmarked relative to) technology $\hat{\mathcal{T}}^\tau$ can be formulated as

$$1/\widehat{ODF}(x_t^j, y_t^j|\hat{\mathcal{T}}^\tau) \equiv \max_{\theta, z^1, \dots, z^n} \lambda$$

such that

$$\sum_{k=1}^{n} z^k y_{m,\tau}^k \geq \lambda\, y_{m,t}^j, m = 1, \dots, q,$$

$$\sum_{k=1}^{n} z^k x_{l,\tau}^k \leq x_{l,t}^j, l = 1, \dots, p,$$

$$\theta \geq 0, z^k \geq 0, k = 1, \dots, n,$$

$$\delta_l \leq \sum_{k=1}^{n} z^k \leq \delta_u.$$

It is worth noting that

$$0 \leq \widehat{ODF}(x, y|\hat{\mathcal{T}}^\tau) \leq 1 \leq \widehat{IDF}(x, y|\hat{\mathcal{T}}^\tau)$$

for any $(x, y) \in \hat{\mathcal{T}}^\tau$ and

$$0 \leq \widehat{IDF}(x, y|\hat{\mathcal{T}}^\tau) \leq 1 \leq \widehat{ODF}(x, y|\hat{\mathcal{T}}^\tau)$$

for any $(x, y) \notin \hat{\mathcal{T}}^\tau$, provided it is possible to reach the frontier by contracting or expanding the inputs or outputs. In other words, there exists $\lambda \in (0, \infty)$ such that $(\lambda x, y) \in \Psi$ and $(x, \lambda y) \in \Psi$. Meanwhile, $\widehat{ODF}(x, y|\hat{\mathcal{T}}^\tau) = 1$ represents 100% efficiency score of the allocation (x,y) relative to the estimated best practice frontier of $\hat{\mathcal{T}}^\tau$.

It is also worth noting that some regularity conditions on the data are needed to avoid computational problems. Specifically, for all $\tau = 1, \dots, T$ we must have:

$$i. \sum_{k=1}^{n} x_{l\tau}^k > 0, l = 1, \dots, p, \quad (42)$$

$$ii. \sum_{k=1}^{n} y_{m\tau}^k > 0, m = 1, \dots, q, \quad (43)$$

$$iii. \sum_{l=1}^{p} x_{l\tau}^k > 0, k = 1, \dots, n, \quad (44)$$

$$iv. \sum_{m=1}^{q} y_{m\tau}^k > 0, k = 1, \dots, n. \quad (45)$$

Estimation via SFA

Succinctly, the main premise of Stochastic Frontier Analysis (SFA) is the acknowledgement that whether all decision making units (DMUs are efficient or not is an empirical question that can and should be statistically tested against the data, while allowing for statistical error. To enable such testing, SFA provides a framework where the production relationship is estimated as a conditional average (of outputs given inputs and other factors, in the case of a production function) but the total deviation from the average is decomposed into two terms, i.e., statistical noise and inefficiency. Both DEA and standard regression methods treat these deviations as a single term, inefficiency in the case of DEA, and statistical noise in the traditional regression context. Both these terms are unobserved by a researcher but with relatively mild assumptions, the different approaches within SFA allow the analyst to estimate them for the sample as a whole (e.g., representing an industry) or for each individual DMU.

SFA was independently proposed by Aigner, Lovell, and Schmidt (ALS) [126] and Meeusen and van den Broeck (MvB) [127]. Battese and Corra [128] and Meeusen and van den Broeck [129], while appearing in the same year, are applications of the methods.

Using conventional notation, let y_i be the single output for observation i. Then the production frontier is written as

$$y_i = f(x_i;\beta) - u_i + v_i = f(x_i;\beta) + \varepsilon_i. \tag{46}$$

Here, $f(x_i;\beta)$ represents the production frontier of a firm (or more generally a DMU), for input vector x_i. Our use of β is to clearly signify that we are parametrically specifying our production function, such as Cobb–Douglas, or something more flexible like translog or generalized quadratic. One benefit of deploying DEA is that it allows eschewing specification of the production relationship, but at the cost of requiring v_i to be absent (or effectively ignoring its presence). A recent literature has developed that attempts to include the composed error term but allows the production technology to be left unspecified. A state-of-the-art discussion is provided by Parmeter and Zelenyuk [96].

The main difference between a standard production function setup, DEA, and SFA is the presence of two distinct error terms in the model. The u_i term captures inefficiency, shortfall from maximal output dictated by the production technology, while the v_i term captures stochastic shocks. The standard neoclassical production function model assumes full efficiency (SFA allows this as a special case, which can be statistically tested). The standard implementation of DEA does not allow for the presence of v_i.

One shortcoming of SFA is that the appearance of inefficiency in Equation (29) lacks any specific structural interpretation. Without a specific structural link, it is difficult to know just how to handle inefficiency in Equation (29). Thus, to estimate the model, several assumptions need to be imposed. First, it is commonly assumed that inputs are statistically independent of u and v, i.e., $u \perp x$ and $v \perp x \ \ \forall x$. Second, u and v are assumed to be independent of one another. Next, given that u_i leads directly to a shortfall in output, it must come from a one-sided distribution, implying that $E[\varepsilon_i|x] \neq 0$. This has two effects if one were to estimate the production frontier using OLS. First, the intercept of technology would not be identified; and second, without any additional information, nothing can be said about inefficiency, which means we cannot construct measures of productive efficiency.

A third issue that arises in current application of SFA/DEA is the appearance of 'determinants of inefficiency.' As it stands in the basic frameworks of both DEA and SFA, if u_i is an independently and identically distributed random variable, there is no policy implication behind it, given that nothing can directly increase or decrease inefficiency. So, the conclusions of such a study would be descriptive (reporting presence or absence of inefficiency) rather than prescriptive or normative.

By denoting $E[u_i]$ as μ_u and $\varepsilon_i^* = v_i - (u_i - \mu_u)$, the benchmark frontier model can be rewritten as

$$y_i = f(x_i;\beta) - \mu_u - (u_i - \mu_u) + v_i \equiv f^*(x_i;\beta) + \varepsilon_i^* \tag{47}$$

and so $E[\varepsilon_i^*|x] = 0$. The OLS estimator could be used to recover mean-inefficiency-adjusted technology $f^*(x_i;\beta) = f(x_i,\beta) - \mu_u$ in this case. However, this is rarely the sole focus when assessing either productivity or productive efficiency. More structure is required for SFM in this case.

ALS's and MvB's approach to extract information on inefficiency, while also estimating technology, was to impose distributional assumptions on u_i and v_i, recovering the implied distribution for ε_i and then estimating all of the parameters of the SFM with the maximum likelihood estimator (MLE). Both ALS and MvB assumed v_i as independent and identically distributed (IID) normal with mean 0 and variance σ_v^2, while the distribution of u_i differed across the papers; ALS assumed that u_i was generated from an IID half-normal distribution, $N_+(0,\sigma_u^2)$; whereas MvB assumed u_i was distributed exponentially, with parameter σ_u. ALS also briefly discussed the exponential distribution, but its use and development is mainly attributed to MvB.

Even though the half-normal and exponential distributions are distinct, they possess several common aspects. Both densities have modes at zero and monotonically decay (albeit at different speeds) as u_i increases. The zero mode property is indicative of an industry where there is a tendency for higher efficiency for the majority of the DMUs. Both densities would be classified as single parameter distributions, which means that both, the mean and the variance, depend on the single-parameter, and these distributions also possess the scaling property [130]. Papadopoulos and Parmeter [131] provide more discussion on the empirical tradeoffs involved between use of the half-normal and exponential distributions.

The Distribution of ε

Estimation of Equation (29) with maximum likelihood requires that the density of ε, $f_\varepsilon(\varepsilon)$, is known. $f_\varepsilon(\varepsilon)$ can be determined through the distributional assumptions invoked for v and u. Not all pairs of distributional assumptions for v and u will lead to a tractable density of $f_\varepsilon(\varepsilon)$ which permits estimation via maximum likelihood. Fortunately, the half-normal specification of ALS and the exponential specification of MvB (along with the normal assumption for v), produce a density for ε that has a closed-form solution; direct application of maximum likelihood is relatively straightforward in this setting.

The density of the composed error for the normal-half-normal specification is given by,

$$f_\varepsilon(\varepsilon) = \frac{2}{\sigma}\phi(\varepsilon/\sigma)\Phi(-\varepsilon\lambda/\sigma), \tag{48}$$

where $\phi(\cdot)$ is the standard normal probability density function (PDF); while $\Phi(\cdot)$ is the standard normal cumulative distribution function (CDF), with the parameterization $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$ and $\lambda = \sigma_u/\sigma_v$. The parameter λ is commonly interpreted as the proportion of variation in ε due to inefficiency (relative to noise). The density of ε in Equation (31) can be characterized as that of a skew normal random variable with location parameter 0, scale parameter σ, and skew parameter $-\lambda$. This connection has only recently appeared in the efficiency and productivity literature [132].

The PDF of a skew normal random variable u is $f_u(u) = 2\phi(u)\Phi(\alpha u)$. The distribution is right skewed if $\alpha > 0$ and is left skewed if $\alpha < 0$. We can also place the normal truncated-normal pairs of distributional assumptions in this class. The PDF of u with location ξ, scale ω, and skew parameter α is $f_u(u) = \frac{2}{\omega}\phi\left(\frac{u-\xi}{\omega}\right)\Phi\left(\alpha\left(\frac{u-\xi}{\omega}\right)\right)$. O'Hagan and Leonard [133] and Azzalini [134] have provided more details on this.

From $f_\varepsilon(\varepsilon)$ in Equation (31), along with independence assumptions on u_i and v_i, the log-likelihood function is:

$$\ln\mathcal{L} = \ln\left(\prod_{i=1}^{n} f_\varepsilon(\varepsilon)\right) = -n\ln\sigma + \sum_{i=1}^{n} \ln\Phi(-\varepsilon_i\lambda/\sigma) - \frac{1}{2\sigma^2}\sum_{i=1}^{n} \varepsilon_i^2, \quad (49)$$

where $\varepsilon_i = y_i - f(x_i;\beta)$. The SFM can be estimated using the traditional maximum likelihood estimator (MLE). The benefit of this is that under the assumption of correct distributional specification of ε, the MLE is asymptotically efficient, i.e., consistent and asymptotically normal, and its asymptotic variance reaches the Cramer–Rao lower bound. A further benefit is that a range of testing options are available. For instance, tests related to β can easily be undertaken using any of the classic trilogy of tests: Wald, Lagrange multiplier, or likelihood ratio. The ability to readily and directly conduct asymptotic inference is one of the major benefits of SFA over DEA.

This in no way suggests that inference cannot be undertaken when the DEA estimator is deployed. Rather, the DEA estimator has an asymptotic distribution that is much more complicated than the parametric MLE, and so direct asymptotic inference is not available; bootstrapping techniques are required for many of the most popular DEA estimators [136, 137].

Estimation of Individual Inefficiency

Once the parameters of the SFM have been estimated, estimates of firm-level productivity and efficiency can be recovered. Firms can be ranked according to estimated efficiency. The identity of underperforming firms as well as those who are deemed best practice can also be gleaned from the SFM.

The only direct estimate coming from the normal-half-normal SFM is $\hat{\sigma}_u^2$. This provides context regarding the shape of the half-normal distribution on u_i and the industry average efficiency $E[u]$, but not on the absolute level of inefficiency for a given firm. If we are only concerned with the average level of technical efficiency for the population, then this is all the information that is needed. Yet, if we want to know about a specific firm, then something else is required. The main approach to estimating firm-level inefficiency is the conditional mean estimator of Jondrow, Lovell, Materov, and Schmidt [135], commonly known as the JLMS estimator. Their idea was to calculate the expected value of u_i conditional on the realization of composed error of the model, $\varepsilon_i \equiv v_i - u_i$, i.e., $E[u_i|\varepsilon_i]$. This conditional mean of u_i for given ε_i gives a point prediction of u_i. The composed error contains individual-specific information, and the conditional expectation is one measure of firm-specific inefficiency. Jondrow, et al. [135] also suggested an alternative estimator based on the conditional mode.

Jondrow, et al. [135] show that for the normal-half-normal specification of the SFM, the conditional density function of u_i for given ε_i, $f_{u_i|\varepsilon_i}(u_i|\varepsilon_i)$, is $N_+(\mu_{*i}, \sigma_*^2)$, where

$$\mu_{*i} = \frac{-\varepsilon_i \sigma_u^2}{\sigma^2} \tag{50}$$

and

$$\sigma_*^2 = \frac{\sigma_v^2 \sigma_u^2}{\sigma^2}. \tag{51}$$

Given the results on the mean of a truncated-normal density, it follows that

$$E[u_i|\varepsilon_i] = \mu_{*i} + \frac{\sigma_* \phi(\frac{\mu_{*i}}{\sigma_*})}{\Phi\left(\frac{\mu_{*i}}{\sigma_*}\right)}. \tag{52}$$

The individual estimates are then obtained by replacing the true parameters in Equation (52) with MLE estimates from the SFM.

Another measure of interest is the Afriat-type level of technical efficiency, defined as

$$e^{-u_i} = Y_i / e^{m(x_i)} e^{v_i} \in [0,1].$$

This efficiency measure is useful in cases where output is measured in algorithmic form during the estimation. Further, technical efficiency is bounded between 0 and 1, making it somewhat easier to interpret it relative to a raw inefficiency score. Since e^{-u_i} is not directly observable, the idea of Jondrow, et al. [135] can be deployed here, and $E[e^{-u_i}|\varepsilon_i]$ can be calculated [138, 139]. In particular for the normal-half-normal model, we have

$$E[e^{-u_i}|\varepsilon_i] = e^{\left(-\mu_{*i}+\frac{1}{2}\sigma_*^2\right)} \frac{\Phi\left(\frac{\mu_{*i}}{\sigma_*} - \sigma_*\right)}{\Phi\left(\frac{\mu_{*i}}{\sigma_*}\right)}, \tag{53}$$

where μ_{*i} and σ_* were defined in Equation (50) and Equation (51), respectively. Technical efficiency estimates for this measure are obtained by replacing the true parameters in Equation (53) with MLE estimates from the SFM. When ranking efficiency scores, one should use estimates of $1 - E[u_i|\varepsilon_i]$, which is the first-order approximation of Equation (53). Similar expressions for the Jondrow, et al. [135] and Battese and Coelli [139] efficiency scores can be derived under the assumption that u is exponential [140], truncated-normal [140], and Gamma [140]. Parmeter and Kumbhakar [141]; Kumbhakar, Wang, and Horncastle [142]; and Kumbhakar, Parmeter, and Zelenyuk [143] provide more details.

Estimation Results for Productivity Indices and their Decompositions

In our discussion of the results, we will focus on both the Labor Productivity Index (LPI) and Malmquist Productivity Index (MPI) and their decompositions (defined and described in more detail in the first chapter of this report). In particular, recall that the level of labor productivity (LP) in a period t is a single-factor productivity (SFP) measure defined as the ratio of (aggregate) output to aggregate labor, i.e.,

$$LP_t = Y_t / L_t , \tag{54}$$

which is then used to define the LPI, as the ratio of labor productivity levels of the two periods of interest, say periods s and t, i.e.,

$$LPI_{st} = \left(\frac{Y_t}{L_t}\right) / \left(\frac{Y_s}{L_s}\right). \tag{55}$$

It is also worth noting that the LP is closely related to the measure of income per capita and highly correlates with it and its dynamics. This is because they both use GDP in the numerator, while the denominator is highly correlated because the number of workers is a relatively stable proportion of the population. Studying the labor productivity and its dynamics is therefore imperative for understanding the dynamics of standards of living. Or, in the words of the Nobel Laureate Paul Krugman, "Productivity isn't everything, but in the long run, it's almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker…" [144].

To construct these productivity indices and decompose each into its attendant parts, we use the data from Penn World Table version 9.1 (PWT 9.1) on expenditure-side real GDP at chained (in million 2011) international dollars, i.e., PPP adjusted as the proxy for aggregate output, and the data on capital and labor as the proxies for the two major inputs for producing the output.

To align with Kumar and Russell's [111] analysis, we use the same countries that were in their sample and also include those APO countries that were missing from their sample. Also, while their analysis focused on 1965 versus 1990, we will hone our results to the years 1991 versus 2017 (the last year available in the most recent PWT). The benefit of this shift in the time period considered is that many APO countries underwent significant structural economic changes in the 1990s and the earlier studies that have examined cross-country labor productivity either did not include the full body of the APO or only included some of these years, but not the full period. These two extensions will provide a more complete understanding of the macroeconomic changes that APO members experienced and more aptly allow us to tie into the explanations underlying changes in the TFPs that are presented earlier.

It may be noted that Kumar and Russell [111] included eight APO countries in their study. Similar samples were used by Henderson and Russell [75]; Henderson and Zelenyuk [145]; and Badunenko and Romero–Avila [146], among others. In principle, all the conclusions drawn from this exercise are in reference to the selected sample as some results may change if the sample is changed substantially (e.g., by adding some outliers such as oil-producing countries, etc.). Analogous results can be obtained and provided for other countries.

Labor Productivity

We begin with a presentation of the labor productivity levels, since they are the simplest and most popular in practice and then discuss the decomposition. In the Appendix, Table 1 presents the full set of estimates of labor productivity for each period (both measured in international 2011 dollars per worker) and their ratio, the LPI, for each country in the sample. Below we mention a few insights.

Labor Productivity levels

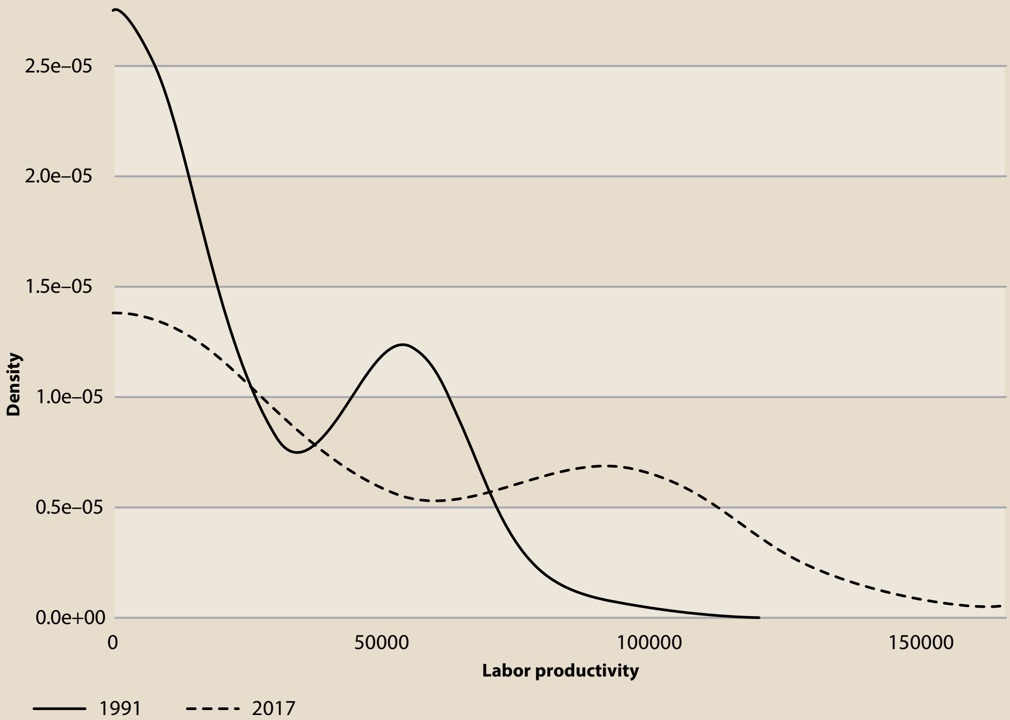
It is interesting to note that there is a great heterogeneity among countries in terms of the level of LP and how it changed over the 26 years that we have studied. For example, the top five countries in the sample by labor productivity in 1991 were Luxembourg (USD90,390), the USA (USD74,857), Belgium (USD66,663), Switzerland (USD64,653), and Italy (USD63,762); while in 2017 they were Ireland (USD167,078), Luxembourg (USD138,440), Singapore (USD128,392), the USA (USD117,974), and Belgium (USD111,771). Notably, while no APO country was among the top countries in terms of labor productivity in 1991, this changed in 2017 when Singapore entered the league, due to an impressive 183% growth in LP, closely followed by Hong Kong (USD106,906) and the ROC (USD95,801), which almost doubled their labor productivities relative to 1991. This confirms the increasing importance of APO countries for the global economy. These countries, which are the leaders in labor productivity levels also provide real examples for other countries to improve labor productivity.

Also, note that the mean and median of labor productivity in the sample were USD29,366 and USD20,443, respectively, in 1991; and USD54,050 and USD45,257, respectively, in 2017. For APO countries, the mean and median were USD18,652 and USD10,276, respectively, in 1991; and USD43,313 and USD29,746, respectively, in 2017. This suggests that both distributions of labor productivity are left skewed and that labor became more productive between 1991 and 2017 in APO member countries than in the other 47 countries under study here. This is not surprising as the average labor productivity in 1991 for APO member countries was roughly 65% that of the other 47 countries. Thus, starting from a lower base, it is natural that the growth of productivity is in some sense easier for APO countries as a whole. We also note that even with the higher growth in labor productivity, in 2017, APO countries still lagged the other 47 countries by roughly 20 percentage points on an average.

It is also interesting to look at the distributions of the LP levels for the two periods as well as the distributions of the LPI, for the whole sample and when dissected into two groups, APO versus non-APO, which we will do with the help of kernel density estimators. Figure 1 presents the estimated densities of LP levels for 1991 and 2017 for the entire sample, and one can see a substantial change between the two periods. Specifically, the bimodality of the LP distribution in

FIGURE 1

ESTIMATED DISTRIBUTIONS OF LP OVER TIME.



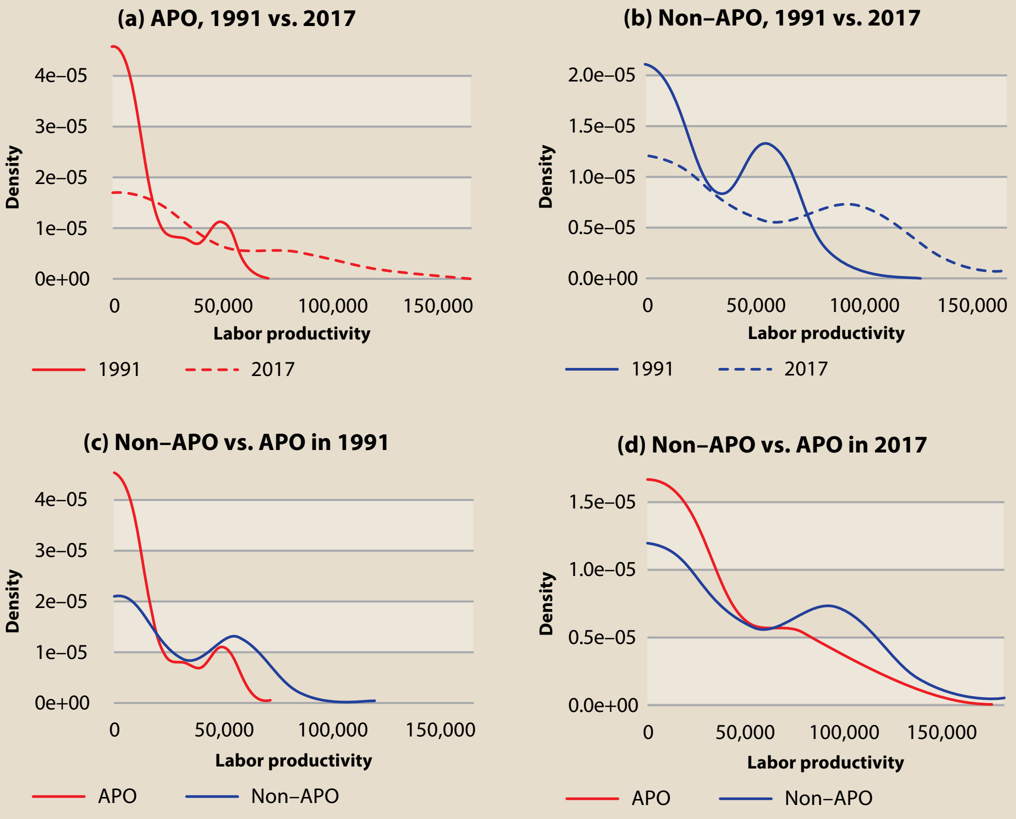
Source: Authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], and PWT 9.1 [80] data.

the 1990s, which was also noted and extensively discussed by Kumar and Russell [111] and in other papers as the two-club phenomenon, has persisted through 2017. Moreover, it became even more pronounced, exhibiting further divergence of the clubs, i.e., the 'rich' and 'poor' (or low-level labor productivity) countries, because the latter remained nearly where they were while the former leaped further, almost doubling over the 26 years that were studied.

To assess labor productivity more clearly, Figure 2 breaks down labor productivity both across time and between APO and non-APO countries. There are several defining features. First, note that both APO and non-APO countries had substantial shifts to the right of the labor productivity distribution over time. Second, one can see that a substantial difference in the estimated densities of labor productivity between APO and non-APO countries existed both in 1991 and 2017, yet the difference became somewhat smaller, largely due to the catching up of the richest APO countries with the other richest countries in the sample, thereby suggesting some convergence. We will come back to the discussion of this phenomenon at the end of this chapter, after our analysis of the decomposition of labor productivity into its key components.

FIGURE 2

VARIOUS COMPARISONS OF ESTIMATED DISTRIBUTIONS OF LP BY TIME AND BY APO/NON-APO STATUS.



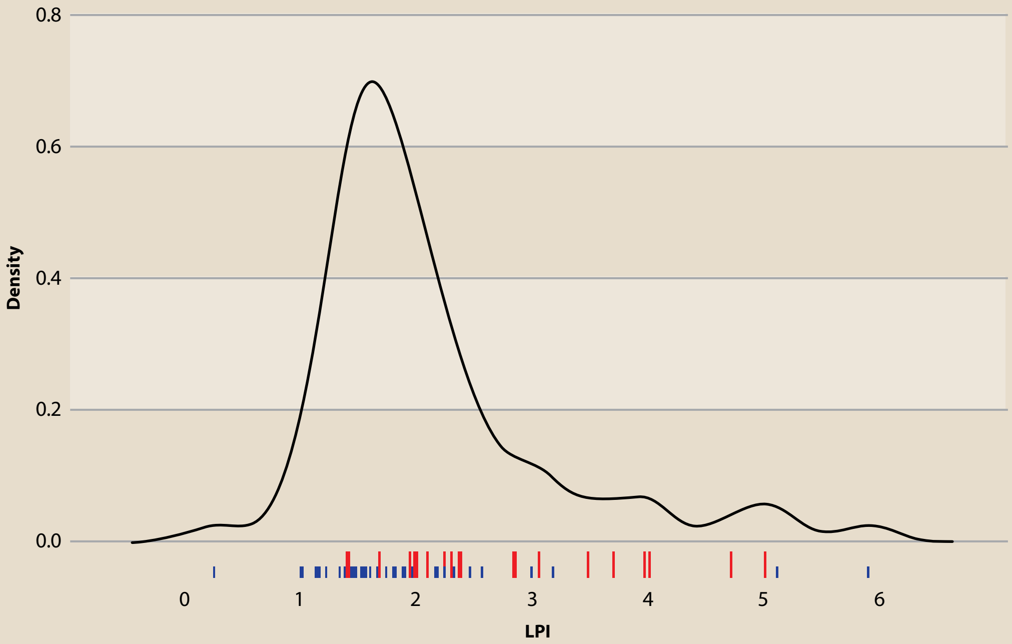
Labor Productivity Indices

We now analyze the change in labor productivity using LPI, presented in the last column of Table 7 in Appendix. This index confirms the immense change in labor productivity over time for the sample, by yielding a numeric value for the change that shows improvement if it is greater than 1 and deterioration if it is less than 1, while (LPI-1)×100% gives the percentage meaning. The table suggests that the mean and median of LPI in the sample were 2.13 and 1.83, respectively, while for APO countries they were 2.74 and 2.38, respectively, thus suggesting that APO countries have progressed substantially more in terms of labor productivity growth than the average in the sample.

Figure 3 plots the kernel density of the LPIs across the 68 countries. We also include the 'rug' of observations, where we highlight in red (APO countries) and blue (non-APO countries) to help discern where groups of countries appear in the full distribution. The rug hints that APO countries did indeed have substantially greater change in labor productivity.

FIGURE 3

ESTIMATED DISTRIBUTIONS OF LPI.



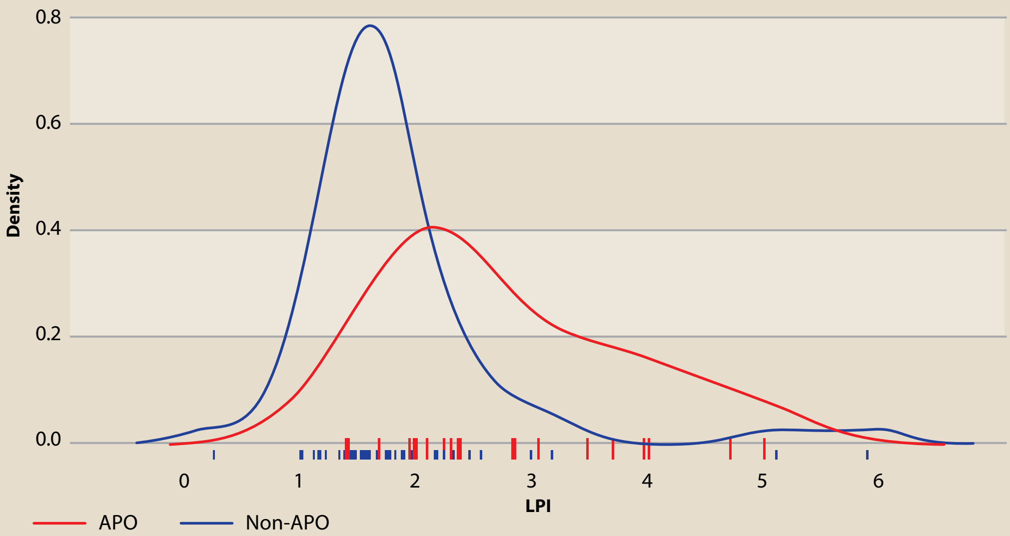
While the rug plot is useful, it is better to split the sample and look at the individual densities of LPI between APO and non-APO countries. This is accomplished in Figure 4, which provides a starker assessment of the differences in the LPI between the two groups of countries. The APO density has a thicker right tail and appears to be first order stochastically dominated by non-APO countries. What we learn here is that over the 26-year-period, APO countries on the whole had larger increases in labor productivity than the 47 other countries considered. This is consistent with the other visual evidence that we presented prior to this as well.

It is notable that for many countries, the change was much bigger than the average. For some, it was close to 500%. The top five leaders in LPI overall were Nigeria (490%), Syria (412%), India (402%), Lao PDR (371%), and Mongolia (301%). Only one country, Zimbabwe, had a fall in labor productivity during this time (it experienced a drop of 73%). Significantly, three of the top five countries are APO members. The top five APO countries in terms of LPI included Vietnam (297%) and IR Iran (271%).

What are the sources of these immense changes in labor productivity? The detailed stories behind the high growths of each of these countries are very different and sometimes specific to peculiar circumstances. For example, for both Nigeria and Syria, the oil price boom obviously had an effect, as was also the case for IR Iran, along with the lifting of international sanctions towards the end of the sample period (the Donald Trump administration ended the accord with IR Iran only after 2017). Detailing each story is obviously well beyond the scope of this study and, in fact, likely requires a more nuanced discussion for every country in the sample to dig into the specifics of improved labor productivity. What is possible, however, is to look at the broad overall tendencies in the sample for the major components of the decomposition of LPI. This will be discussed now.

FIGURE 4

ESTIMATED DISTRIBUTIONS OF LPI ACROSS APO AND NON-APO COUNTRIES.



Decomposition of Labor Productivity Indices

As described in fair detail in this chapter, while the LPI is an SFP index, it can be decomposed into the MPI, which is a multifactor productivity index, and the change due to capital per labor accumulation or capital deepening (KLACC) can be given by,

$$LPI_{st} = MPI_{st} \times KLACC_{st}. \tag{56}$$

In turn, recall that the MPI can be decomposed into efficiency change (EC) and technology change (TC) as follows:

$$MPI_{st} = EC_{st} \times TC_{st}. \tag{57}$$

Combining the last two expressions, we have the decomposition of LPI into three components: efficiency change, technology change, and the change due to accumulation of capital per worker, i.e.,

$$LPI_{st} = EC_{st} \times TC_{st} \times KLACC_{st}. \tag{58}$$

Below, we present and discuss the results for each of these components.

Efficiency of Countries

To decompose the LPI into its major sources, we begin with the estimation and presentation of technology over time, comparing 1991 with 2017. To be able to visualize the data in two dimensions, we normalize both output and capital by labor and present the scatter plot (where the red triangles are observations in 1991, and grey circles are observations in 2017), along with the DEA-estimated frontiers for 1991 and 2017 (see Figure 5). The DEA formulations assumed constant returns to scale, free disposability of inputs and outputs, and no technology implosion assumption. Färe and Zelenyuk [147] and references therein provide discussion on justifications for these assumptions and further details of the formulations. We could also deploy SFA here, as given in Kumbhakar and Wang [148], though the main thrust is consistent across these two methods [96].

Figure 5 shows that there is little to no technological change at both low and medium levels of capital per worker while dramatic changes in technology are observed at high levels of capital per worker. Note that this is similar to what Kumar and Russell [111] found for their period of study (1965–90), albeit even more dramatic, hinting at the increasing importance of high levels of capital per worker for driving technological changes.

In the Appendix, Table 8 presents the full set of results, which we will also illustrate graphically and discuss below. While looking at the subsequent components for any given country is not

FIGURE 5

WORLD PRODUCTION FRONTIERS IN 1991 AND 2017.

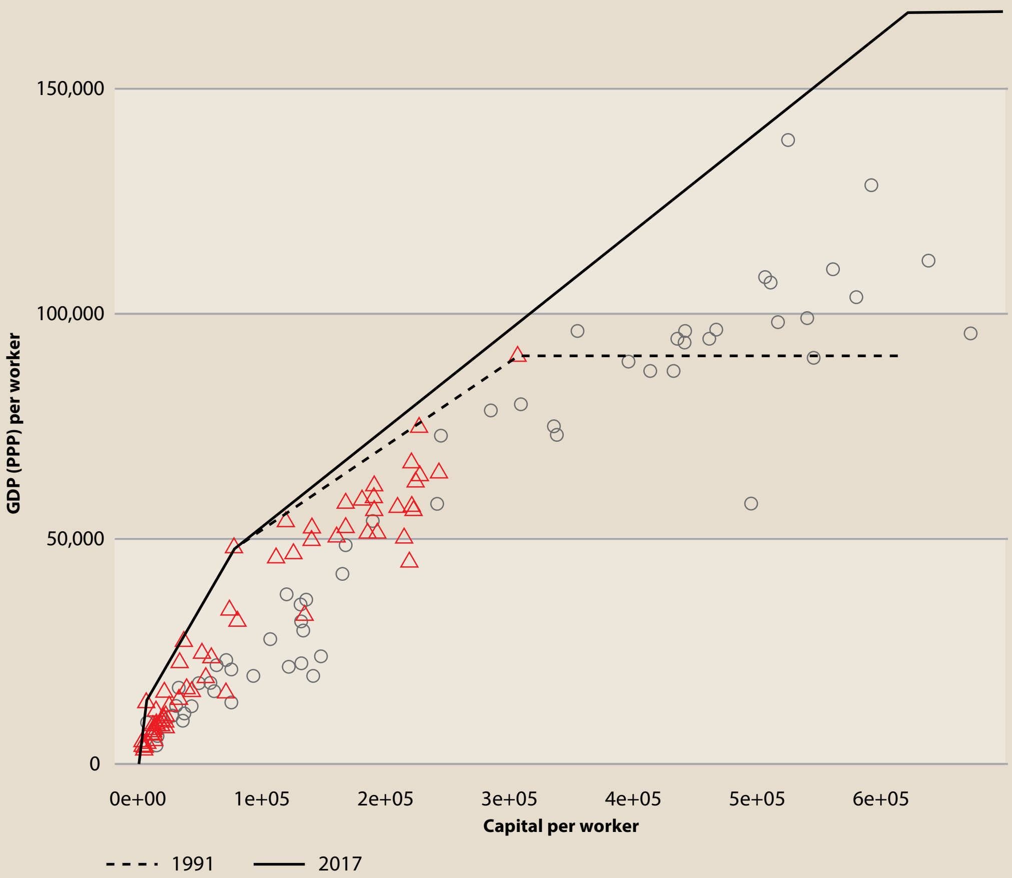


TABLE 1

SUMMARY STATISTICS FOR ESTIMATES OF EFFICIENCY AND PRODUCTIVITY INDICES AND THEIR COMPONENTS FOR THE SAMPLE.

		Efficiency		Efficiency	Technology	KLACC	MPI	LPI	HMBPI
		1991	2017	Change	Change				
Full sample	Mean	0.6461	0.5777	0.9452	1.1091	2.0625	1.0412	2.1331	1.0412
	Median	0.6664	0.5949	0.9012	1.024	1.8614	1.016	1.8293	1.016
	SE	0.0223	0.0197	0.0302	0.0137	0.0795	0.0312	0.1042	0.0312
APO	Mean	0.5563	0.5655	1.0913	1.0517	2.4331	1.1409	2.7448	1.1409
	Median	0.5274	0.5425	0.9879	1.0165	2.1999	1.121	2.3775	1.121
	SE	0.0254	0.02	0.0351	0.0101	0.0835	0.0349	0.1136	0.0349
Non-APO	Mean	0.6863	0.5831	0.8798	1.1347	1.8968	0.9966	1.8598	0.9966
	Median	0.7437	0.628	0.8721	1.0287	1.6423	1.0137	1.6239	1.0137
	SE	0.0153	0.015	0.0197	0.0107	0.0553	0.022	0.0677	0.022

necessarily illuminating to make sweeping conclusions, looking at the overall movement (or lack thereof) of the distribution can be more insightful. We present mean, median, and standard error for all of our measures for the full sample as well as broken down into APO and non-APO countries in Table 1. In particular, Table 1 reveals quite clearly that there are substantial differences in the components underlying changes in labor productivity over time across the two groups of countries.

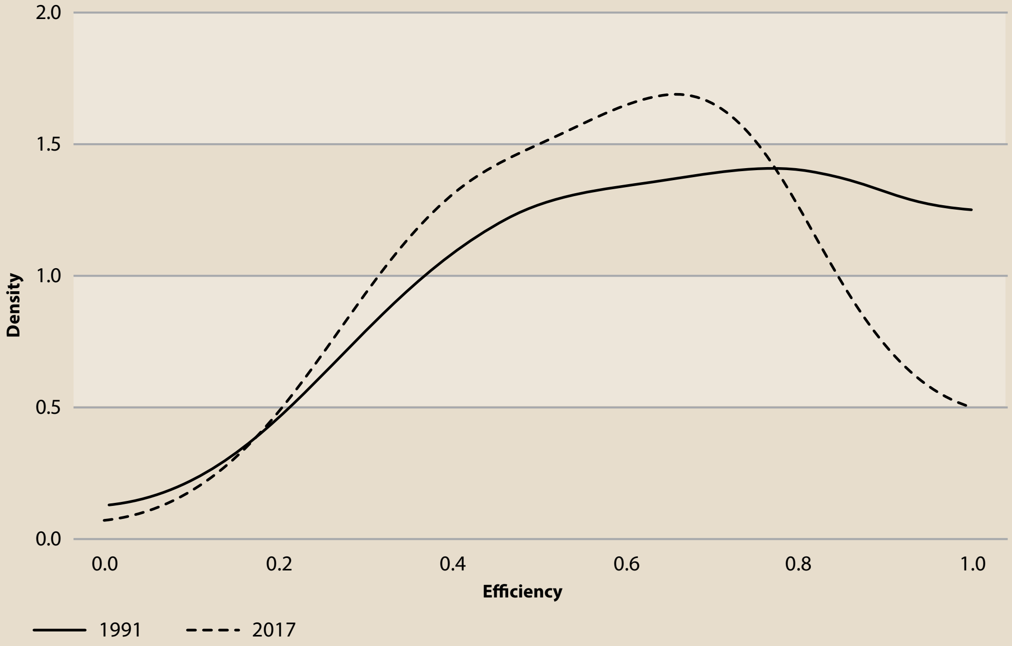
Figure 6 presents the kernel density estimates of estimated technical efficiency. We use a Gaussian kernel with the Silverman rule-of-thumb bandwidth. The reflection approach of Schuster/Silverman is used to account for the boundary at 1. We see from this graph that the distribution of the technical efficiency for the full set of 68 countries changed substantially (the efficiency shrank over the 26-year period). However, this obscures several key differences between APO and non-APO countries and so it is useful to look at these two sub-samples separately and comparatively, as we do below. In particular, to more vividly see how technical efficiency has changed over time, Figure 7 presents a breakdown both by time as well as by APO versus non-APO countries. We also perform a test of equality of the distributions, with bootstrapped p-values reported in Table. To be precise, we use an adaptation of the Li [149] test to the DEA-estimated efficiency framework, where we account for the discontinuity at the boundary following Simar and Zelenyuk [150]. Again, for the bandwidths we use least-squares cross-validation, while for the bootstrap we use 999 replications.

First, note that the statistical test for the full set of 68 countries rejects the hypothesis of equality of efficiency distributions between 1991 and 2017 (at the 1% significance level). Also, it is worth noting (as can be seen from Table 2 in Appendix) that the countries that were on the estimated frontier in 1991 were Luxembourg, Sierra Leone, the ROC, and Zimbabwe; while the countries that were on the estimated frontier in 2017 were Ireland and the USA.

Second, we see that APO member countries as a whole slightly improved in terms of their efficiency distribution, when comparing 1991 with 2017. The test of equality of these distributions suggests

FIGURE 6

ESTIMATED DISTRIBUTIONS OF EFFICIENCY SCORES IN THE SAMPLE (1991 VERSUS 2017).



that the change was statistically insignificant (p-value over 0.6). This is in contrast with non-APO member countries, where the 2017 distribution shifted inward (away from 100% efficiency). Figure 7 suggests that this was due to many countries not being able to catch up with the frontier that rapidly moved out at high levels of capital per worker, making them more inefficient than they were in 1991.

Third, one can see that a substantial difference in the estimated densities of technical efficiency between APO and non-APO countries existed in 1991, which is also confirmed by the statistical test, which rejected the hypothesis of equality of these distributions at the 5% level of significance. On the other hand, in 2017, one can see that there was already very little difference in the estimated densities of technical efficiency between APO and non-APO countries (the statistical test indeed could not reject the equality of these distributions). Thus, between 1991 and 2017, we observe evidence of convergence in the efficiency distributions between the two groups. A broad explanation for this is that in 1991, APO countries were more inefficient relative to non-APO countries. The vast majority of APO member countries did not move far enough in capital–labor space, so it would seem natural that over the 26 years, improvements in efficiency could be made using the 'same' technology. For non-APO member countries, they expanded in capital–labor space where 'new' technology had to be learned, and so some additional inefficiencies appeared for many countries, thus allowing APO members to catch up in terms of efficiency levels.

It is worth noting (as can also be seen from Table 2 in Appendix) that the top five APO countries in terms of estimated efficiency scores in 1991 were the ROC (100%), Hong Kong (96.7%), Singapore (83.8%), Japan (81.0%), and Fiji (78.6%). Meanwhile, in 2017, the top five APO countries in terms of efficiency were the ROC (87.7%), Turkey (80.4%), Singapore (80.0%), Malaysia (76.4%), and Hong Kong (74.8%).

FIGURE 7

VARIOUS COMPARISONS OF ESTIMATED DISTRIBUTIONS OF EFFICIENCY SCORES BY TIME AND BY APO/NON-APO STATUS.

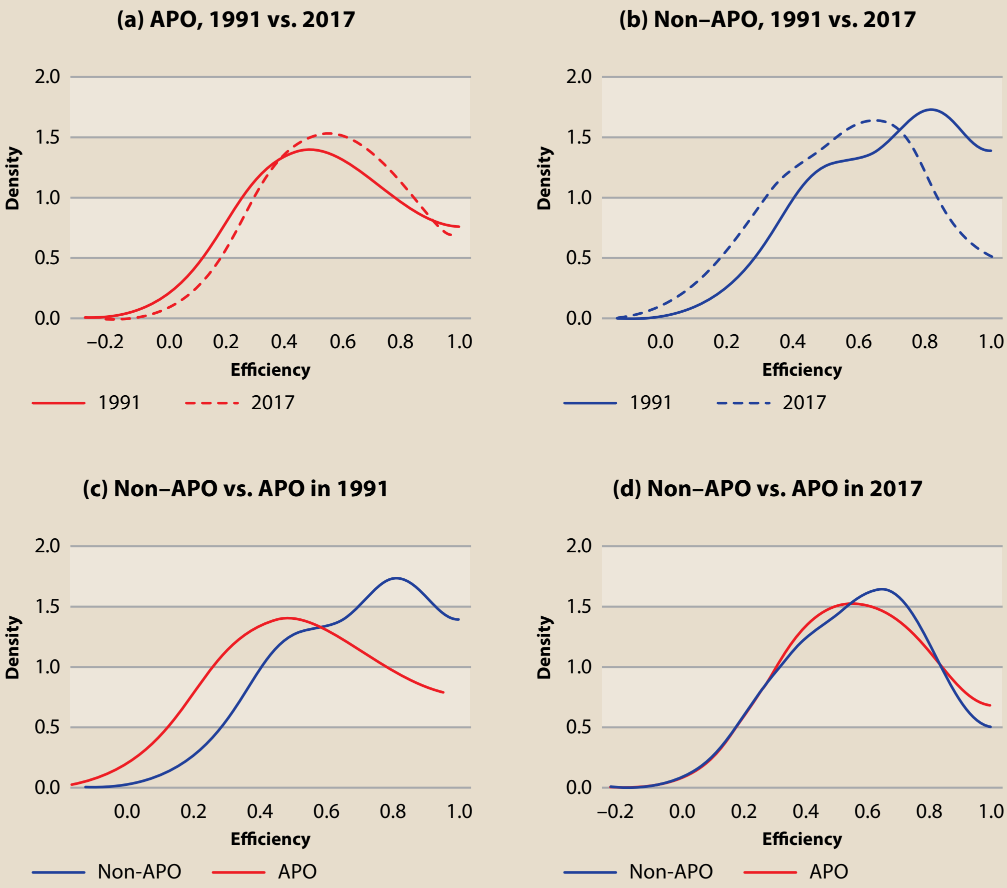


TABLE 2

BOOTSTRAP P-VALUES USING THE LI TEST FOR EQUALITY OF DISTRIBUTIONS ACROSS VARIOUS SCENARIOS.

Hypothesis	Bootstrap *p*-value
All countries: 1991 vs. 2017	0.009
APO: 1991 vs. 2017	0.614
non-APO: 1991 vs. 2017	0.002
1991: APO vs. non-APO	0.044
2017: APO vs. non-APO	0.532

Source: Li [149].

Moving on, Figure 8 plots the kernel estimated density of EC across the 68 countries. Recall that EC is an index defined as the ratio of the efficiency score in the ‘current period’ (here 2017) to the efficiency score in the ‘base period’ (here 1991). It shows the relative improvement in efficiency (if bigger than 1) or deterioration in efficiency (if less than 1). Meanwhile, subtracting 1 from this index and multiplying that by 100% gives the percentage meaning of this index.

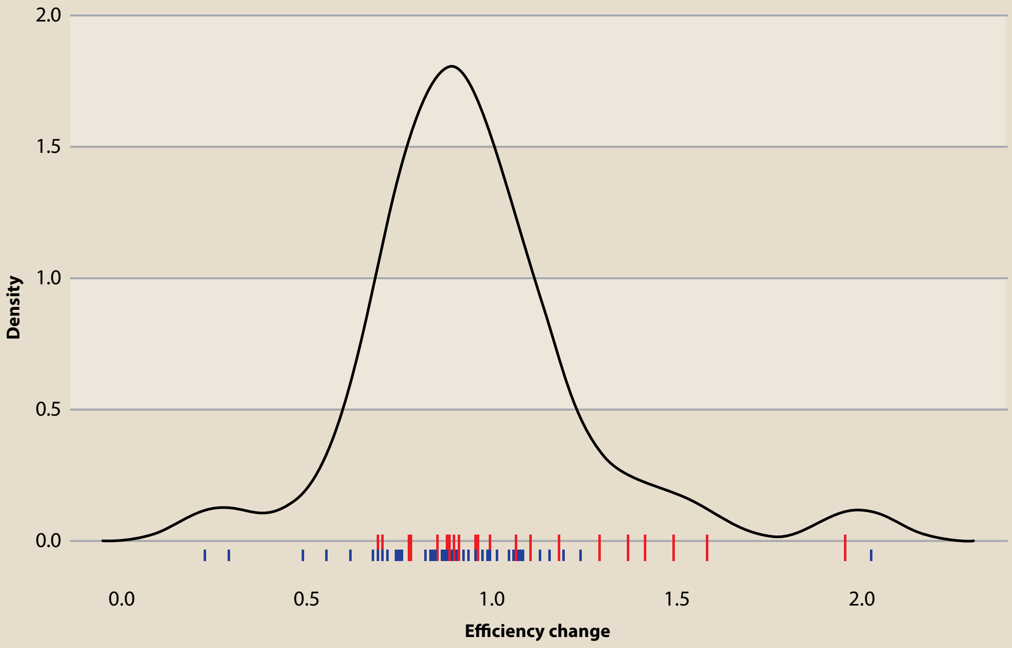
Note that the distribution is centered below 1, while the mode is below 1, the mean is 0.945, and the median is 0.901. These suggest that that there was a deterioration of the distribution of efficiency over time, although some countries had an improvement in efficiency.

As we did for other figures above, we also present the 'rug' of observations where we highlight APO countries in red and non-APO countries in blue to help discern where groups of countries appear in the full distribution. It appears that a great majority of APO countries comprise the upper half of the distribution of efficiency change, consistent with the movement to the right that is observed in panel (a) of Figure 7. This means that a majority of APO countries experienced a positive efficiency improvement or efficiency was catching up.

Figure 9 breaks down the density of efficiency change in Figure 8 between APO and non-APO countries. This provides a starker assessment of efficiency changes. The APO density has a longer right tail, consistent with the notion that APO member countries experienced a greater change in efficiency than non-APO countries. Moreover, the mean and the median of estimated efficiency change for APO countries are 1.091 and 0.988, respectively; while for non-APO countries these are 0.880 and 0.872, respectively. This shows that for both APO and non-APO countries, more than half of them experienced declines in efficiency. Yet, on an average, APO member countries improved their technical efficiency from 1991 to 2017, while the average for non-APO countries declined just over 10% in terms of efficiency.

FIGURE 8

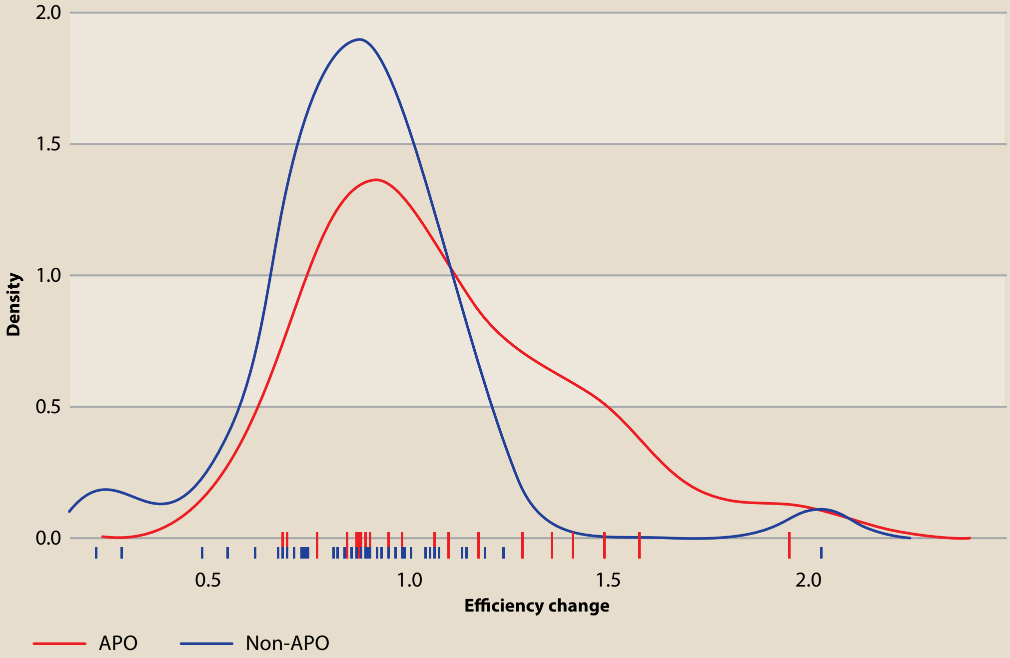
ESTIMATED DISTRIBUTION OF EFFICIENCY CHANGE INDEX.



Also, it is worth noting that the top five APO countries in terms of efficiency improvement were IR Iran (95.3%), India (57.8%), Lao PDR (49.1%), Mongolia (41.2%), and Cambodia (36.2%). While enjoying the high efficiency change, note that all these countries still have substantial room for improvement in efficiency. For example, IR Iran had an efficiency score of 68% in 2017, while India was still at 39%.

FIGURE 9

ESTIMATED DISTRIBUTION OF EFFICIENCY CHANGE INDEX BY APO AND NON-APO COUNTRIES.



Technology Change

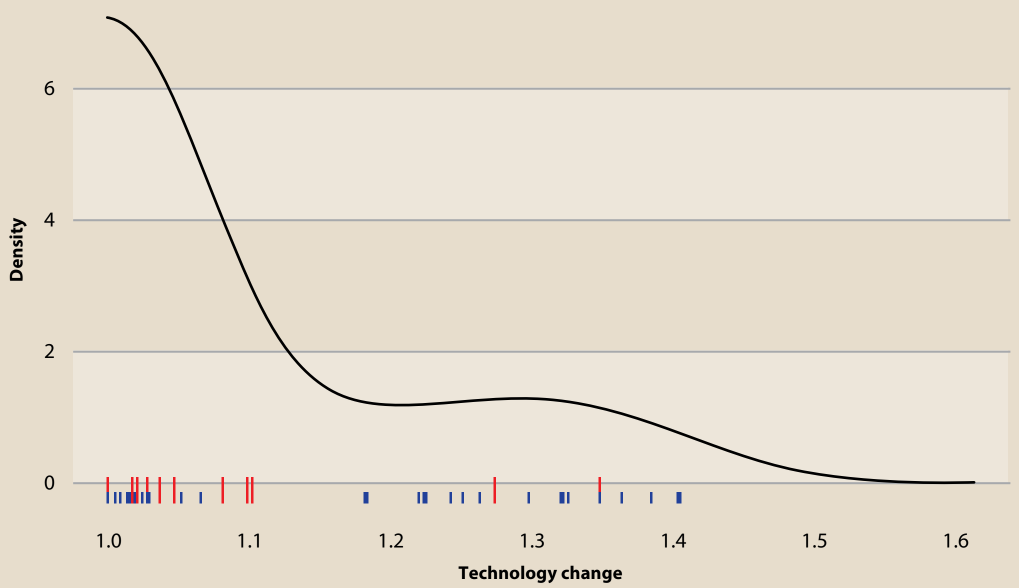
In the Appendix, Table 8 also presents the estimates of technology change (TC) for each country. Recall that TC is an index (defined and described in more detail earlier) that, together with the EC index described above, decomposes the Malmquist (and a multifactor) productivity index. Intuitively, it shows the relative improvement in technology (if bigger than 1) and no change if equal to 1. While it is possible to imagine examples of technological regress, normally it is advised to impose the restriction of such impossibility, as we did, and hence all the estimates of technology change indices are greater or equal to 1. Thus, $(TC\text{-}1)\times 100\%$ gives the percentage meaning of the estimate of technology improvement.

Figure 10 plots the kernel density of estimated TC across the 68 countries. As above, we also highlight APO countries in red and non-APO countries in blue to help visualize where the groups of countries appear in the full distribution. As is consistent with Figure 5, one can see that there was a large increase in technology change between 1991 and 2017. (We use Gaussian kernel with the reflection method to account for the boundary, as the no-technology implosion assumption implies that technology change cannot be below 1.) Moreover, it appears that technology change arose more broadly in non-APO member countries, largely due to countries with high capital per worker, which are predominantly the developed countries, while the majority of APO countries are typically considered as developing or emerging economies. In particular, the top five countries in the sample in terms of technology change were Italy (40.6%), Belgium (40.5%), Ireland (38.5%), Austria (36.4%), and Norway (34.9%).

Figure 11 breaks down the density of technology change in Figure 10 between APO and non-APO countries. This provides a starker assessment of technology change. In contrast to efficiency change, here we see a pronounced hump in the density of technology change for non-APO countries.

FIGURE 10

ESTIMATED DISTRIBUTION OF TECHNOLOGY CHANGE INDEX.



It appears that while both groups of countries saw technology changes, the rate of change differed greatly among the two groups. The top five APO countries in terms of technology change were Singapore (34.7%), Hong Kong (27.4%), Japan (10.3%), the ROC (9.9%), and the ROK (8.2%).

Notably, Singapore and Hong Kong were among the top 10 countries in terms of technology change in the full sample. The mean and median of technology change for APO countries were 1.05 and 1.02, respectively; while for non-APO countries in the sample these were 1.13 and 1.03, respectively. The large difference in the means is driven by a group of countries that were essential for the expansion of global technology. This is likely driven by the need for technology to expand in response to rapid increases in capital as well as the necessary investments in human capital that usually accompany such an expansion.

Multifactor Productivity Change

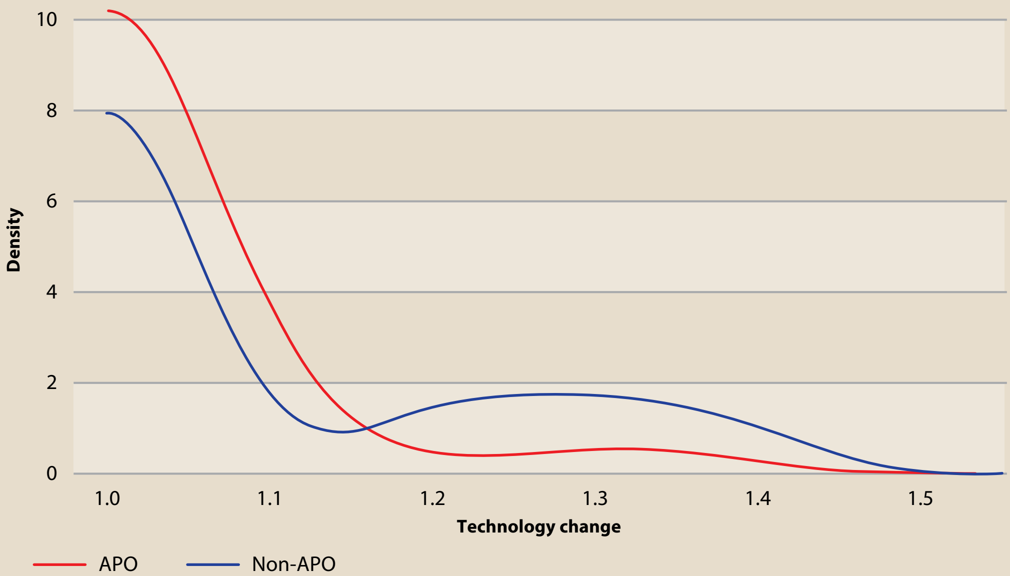
In the Appendix, Table 8 also presents the estimates of the MPI, which is a multifactor productivity index and is advantageous relative to the LPI, which is a single-factor productivity index, in that it accounts not just for one factor of production (labor in case of LPI) but for all of the inputs considered (labor and capital). Another advantage is that it can be decomposed into the EC and TC components we estimated and discussed above. MPI indicates a relative improvement in multifactor productivity (if bigger than 1) or a deterioration (if less than 1).

Figure 12 plots the kernel density of the estimated MPI (a product of EC and TC) across the 68 countries in the sample. Again, to help discern where groups of countries appear in the full distribution, we highlight APO countries in red and non-APO countries in blue, and one can see that majority of APO countries had improvements in their MFP index.

Figure 13 breaks down the density of estimated MPI in Figure 12 by APO and non-APO countries. This provides a starker assessment of MFP change. Notably, the estimated density of MPI for APO

FIGURE 11

ESTIMATED DENSITY OF TECHNOLOGY CHANGE INDEX BY APO AND NON-APO COUNTRIES.



group has a shorter left tail (where the MPI is showing deterioration in MFP) and a thicker right tail (where the MPI is showing improvement in MFP). This suggests that the APO countries enjoyed better MFP than the non-APO countries. The mean and the median of the MPI for APO countries were 1.14 and 1.12, respectively; while for non-APO countries, these were 1.00 and 1.01, respectively. The large differences in average MPI across APO and non-APO countries is driven by efficiency change.

FIGURE 12

ESTIMATED DISTRIBUTION OF THE ESTIMATED MPI.

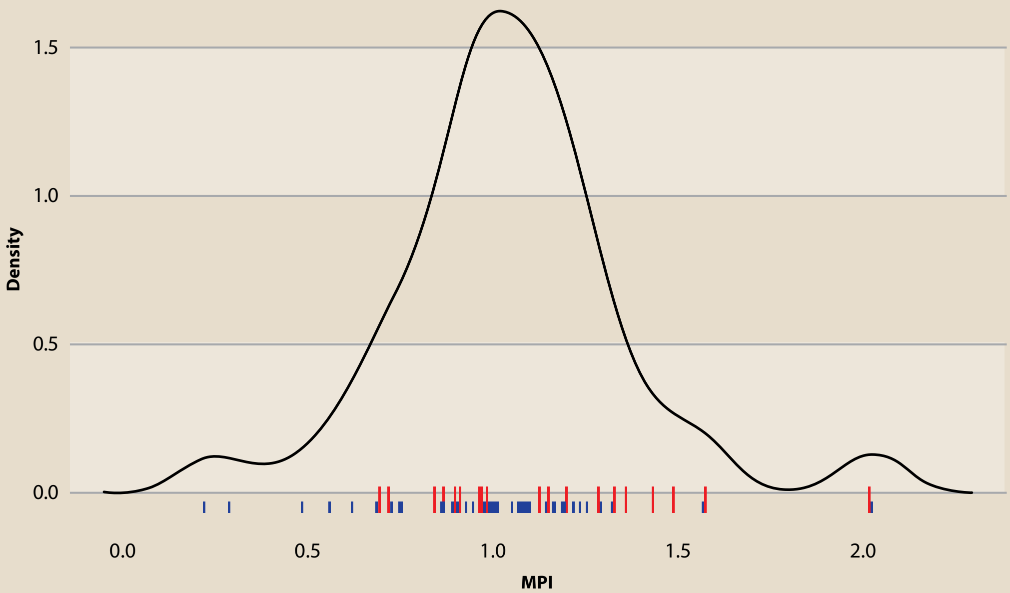
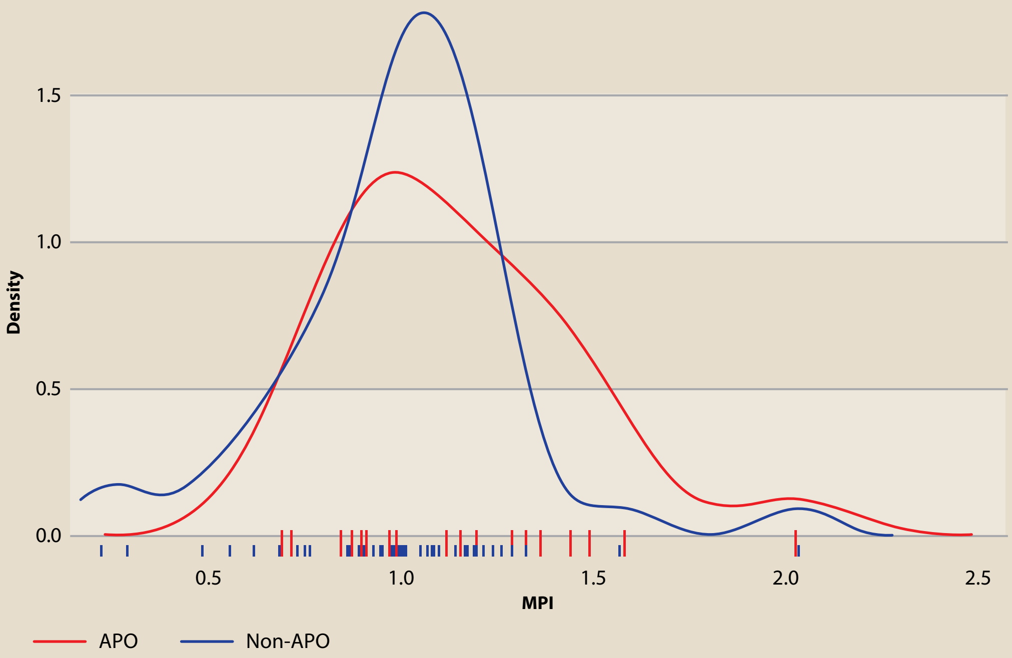


Table 1 shows that technology change was above one for both groups on an average but efficiency change was above 1 for APO countries and below 1 for non-APO countries. Combined, this helps to understand why APO member countries appear more productive than the rest of the world, on average. The top five APO countries in terms of multifactor productivity change were IR Iran (2.02), India (1.58), Lao PDR (1.49), Mongolia (1.44), and Cambodia (1.36). Note that these are also the same five APO countries (in the same order) that had the highest estimated efficiency improvements between 1991 and 2017.

FIGURE 13

ESTIMATED DISTRIBUTIONS OF MPI BY APO AND NON-APO COUNTRIES.



Capital Deepening

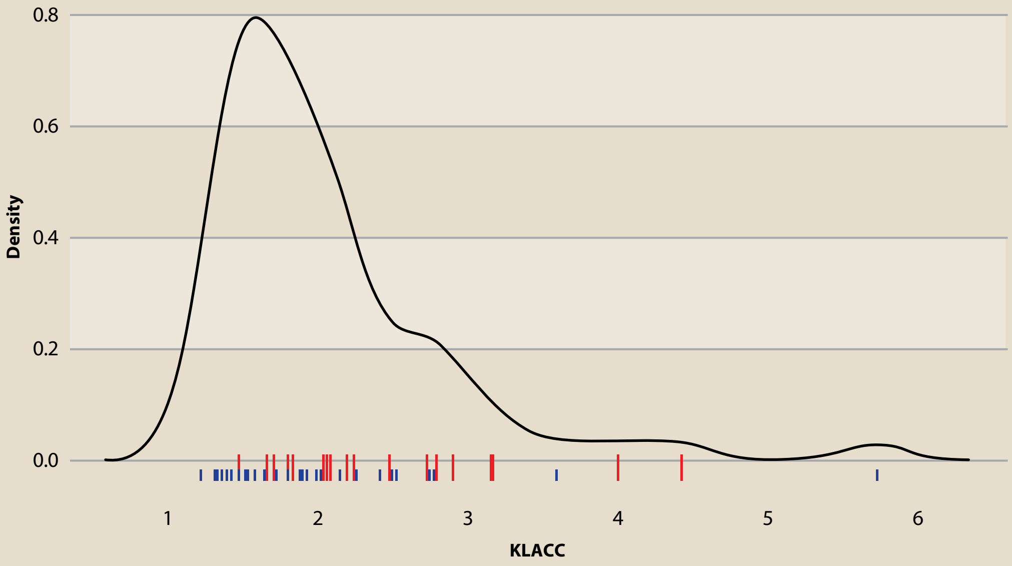
Table 1 also presents the estimates of the KLACC, i.e., the contribution to Labor Productivity Index (LPI) due to the change in capital per worker, which sometimes is referred to as the 'capital deepening' effect on labor productivity. Here, recall that KLACC is also an index that establishes the link connecting the LPI (an SFP index, with respect to labor) with the MPI (an MFP index), in the sense that $LPI = MPI \times KLACC$. As an index, it shows the relative improvement if bigger than 1 and deterioration if less than 1, with the percentage meaning obtained by subtracting 1 and multiplying by 100%.

Figure 14 plots the kernel density of estimated KLACC. Again, we highlight APO countries in red and non-APO countries in blue, to visualize where groups of countries appear in the full distribution. It can be noticed that APO countries also enjoyed more productivity growth due to capital deepening.

Meanwhile, Figure 15 breaks down the density of estimated KLACC in Figure 14 across APO and non-APO countries, which provides a more vivid assessment of the contribution to productivity growth due to the accumulation of capital per worker. Indeed, the density of KLACC for APO has a substantially thicker right tail and appears to be first order stochastically dominated by non-APO countries.

FIGURE 14

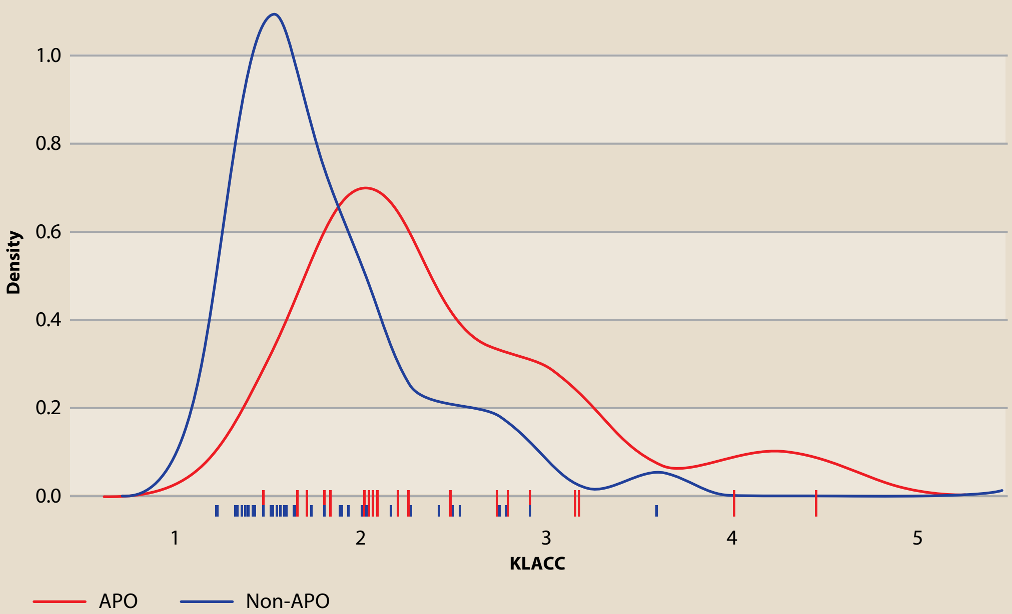
ESTIMATED DISTRIBUTION OF CAPITAL DEEPENING.



The mean and the median of the KLACC for APO countries were 2.43 and 2.20, respectively; while for non-APO countries, these were 1.90 and 1.64, respectively. The top five APO countries in terms of KLACC were Vietnam (4.44), Indonesia (4.01), India (3.18), Lao PDR (3.16), and Sri Lanka (2.91).

FIGURE 15

ESTIMATED DISTRIBUTIONS OF CAPITAL DEEPENING BY APO AND NON-APO COUNTRIES.



Rankings

Finally, Table 3 provides the rank of each of the APO member countries across our various measures within the APO group. There are many noteworthy features in this table. First, one can see that the ROC is the most (and the only) efficient country in both the periods. Other highly efficient countries in both periods include Hong Kong, Singapore, Japan, and Turkey. These same countries were also among the best in technology change, although none of them were among the top countries for the LPI or the MPI.

Meanwhile, the top improvers in efficiency change (or catching up to the frontier) were IR Iran, India, Lao PDR, Mongolia, and Cambodia. With the exception of Cambodia, these countries were among the leaders in labor productivity growth; while India, Lao PDR, and Mongolia were also among the leaders in capital deepening. Cambodia and IR Iran were among the outsiders in capital deepening, which restricted their labor productivity growth.

TABLE 3

RANKING BY CATEGORY ACROSS APO MEMBER COUNTRIES.

	Efficiency 1991	Efficiency 2017	Efficiency change	Technical change	Capital deepening	MPI	LPI
Bangladesh	15	20	18	17	8	19	14
Cambodia	20	19	5	17	20	5	13
ROC	1	1	16	4	12	15	15
Fiji	5	11	21	17	14	21	21
Hong Kong	2	5	19	2	15	13	17
Indonesia	11	18	20	9	2	20	8
India	21	17	2	17	3	2	1
IR Iran	17	8	1	7	17	1	5
Japan	4	6	15	3	21	14	20
ROK	7	7	10	5	16	10	12
Lao PDR	19	16	3	17	4	3	2
Sri Lanka	12	10	7	10	5	8	6
Mongolia	16	12	4	12	6	4	3
Malaysia	9	4	6	8	18	6	10
Nepal	18	21	17	17	9	18	18
Pakistan	8	9	11	17	19	12	19
Philippines	13	15	13	17	11	16	16
Singapore	3	3	12	1	10	7	9
Thailand	14	13	8	11	7	11	7
Turkey	6	2	9	6	13	9	11
Vietnam	10	14	14	17	1	17	4

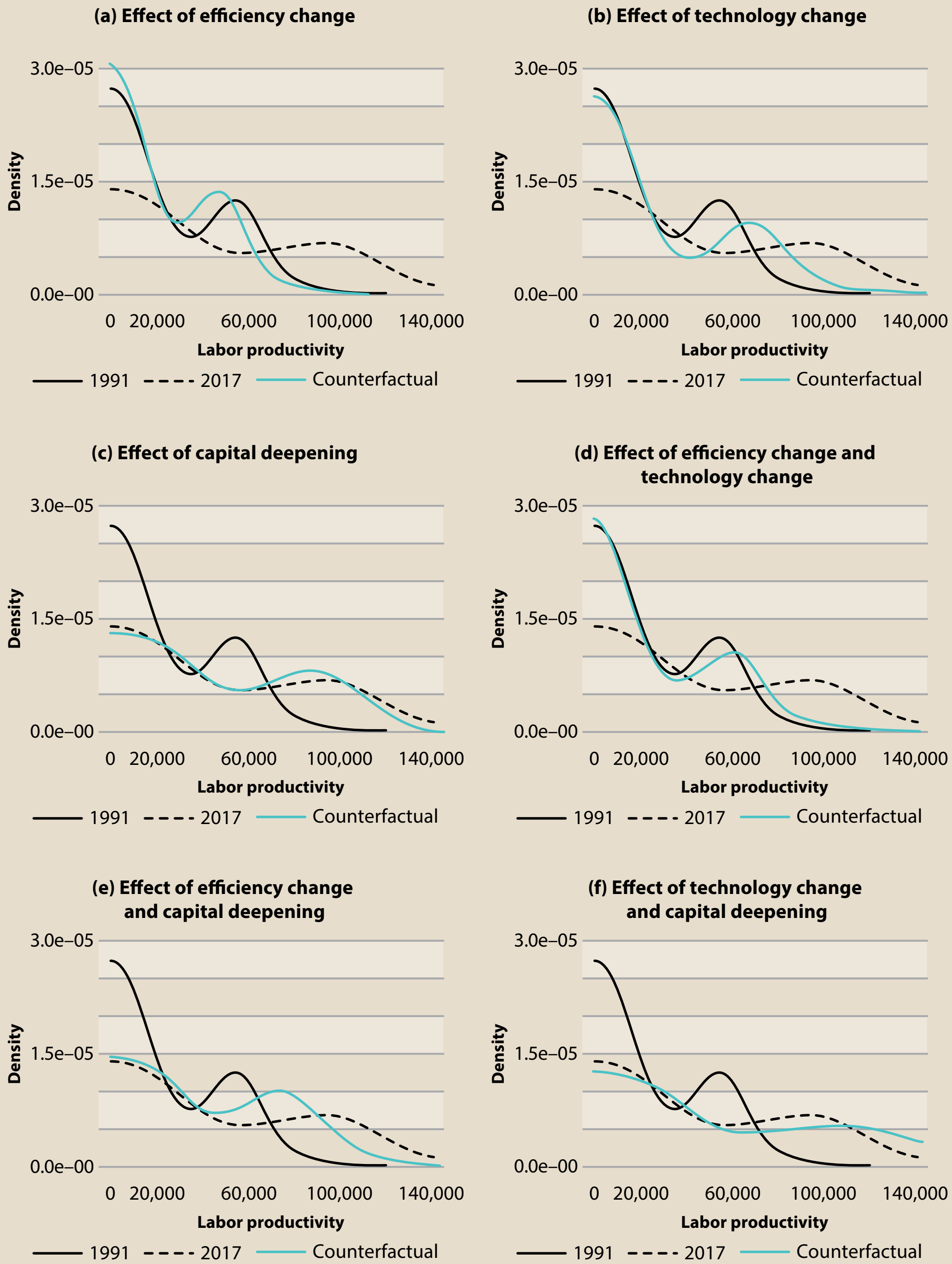
Further Discussion

These results on the LPI, the MPI, and their decompositions, taken together, suggest that improvements in productivity for APO countries were driven by efficiency change and capital deepening, while for non-APO countries the main drivers were technology change and capital deepening. It is worth stating again that the insights from Figure 5 suggest that all of the change in technology occurred in the space where high levels of capital per worker was observed.

Thus, the successful APO countries that had substantial increases in productivity due to capital deepening are, in a sense, building the capacity that is necessary (albeit not sufficient) for future technological changes (perhaps driven by increased demand for more human capital). This is similar to the rise of the Asian Tigers in the second half of the last century, when they were well below the technology frontier in the 1960s, but the improving economic institutions and favorable investment climate led to rapid capital accumulation in various industries, which eventually helped those countries catch up with the world's production frontier and eventually even move it.

FIGURE 16

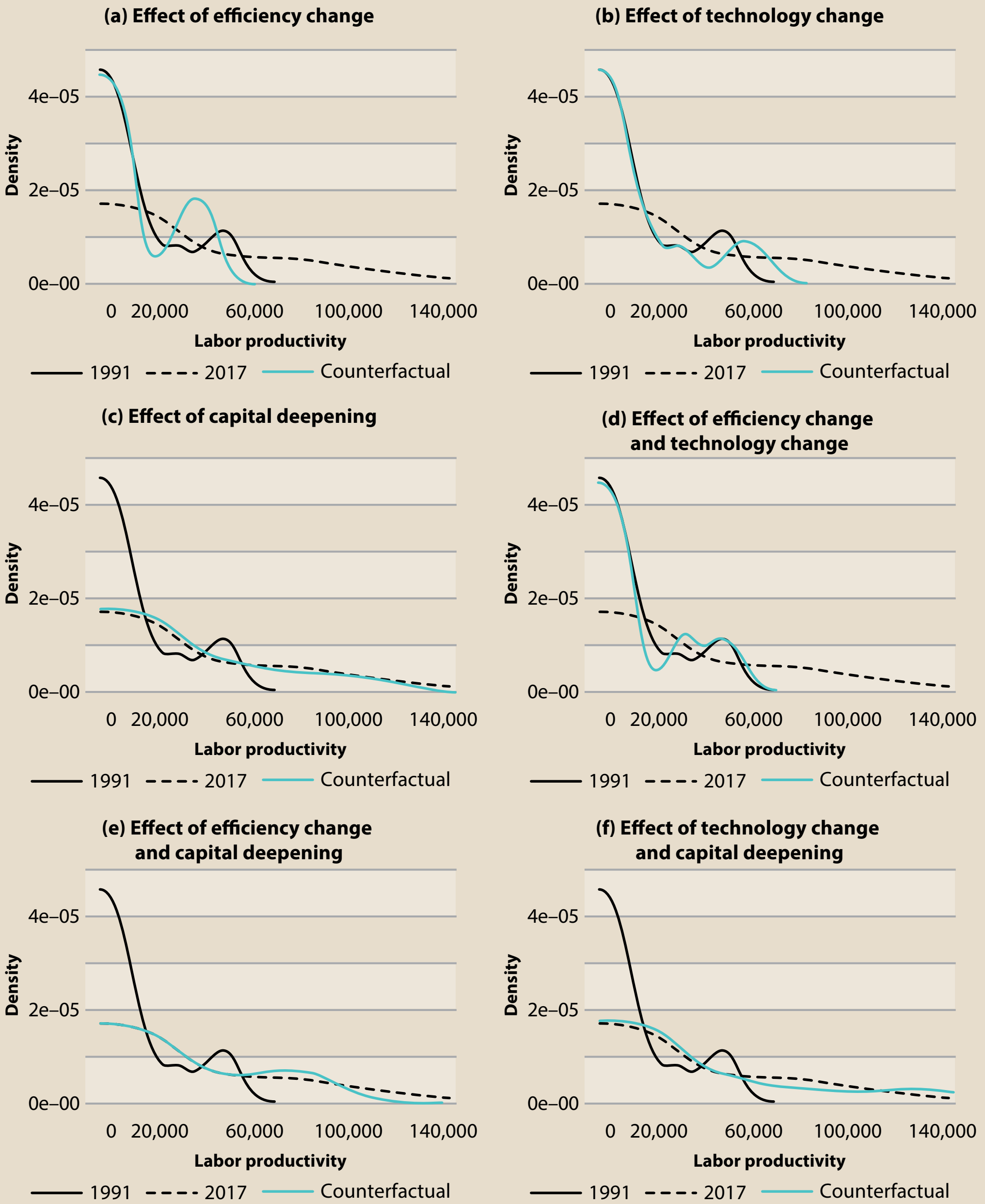
COUNTERFACTUAL DECOMPOSITION OF DISTRIBUTIONS OF LABOR PRODUCTIVITY INDEX.



It is also useful to look at the counterfactual analysis of the change in the distribution of LP, as was originally proposed by Kumar and Russell [111]. Figure 16 presents six panels, all of which show the distributions of LP in 1991 and 2017 and a counterfactual distribution obtained by adjusting the LP distribution of 1991 by the components of the LPI decomposition. This illustrates the contribution to the evolution of LPI from 1991 to 2017 by the major sources measured by those components. Table 4 also reports the results (p-values) of statistical tests of equality of distributions, to check if the adjustment by a component made the counterfactual distribution statistically indistinguishable from the LP distribution of 2017. The null hypothesis for each row of the table corresponds to equality of the 2017 distribution of LP to the 19191 distribution of LP adjusted by the component(s) used for the adjustment.

FIGURE 17

COUNTERFACTUAL DECOMPOSITION OF DISTRIBUTIONS OF LPI IN APO MEMBER COUNTRIES.



In particular, panel (a) depicts that adjustment by efficiency change affects the LP distribution. One can see that LP distributions actually moved away from 2017's distribution due to this adjustment and remained statistically different from the LP distribution of 2017 (p-value<1%). Panel (b) depicts the adjustment by technology change and while the LP distribution moved closer towards that of 2017, it still remained statistically different from it (p-value<1%).

Panel (c) depicts the adjustment due to the capital deepening effect. One can see that it became very similar to the LP distribution of 2017 and, in fact statistically not distinguishable from it (p-value=89%). Panel (d) depicts the adjustment by efficiency change together with technology change (i.e., adjustment by the MPI), while panel (e) depicts the adjustment by efficiency change together with capital change. Both of these adjustments were relatively small, especially the former, as confirmed by the statistical tests suggesting they were still significantly different from the 2017 distribution (p-values are below 3%). Finally, panel (f) depicts the adjustment by the capital deepening effect together with technology change and one can see that the resulting counterfactual distribution became very similar to the LP distribution of 2017 and statistically not distinguishable from it (p-value>60%).

TABLE 4

BOOTSTRAP P-VALUES USING THE LI [149] TEST FOR EQUALITY OF DISTRIBUTIONS ACROSS VARIOUS SCENARIOS.

Counterfactural	*p*-values	
	Full sample	APO
EffCh	0.000	0.049
TechCh	0.002	0.071
KACC	0.894	0.955
EffCh× TechCh	0.001	0.052
EffCh× KACC	0.027	0.964
TechCh×KACC	0.624	0.954

Overall, we see that it is indeed the capital deepening that was the main driving force of the change in LP over time. It alone shifts the 1991 LP distribution enough so that it is statistically indistinguishable from that in 2017.

Figure 17 presents similar analysis for APO countries while Table 4 reports the results (p-values) of statistical tests of equality of distributions and we basically arrive at the same conclusion. There is one exception: the adjustment for capital deepening together with efficiency change also made the resulting counterfactual distribution indistinguishable from that in 2017 for the APO group while not for the entire sample. This is due to the fact that the efficiency change for APO countries was not big enough to offset the effect from capital deepening.

Thus, for both the APO group and the entire sample, we can conclude that neither MFP nor technology change was responsible for the dramatic shift in labor productivity and income per capita. It was the capital deepening effect.

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APPENDIX

TABLE 1

TFP1 (RAW DATA) RESULTS.

	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
1	APO	Bangladesh	4.4	4.4	4.4	4.5	4.6	4.7	4.7
2	APO	Cambodia		4.7	4.5	4.5	4.5	4.6	4.7
3	APO	ROC							
4	APO	Fiji							
5	APO	Hong Kong	6.3	6.4	6.3	6.4	6.5	6.5	6.6
6	APO	India	4.4	4.5	4.6	4.7	4.9	5.0	5.1
7	APO	Indonesia	4.4	4.5	4.4	4.5	4.7	4.9	4.9
8	APO	IR Iran	5.6	5.6	5.5	5.6	5.7	5.6	
9	APO	Japan	6.8	6.7	6.7	6.7	6.7	6.7	6.7
10	APO	ROK	6.0	6.1	6.2	6.3	6.4	6.4	6.4
11	APO	Lao PDR			5.1	4.6	4.6	4.7	
12	APO	Malaysia	5.7	5.8	5.8	5.9	5.9	6.0	6.0
13	APO	Mongolia					5.6	5.3	5.3
14	APO	Nepal				4.5	4.3	4.3	4.2
15	APO	Pakistan	4.7	4.7	4.7	4.8	4.7	4.8	4.9
16	APO	Philippines	4.9	4.8	4.9	4.9	5.0	5.2	5.3
17	APO	Singapore	6.1	6.3	6.4	6.5	6.6	6.7	6.7
18	APO	Sri Lanka	4.6	4.8	4.9	5.0	5.2	5.3	5.4
19	APO	Thailand	5.0	5.2	5.0	5.2	5.3	5.4	5.5
20	APO	Turkey	6.4	6.3	6.3	6.3	6.3	6.4	6.4
21	APO	Vietnam	4.9	4.7	4.6	4.6	4.6	4.7	4.8
22	Non–APO	Afghanistan					5.5	7.0	7.1
23	Non–APO	Albania					5.6	7.0	7.0
24	Non–APO	Algeria	5.5	5.4	5.5	5.6	5.5	7.0	7.0
25	Non–APO	Angola			6.2	5.6	5.6	6.9	6.9
26	Non–APO	Argentina	5.7	5.8	5.8	5.8	6.0	6.9	6.9
27	Non–APO	Armenia		5.0	4.9	5.2	5.0	6.8	6.8
28	Non–APO	Australia	6.8	6.8	6.9	6.9	6.9	6.8	6.8

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
29	Non–APO	Austria	6.6	6.6	6.7	6.7	6.6	6.8	6.8
30	Non–APO	Azerbaijan		5.7	5.3	5.3	5.8	6.8	6.8
31	Non–APO	Bahrain			6.7	6.2	6.0	6.8	6.8
32	Non–APO	Barbados					6.0	6.7	6.7
33	Non–APO	Belarus	5.8	5.1	5.2	5.4	5.6	7.0	6.7
34	Non–APO	Belgium	6.8	6.8	6.8	6.8	6.7	6.7	6.7
35	Non–APO	Belize	3.8	3.9	4.0	4.1	4.1	6.7	6.7
36	Non–APO	Benin	4.0	4.1	4.2	4.2	4.2	6.7	6.7
37	Non–APO	Bhutan			4.4	4.0	4.2	6.7	6.6
38	Non–APO	Bolivia	4.7	4.8	4.8	4.8	4.9	6.6	6.6
39	Non–APO	Bosnia and Herzegovina					5.8	6.6	6.6
40	Non–APO	Botswana	5.1	5.1	5.2	5.2	5.2	6.6	6.6
41	Non–APO	Brazil	6.0	6.0	5.9	5.9	6.0	6.5	6.6
42	Non–APO	Brunei Darussalam	6.2	5.9	5.7	5.7	5.6	6.7	6.6
43	Non–APO	Bulgaria	6.2	6.1	5.8	5.8	5.7	6.5	6.5
44	Non–APO	Burkina Faso	3.9	3.9	4.0	4.2	4.2	6.5	6.5
45	Non–APO	Burma					5.5	6.5	6.4
46	Non–APO	Burundi			4.3	3.9	3.8	6.3	6.4
47	Non–APO	Cabo Verde					4.5	6.3	6.3
48	Non–APO	Cameroon	4.5	4.3	4.4	4.5	4.5	6.2	6.2
49	Non–APO	Canada	6.7	6.7	6.8	6.8	6.8	6.2	6.2
50	Non–APO	Central African Republic					4.8	6.2	6.2
51	Non–APO	Chad					5.0	6.2	6.2
52	Non–APO	Chile	6.0	6.1	6.2	6.2	6.2	6.2	6.2
53	Non–APO	China		5.4	5.1	5.2	5.5	6.1	6.2
54	Non–APO	Colombia	5.7	5.7	5.6	5.6	5.7	6.0	6.1
55	Non–APO	Comoros	3.8	3.8	3.8	3.8	3.9	6.0	6.1
56	Non–APO	Costa Rica	5.4	5.5	5.5	5.6	5.7	6.1	6.1
57	Non–APO	Cote d'Ivoire					5.7	5.9	6.0
58	Non–APO	Croatia		6.8	6.3	6.2	6.1	6.0	6.0
59	Non–APO	Cuba	5.3	5.0	5.2	5.4	5.5	5.9	5.9
60	Non–APO	Cyprus	5.4	5.5	5.6	5.7	5.7	5.9	5.9
61	Non–APO	Czech Republic	6.8	6.5	6.3	6.3	6.3	6.0	5.9
62	Non–APO	Democratic Republic of Congo		5.1	4.5	4.3	4.3	5.9	5.9
63	Non–APO	Denmark	6.7	6.8	6.8	6.8	6.8	6.0	5.9

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
64	Non–APO	Dominican Republic	5.3	5.4	5.5	5.5	5.6	6.0	5.9
65	Non–APO	Ecuador	5.3	5.2	5.2	5.3	5.3	5.8	5.8
66	Non–APO	Egypt	5.3	5.3	5.4	5.4	5.5	5.7	5.8
67	Non–APO	El Salvador	5.8	5.5	5.3	5.2	5.2	5.8	5.8
68	Non–APO	Equatorial Guinea				6.5	5.9	5.7	5.8
69	Non–APO	Eritrea		4.7	4.4	4.2	4.0	5.7	5.8
70	Non–APO	Estonia		6.0	5.8	5.9	5.7	5.7	5.8
71	Non–APO	Eswatini	4.4	4.4	4.4	4.6	4.7	5.7	5.7
72	Non–APO	Finland	6.4	6.4	6.6	6.6	6.6	5.6	5.7
73	Non–APO	France	6.7	6.7	6.8	6.8	6.7	5.7	5.7
74	Non–APO	Gabon	5.2	5.3	5.2	5.2	5.2	5.6	5.7
75	Non–APO	Georgia					6.0	5.6	5.7
76	Non–APO	Germany	6.8	6.7	6.8	6.7	6.7	5.5	5.7
77	Non–APO	Ghana					5.2	5.6	5.7
78	Non–APO	Greece	6.3	6.2	6.3	6.4	6.4	5.7	5.7
79	Non–APO	Guatemala	5.1	5.2	5.2	5.2	5.2	5.6	5.6
80	Non–APO	Guinea					4.8	5.6	5.6
81	Non–APO	Guinea–Bissau			4.8	4.3	4.1	5.5	5.5
82	Non–APO	Guyana					5.4	5.6	5.5
83	Non–APO	Haiti	5.1	4.7	4.6	4.3	4.2	5.4	5.5
84	Non–APO	Honduras	4.7	4.7	4.7	4.7	4.8	5.5	5.5
85	Non–APO	Hungary	7.0	6.4	6.2	6.3	6.1	6.0	5.5
86	Non–APO	Iceland	5.3	5.2	5.4	5.5	5.5	5.5	5.4
87	Non–APO	Iraq					7.0	5.6	5.4
88	Non–APO	Ireland	6.4	6.5	6.8	6.8	6.7	5.4	5.4
89	Non–APO	Israel	6.5	6.6	6.6	6.6	6.6	5.3	5.4
90	Non–APO	Italy	6.9	6.9	6.9	6.8	6.7	5.4	5.3
91	Non–APO	Jamaica					5.7	5.4	5.3
92	Non–APO	Jordan	5.0	5.1	5.1	5.3	5.4	5.3	5.3
93	Non–APO	Kazakhstan	5.9	5.3	5.4	5.8	5.9	5.4	5.3
94	Non–APO	Kenya	4.7	4.6	4.6	4.6	4.6	5.3	5.3
95	Non–APO	Kuwait					7.6	5.3	5.3
96	Non–APO	Kyrgyz Republic		4.6	4.4	4.4	4.3	5.3	5.3
97	Non–APO	Latvia		6.4	5.9	5.9	5.6	5.3	5.3
98	Non–APO	Lebanon	6.2	5.9	5.7	5.7	5.9	5.3	5.3
99	Non–APO	Lesotho	4.4	4.3	4.1	4.1	4.2	5.2	5.2

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
100	Non–APO	Liberia			5.6	4.5	4.4	5.3	5.2
101	Non–APO	Lithuania		6.5	6.0	6.1	6.0	5.1	5.2
102	Non–APO	Luxembourg	6.3	6.3	6.5	6.5	6.5	5.2	5.2
103	Non–APO	Macau	5.6	5.6	5.5	5.9	6.2	5.2	5.2
104	Non–APO	Macedonia	5.8	5.3	5.2	5.1	5.1	5.1	5.1
105	Non–APO	Madagascar	4.1	4.0	4.0	4.0	3.9	5.1	5.1
106	Non–APO	Malawi				4.8	4.5	5.1	5.1
107	Non–APO	Mali	4.6	4.4	4.4	4.5	4.5	5.0	5.0
108	Non–APO	Malta			6.2	5.7	5.6	4.9	5.0
109	Non–APO	Mauritania	4.6	4.6	4.5	4.5	4.6	5.1	5.0
110	Non–APO	Mauritius	4.8	4.8	4.9	5.0	5.1	4.8	4.9
111	Non–APO	Mexico	6.0	5.9	6.0	5.9	5.9	5.1	4.9
112	Non–APO	Moldova		5.4	4.7	4.8	4.8	4.8	4.9
113	Non–APO	Montenegro					5.2	4.9	4.8
114	Non–APO	Morocco	5.2	5.0	5.1	5.1	5.2	4.8	4.8
115	Non–APO	Mozambique	4.4	4.3	4.0	4.2	4.3	4.8	4.8
116	Non–APO	Namibia	5.3	5.3	5.3	5.3	5.3	4.6	4.7
117	Non–APO	Netherlands	6.8	6.8	6.8	6.8	6.8	4.7	4.7
118	Non–APO	New Zealand	6.3	6.4	6.4	6.5	6.4	4.6	4.7
119	Non–APO	Nicaragua	4.2	4.2	4.3	4.3	4.4	4.8	4.6
120	Non–APO	Niger					4.2	4.5	4.5
121	Non–APO	Nigeria	5.3	5.2	5.1	5.4	5.5	4.5	4.5
122	Non–APO	Norway	6.9	6.9	7.0	7.0	7.0	4.5	4.4
123	Non–APO	Oman			7.3	6.6	6.4	4.4	4.4
124	Non–APO	Palestinian Territory, Occupied/West Bank and Gaza		5.4	5.1	5.0	5.1	4.3	4.4
125	Non–APO	Panama	5.1	5.1	5.2	5.3	5.5	4.4	4.3
126	Non–APO	Paraguay	5.2	5.3	5.1	5.1	5.3	4.3	4.3
127	Non–APO	Peru	5.3	5.3	5.3	5.3	5.5	4.3	4.3
128	Non–APO	Poland		6.8	6.4	6.3	6.3	4.3	4.3
129	Non–APO	Portugal	6.4	6.3	6.4	6.3	6.2	4.3	4.3
130	Non–APO	Puerto Rico	6.4	6.5	6.6	6.6	6.5	4.2	4.2
131	Non–APO	Qatar				7.0	6.9	4.3	4.2
132	Non–APO	Republic of Congo	4.8	4.7	4.7	4.8	4.9	4.3	4.2
133	Non–APO	Romania	6.3	6.0	5.8	5.9	5.9	4.3	4.2

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
134	Non–APO	Russia	6.3	5.7	5.7	5.9	5.9	4.2	4.2
135	Non–APO	Rwanda	3.9	3.5	3.8	4.0	4.2	4.1	4.1
136	Non–APO	Saint Lucia					5.1	4.2	4.1
137	Non–APO	Saudi Arabia			7.8	7.2	6.8	4.1	4.1
138	Non–APO	Senegal	4.7	4.6	4.7	4.8	4.8	4.1	4.1
139	Non–APO	Serbia		6.1	5.6	5.6	5.6	4.2	4.1
140	Non–APO	Sierra Leone				4.5	4.4	3.9	3.9
141	Non–APO	Slovakia		6.3	6.0	6.1	6.1	3.9	3.9
142	Non–APO	Slovenia	6.6	6.3	6.2	6.1	6.1	3.7	3.6
143	Non–APO	South Africa	5.8	5.8	5.8	5.8	5.9	6.8	
144	Non–APO	South Sudan					5.6	5.7	
145	Non–APO	Spain	6.6	6.6	6.6	6.6	6.5	5.5	
146	Non–APO	Sudan	5.2	5.2	5.2	5.2	5.3	5.5	
147	Non–APO	Suriname					5.7	5.5	
148	Non–APO	Sweden	6.6	6.6	6.7	6.8	6.7	5.4	
149	Non–APO	Switzerland	6.9	6.9	6.9	6.9	6.9	5.0	
150	Non–APO	Tajikistan		4.0	3.8	4.1	4.3	5.0	
151	Non–APO	Tanzania	4.8	4.4	4.3	4.4	4.4	4.7	
152	Non–APO	The Bahamas	5.9	5.7	5.6	5.5	5.3	4.4	
153	Non–APO	The Gambia				4.8	4.6	4.4	
154	Non–APO	Timor–Leste			5.1	5.3	5.4	4.2	
155	Non–APO	Togo	3.8	3.8	3.9	3.8	3.9	4.1	
156	Non–APO	Tonga					4.2		
157	Non–APO	Tunisia	5.1	5.1	5.2	5.3	5.4		
158	Non–APO	Turkmenistan					6.0		
159	Non–APO	Uganda	4.2	4.2	4.3	4.3	4.5		
160	Non–APO	Ukraine	5.7	4.8	4.7	5.0	5.0		
161	Non–APO	United Arab Emirates				7.3	6.7		
162	Non–APO	UK	6.8	6.8	6.8	6.9	6.8		
163	Non–APO	USA	6.9	6.9	7.0	7.0	6.9		
164	Non–APO	Uruguay	5.5	5.5	5.6	5.5	5.7		
165	Non–APO	Uzbekistan	5.4	4.9	4.8	4.9	5.0		
166	Non–APO	Vanuatu				4.4	4.0		
167	Non–APO	Venezuela	6.2	6.1	6.0	6.1	6.1		
168	Non–APO	Zambia					5.7		
169	Non–APO	Zimbabwe					5.3		

Source: Authors' estimation based on the WDI [76] and ILO [77] data.

TABLE 2

TFP2 (RAW DATA) RESULTS.

	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
1	APO	Bangladesh						4.2	4.3
2	APO	Cambodia		4.4	4.2	4.3	4.2	4.3	4.3
3	APO	ROC							
4	APO	Fiji							
5	APO	Hong Kong	5.6	5.7	5.6	5.6	5.7	5.7	5.8
6	APO	India	4.2	4.2	4.2	4.3	4.4	4.5	4.6
7	APO	Indonesia	4.1	4.2	4.0	4.1	4.1	4.3	4.4
8	APO	IR Iran	5.2	5.1	5.0	5.0	5.1	5.0	
9	APO	Japan	6.1	6.0	6.0	5.9	5.9	5.9	5.9
10	APO	ROK	5.3	5.4	5.4	5.5	5.5	5.5	5.5
11	APO	Lao PDR						4.3	
12	APO	Malaysia	5.1	5.2	5.2	5.2	5.2	5.2	5.3
13	APO	Mongolia						4.6	4.6
14	APO	Nepal						3.9	3.8
15	APO	Pakistan						4.4	4.5
16	APO	Philippines	4.4	4.3	4.3	4.4	4.5	4.6	4.7
17	APO	Singapore						5.9	5.9
18	APO	Sri Lanka	4.1	4.1	4.2	4.3	4.5	4.7	4.7
19	APO	Thailand	4.7	4.8	4.7	4.7	4.7	4.8	4.9
20	APO	Turkey	6.1	5.9	5.9	5.9	5.8	5.8	5.8
21	APO	Vietnam						4.2	4.3
22	Non–APO	Albania					4.9	4.7	6.3
23	Non–APO	Algeria	5.2	5.1	5.1	5.2	5.1	5.1	6.2
24	Non–APO	Argentina	5.2	5.3	5.3	5.2	5.4	5.3	6.2
25	Non–APO	Armenia						4.5	6.1
26	Non–APO	Australia	6.0	6.0	6.1	6.1	6.1	6.0	6.1
27	Non–APO	Austria	6.1	6.0	6.0	6.0	6.0	5.9	6.0
28	Non–APO	Bahrain						5.5	6.0
29	Non–APO	Barbados					5.4		6.0
30	Non–APO	Belgium	6.1	6.1	6.1	6.1	6.0	6.0	6.0
31	Non–APO	Belize						3.5	6.0
32	Non–APO	Benin	3.9	3.9	3.9	3.9	3.9	3.9	6.0
33	Non–APO	Bolivia	4.2	4.2	4.2	4.2	4.3	4.5	6.0

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
34	Non–APO	Botswana						4.6	6.0
35	Non–APO	Brazil	5.7	5.6	5.5	5.4	5.5	5.5	6.0
36	Non–APO	Brunei Darussalam						4.9	6.0
37	Non–APO	Bulgaria	5.6	5.5	5.2	5.1	5.0	5.0	6.0
38	Non–APO	Burma					5.1	4.6	5.9
39	Non–APO	Burundi						3.4	5.9
40	Non–APO	Cameroon	4.2	4.0	4.0	4.1	4.1	4.2	5.9
41	Non–APO	Canada	6.0	6.0	6.0	6.0	6.0	6.0	5.9
42	Non–APO	Central African Republic						3.8	5.8
43	Non–APO	Chile	5.4	5.5	5.6	5.6	5.5	5.5	5.8
44	Non–APO	China		5.0	4.6	4.7	4.9	5.0	5.8
45	Non–APO	Colombia	5.3	5.3	5.1	5.2	5.1	5.1	5.6
46	Non–APO	Costa Rica	4.9	5.0	5.0	5.0	5.1	5.1	5.6
47	Non–APO	Cote d'Ivoire					5.3	5.1	5.5
48	Non–APO	Croatia						5.2	5.5
49	Non–APO	Cuba	4.7	4.4	4.5	4.7	4.8	4.9	5.5
50	Non–APO	Cyprus						4.8	5.4
51	Non–APO	Czech Republic						5.4	5.4
52	Non–APO	Democratic Republic of Congo						4.0	5.4
53	Non–APO	Denmark	6.0	6.1	6.1	6.0	6.0	6.0	5.4
54	Non–APO	Dominican Republic	4.9	4.9	5.0	5.0	5.1	5.1	5.3
55	Non–APO	Ecuador	4.8	4.8	4.7	4.8	4.8	4.8	5.3
56	Non–APO	Egypt	5.0	5.0	5.0	4.9	5.0	5.0	5.3
57	Non–APO	El Salvador	5.5	5.1	4.9	4.7	4.6	4.7	5.3
58	Non–APO	Estonia						4.9	5.3
59	Non–APO	Eswatini						4.4	5.3
60	Non–APO	Finland	5.9	5.8	5.9	6.0	5.9	5.8	5.3
61	Non–APO	France	6.2	6.1	6.1	6.1	6.0	6.0	5.3
62	Non–APO	Gabon						4.7	5.2
63	Non–APO	Germany	6.2	6.1	6.1	5.9	5.9	5.9	5.2
64	Non–APO	Ghana					4.7	4.8	5.2
65	Non–APO	Greece	5.7	5.6	5.7	5.7	5.6	5.4	5.2

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
66	Non–APO	Guatemala	4.9	4.9	4.9	4.9	4.9	4.9	5.1
67	Non–APO	Guyana					4.8	4.5	5.1
68	Non–APO	Haiti						3.8	5.1
69	Non–APO	Honduras	4.3	4.3	4.3	4.3	4.3	4.3	5.1
70	Non–APO	Hungary	6.3	5.7	5.5	5.5	5.3	5.3	5.1
71	Non–APO	Iceland						4.7	5.0
72	Non–APO	Ireland	5.7	5.8	6.0	6.1	5.9	6.1	5.0
73	Non–APO	Israel						5.9	5.0
74	Non–APO	Italy	6.3	6.3	6.2	6.2	6.0	5.9	5.0
75	Non–APO	Jamaica					5.0	4.8	5.0
76	Non–APO	Jordan						4.6	5.0
77	Non–APO	Kazakhstan						5.2	4.9
78	Non–APO	Kenya	4.4	4.3	4.2	4.2	4.2	4.2	4.9
79	Non–APO	Kuwait						6.5	4.9
80	Non–APO	Kyrgyz Republic						3.6	4.9
81	Non–APO	Latvia						5.0	4.9
82	Non–APO	Lesotho						3.9	4.9
83	Non–APO	Liberia						3.9	4.8
84	Non–APO	Lithuania						5.2	4.8
85	Non–APO	Luxembourg	5.7	5.7	5.8	5.8	5.8	5.8	4.8
86	Non–APO	Macau						5.5	4.8
87	Non–APO	Malawi				4.5	4.2	4.1	4.8
88	Non–APO	Mali	4.5	4.3	4.3	4.4	4.4	4.2	4.8
89	Non–APO	Malta			5.5	5.0	4.9	4.9	4.7
90	Non–APO	Mauritania						4.2	4.7
91	Non–APO	Mauritius	4.3	4.3	4.5	4.5	4.5	4.5	4.7
92	Non–APO	Mexico	5.6	5.4	5.5	5.3	5.3	5.3	4.6
93	Non–APO	Morocco	5.0	4.8	4.8	4.8	4.9	4.9	4.6
94	Non–APO	Mozambique	4.3	4.2	3.9	4.1	4.2	4.1	4.6
95	Non–APO	Namibia						5.0	4.6
96	Non–APO	Netherlands	6.1	6.1	6.1	6.1	6.0	6.0	4.5
97	Non–APO	New Zealand	5.6	5.6	5.6	5.7	5.7	5.7	4.5
98	Non–APO	Nicaragua	3.9	3.9	3.9	3.9	3.9	4.0	4.4

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2018
99	Non–APO	Niger					4.1	4.0	4.4
100	Non–APO	Norway	6.2	6.2	6.2	6.3	6.2	6.2	4.4
101	Non–APO	Panama	4.6	4.5	4.6	4.7	4.9	5.0	4.3
102	Non–APO	Paraguay	4.8	4.9	4.7	4.6	4.7	4.8	4.3
103	Non–APO	Peru	4.8	4.8	4.7	4.7	4.9	5.0	4.2
104	Non–APO	Poland		6.2	5.7	5.5	5.5	5.5	4.2
105	Non–APO	Portugal	5.9	5.8	5.8	5.8	5.7	5.6	4.2
106	Non–APO	Qatar						6.2	4.2
107	Non–APO	Republic of Congo						4.5	4.0
108	Non–APO	Romania						5.2	4.0
109	Non–APO	Russia	5.6	5.0	4.9	5.1	5.2	5.2	4.0
110	Non–APO	Rwanda						4.0	4.0
111	Non–APO	Saudi Arabia						6.0	4.0
112	Non–APO	Senegal	4.5	4.5	4.6	4.7	4.6	4.7	4.0
113	Non–APO	Sierra Leone				4.3	4.1	3.9	4.0
114	Non–APO	Slovakia						5.3	4.0
115	Non–APO	Slovenia						5.3	3.9
116	Non–APO	South Africa	5.4	5.2	5.3	5.3	5.2	5.2	3.8
117	Non–APO	Spain	6.2	6.0	6.0	5.9	5.8	5.7	3.8
118	Non–APO	Sudan	5.0	5.0	5.0	5.0	5.1	5.0	3.7
119	Non–APO	Sweden	5.9	5.9	6.0	6.0	6.0	6.0	3.7
120	Non–APO	Switzerland	6.2	6.2	6.2	6.2	6.0	6.0	3.7
121	Non–APO	Tanzania						4.0	3.5
122	Non–APO	The Gambia						4.0	3.4
123	Non–APO	Togo						3.6	
124	Non–APO	Tunisia	4.8	4.7	4.8	4.8	4.9		
125	Non–APO	Uganda	3.9	4.0	4.0	4.0	4.1	4.0	
126	Non–APO	Ukraine						4.1	
127	Non–APO	United Arab Emirates						6.1	
128	Non–APO	UK	6.2	6.2	6.2	6.1	6.0	6.0	
129	Non–APO	USA	6.1	6.1	6.1	6.1	6.1	6.1	
130	Non–APO	Uruguay	5.0	5.0	5.0	5.0	5.2	5.2	
131	Non–APO	Venezuela	5.8	5.7	5.6	5.5	5.5	5.4	
132	Non–APO	Zimbabwe					4.8	4.6	

Source: Authors' estimation, using the WDI [76], ILO [77], Barro and Lee [78], and Lee and Lee [79].

TABLE 3

TFP 1 (RAW DATA) RESULTS FROM PWT 9.1.

	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
1	APO	Bangladesh	5.4	5.3	5.2	5.1	5.3	5.4	5.4
2	APO	Cambodia	4.7	5.0	4.8	5.0	5.1	5.2	5.2
3	APO	ROC	6.8	6.8	6.9	6.9	6.8	6.8	6.8
4	APO	Fiji	5.2	5.2	5.3	5.1	5.2	5.2	5.1
5	APO	Hong Kong	6.6	6.7	6.6	6.8	6.6	6.5	6.5
6	APO	India	5.0	5.1	5.3	5.4	5.6	5.7	5.8
7	APO	Indonesia	5.7	5.9	5.6	5.6	5.7	5.8	5.9
8	APO	IR Iran	5.7	5.9	6.2	6.6	6.7	6.5	6.6
9	APO	Japan	6.7	6.7	6.7	6.7	6.7	6.8	6.8
10	APO	ROK	6.4	6.5	6.6	6.6	6.7	6.7	6.7
11	APO	Lao PDR	4.8	4.8	4.9	5.0	5.4	5.5	5.5
12	APO	Malaysia	6.2	6.3	6.2	6.4	6.4	6.5	6.5
13	APO	Mongolia	4.9	4.8	4.8	5.0	5.4	5.7	5.7
14	APO	Nepal	4.9	4.8	4.8	4.7	4.9	5.0	5.1
15	APO	Pakistan	5.9	5.9	5.9	5.9	6.0	6.1	6.1
16	APO	Philippines	5.8	5.9	5.7	5.7	5.8	5.9	6.0
17	APO	Singapore	6.4	6.2	6.6	6.7	6.7	6.7	6.8
18	APO	Sri Lanka	5.7	5.9	5.9	5.9	6.1	6.3	6.3
19	APO	Thailand	5.7	5.7	5.5	5.8	5.9	6.0	6.1
20	APO	Turkey	6.5	6.5	6.6	6.7	6.7	6.8	6.9
21	APO	Vietnam	5.2	5.3	5.2	5.2	5.5	5.6	5.6
22	Non–APO	Albania	4.9	5.2	5.4	5.4	5.7	5.7	5.7
23	Non–APO	Algeria	6.3	6.2	6.3	6.4	6.5	6.4	6.4
24	Non–APO	Angola	4.9	4.8	4.7	5.3	5.5	5.3	5.2
25	Non–APO	Anguilla	2.6	2.8	2.9				
26	Non–APO	Antigua and Barbuda	4.2			4.2			
27	Non–APO	Argentina	6.0	6.3	6.3	6.3	6.4	6.4	6.4
28	Non–APO	Armenia	5.5	4.7	5.0	5.5	5.8	5.8	5.9
29	Non–APO	Aruba	4.7	5.0	4.8	4.7	4.6	4.5	4.3
30	Non–APO	Australia	6.7	6.7	6.8	6.9	6.9	6.8	6.9
31	Non–APO	Austria	6.4	6.5	6.7	6.8	6.7	6.7	6.7
32	Non–APO	Azerbaijan	6.5	4.9	4.9	5.6	6.6	6.4	6.4
33	Non–APO	Bahrain	5.2	5.4	5.8	5.9	6.1	6.1	6.1
34	Non–APO	Barbados	5.6	5.7	5.7	5.3	4.8	4.4	4.3
35	Non–APO	Belarus	6.0	5.5	5.7	6.0	6.4	6.2	6.2
36	Non–APO	Belgium	6.5	6.6	6.7	6.8	6.7	6.6	6.6

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
37	Non–APO	Belize	4.6	4.8	4.7	4.8	4.7	4.7	4.7
38	Non–APO	Benin	4.7	4.5	4.8	5.0	5.0	5.0	5.0
39	Non–APO	Bermuda	7.6	7.4	6.8	4.8			
40	Non–APO	Bhutan	4.2	4.2	4.4	4.6	4.8	4.8	4.8
41	Non–APO	Bolivia	5.3	5.5	5.4	5.5	5.7	5.7	5.7
42	Non–APO	Bosnia and Herzegovina	4.3	5.3	6.0	6.0	6.1	6.1	6.1
43	Non–APO	Botswana	5.6	5.6	5.8	5.9	5.7	5.7	5.7
44	Non–APO	Brazil	5.8	6.1	6.0	5.9	6.1	6.1	6.1
45	Non–APO	British Virgin Islands	3.3						
46	Non–APO	Brunei Darussalam	5.7	5.6	5.8	6.1	6.0	5.8	5.7
47	Non–APO	Bulgaria	6.7	6.4	6.2	6.3	6.2	6.2	6.3
48	Non–APO	Burkina Faso	4.7	4.7	4.9	5.0	5.0	5.0	5.1
49	Non–APO	Burma	4.9	5.2	5.1	5.2	5.6	5.7	5.7
50	Non–APO	Burundi	4.6	4.4	4.3	4.3	4.5	4.5	4.6
51	Non–APO	Cabo Verde	3.7	3.8	4.2	4.3	4.5	4.6	4.7
52	Non–APO	Cameroon	5.3	5.3	5.4	5.3	5.3	5.4	5.4
53	Non–APO	Canada	6.7	6.7	6.9	6.9	6.8	6.8	6.8
54	Non–APO	Cayman Islands	4.4	4.3	4.5	4.5			
55	Non–APO	Central African Republic	4.5	4.6	4.5	4.4	4.2	4.0	4.0
56	Non–APO	Chad	5.0	5.0	4.9	5.2	5.5	5.3	5.0
57	Non–APO	Chile	6.1	6.3	6.2	6.3	6.5	6.5	6.5
58	Non–APO	China	5.3	5.5	5.5	5.7	5.9	5.9	5.9
59	Non–APO	Colombia	6.0	6.0	5.8	5.9	6.1	6.1	6.1
60	Non–APO	Comoros	4.0	4.1	4.0	4.1	4.0	4.4	4.4
61	Non–APO	Costa Rica	5.9	6.0	6.0	6.0	6.0	6.1	6.2
62	Non–APO	Cote d'Ivoire	5.4	5.3	5.4	5.6	5.4	5.6	5.6
63	Non–APO	Croatia	5.9	5.9	6.0	6.2	6.2	6.2	6.2
64	Non–APO	Cyprus	5.4	5.5	5.7	5.7	5.7	5.7	5.7
65	Non–APO	Czech Republic	6.2	6.2	6.2	6.3	6.3	6.3	6.4
66	Non–APO	Democratic Republic of Congo	4.7	4.4	4.1	4.2	4.5	4.7	4.6
67	Non–APO	Denmark	6.3	6.4	6.6	6.6	6.6	6.6	6.6
68	Non–APO	Djibouti	4.7	4.9	4.8	4.8	4.2	4.4	4.7
69	Non–APO	Dominica	4.3	4.4	4.3				
70	Non–APO	Dominican Republic	5.7	5.9	5.9	5.9	6.1	6.2	6.2
71	Non–APO	Ecuador	5.8	5.6	5.5	5.7	5.9	5.8	5.8

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
72	Non–APO	Egypt	6.1	6.3	6.3	6.3	6.5	6.7	6.7
73	Non–APO	El Salvador	5.5	5.7	5.7	5.7	5.7	5.7	5.7
74	Non–APO	Equatorial Guinea	4.7	4.5	5.6	6.4	6.2	5.6	5.5
75	Non–APO	Estonia	5.6	5.4	5.6	5.8	5.8	5.8	5.9
76	Non–APO	Eswatini	5.4	5.4	5.4	5.4	5.2	5.2	5.2
77	Non–APO	Ethiopia	4.9	4.7	4.5	4.6	4.8	4.9	4.8
78	Non–APO	Finland	6.3	6.4	6.6	6.6	6.6	6.6	6.6
79	Non–APO	France	6.7	6.7	6.9	6.9	6.8	6.8	6.8
80	Non–APO	Gabon	5.9	5.8	5.8	5.9	5.8	5.8	5.8
81	Non–APO	Georgia	6.1	5.0	5.0	5.4	5.9	6.2	6.3
82	Non–APO	Germany	6.6	6.7	6.8	6.9	6.8	6.8	6.8
83	Non–APO	Ghana	5.1	5.1	5.3	5.2	5.2	5.3	5.3
84	Non–APO	Greece	6.2	6.2	6.4	6.5	6.4	6.2	6.2
85	Non–APO	Grenada	4.0	4.1	4.2	4.0	3.9	3.9	4.0
86	Non–APO	Guatemala	5.9	5.9	5.9	5.8	5.8	5.9	5.9
87	Non–APO	Guinea	5.8	5.8	5.6	5.2	5.2	5.3	5.3
88	Non–APO	Guinea–Bissau	4.2	4.3	4.4	4.3	4.4	4.5	4.6
89	Non–APO	Haiti	4.6	4.6	5.0	4.8	4.6	4.6	4.5
90	Non–APO	Honduras	5.5	5.5	5.4	5.4	5.3	5.3	5.4
91	Non–APO	Hungary	6.0	6.2	6.3	6.4	6.3	6.2	6.2
92	Non–APO	Iceland	5.2	5.2	5.4	5.5	5.5	5.5	5.5
93	Non–APO	Iraq	5.2	5.5	6.3	6.2	6.6	6.9	6.9
94	Non–APO	Ireland	6.3	6.5	6.8	7.0	6.8	7.1	7.1
95	Non–APO	Israel	6.4	6.5	6.7	6.6	6.6	6.7	6.7
96	Non–APO	Italy	6.7	6.7	6.8	6.8	6.7	6.7	6.7
97	Non–APO	Jamaica	5.4	5.5	5.5	5.4	5.2	5.2	5.2
98	Non–APO	Jordan	5.4	5.5	5.5	5.7	6.1	6.2	6.2
99	Non–APO	Kazakhstan	6.1	5.5	5.5	5.9	6.5	6.5	6.5
100	Non–APO	Kenya	5.5	5.4	5.3	5.3	5.4	5.4	5.5
101	Non–APO	Kuwait	5.4	6.5	6.6	7.0	7.1	6.7	6.6
102	Non–APO	Kyrgyz Republic	6.0	5.2	4.9	5.0	5.4	5.9	6.3
103	Non–APO	Latvia	6.0	5.5	5.7	5.8	5.8	5.8	5.8
104	Non–APO	Lebanon	5.7	5.4	5.5	6.0	6.3	6.1	6.1
105	Non–APO	Lesotho	5.1	5.1	4.9	5.0	4.7	4.9	4.9
106	Non–APO	Liberia	4.1	3.0	4.4	4.6	4.3	4.2	4.2
107	Non–APO	Lithuania	6.0	5.8	5.9	6.1	6.1	6.2	6.2

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
108	Non–APO	Luxembourg	5.6	5.6	6.0	6.0	5.9	6.1	6.1
109	Non–APO	Macau	5.6	5.8	5.7	6.1	6.6	6.4	6.4
110	Non–APO	Macedonia	5.4	5.4	5.5	5.5	5.6	5.7	5.8
111	Non–APO	Madagascar	5.0	4.8	4.8	4.8	4.8	4.8	4.8
112	Non–APO	Malawi	4.8	4.8	4.6	4.7	4.7	4.8	4.8
113	Non–APO	Maldives	4.9	4.9	5.0	5.3	5.0	5.1	5.1
114	Non–APO	Mali	5.0	5.1	5.3	5.3	5.5	5.4	5.5
115	Non–APO	Malta	5.2	5.2	5.5	5.5	5.4	5.5	5.6
116	Non–APO	Mauritania	4.8	4.9	5.0	5.2	5.3	5.2	5.1
117	Non–APO	Mauritius	5.8	5.7	5.8	5.7	5.6	5.8	5.9
118	Non–APO	Mexico	6.5	6.3	6.5	6.4	6.3	6.4	6.4
119	Non–APO	Moldova	5.4	4.9	4.6	5.0	5.4	5.5	5.5
120	Non–APO	Montenegro	5.2	4.7	5.0	5.1	5.5	5.4	5.5
121	Non–APO	Morocco	5.9	5.9	5.9	5.8	5.8	5.8	5.9
122	Non–APO	Mozambique	4.8	4.6	4.8	5.1	4.9	4.9	4.9
123	Non–APO	Namibia	5.4	5.4	5.5	5.6	5.6	5.8	5.7
124	Non–APO	Netherlands	6.6	6.6	6.8	6.9	6.8	6.7	6.8
125	Non–APO	New Zealand	6.3	6.4	6.5	6.5	6.6	6.6	6.6
126	Non–APO	Nicaragua	5.2	5.3	5.3	5.3	5.3	5.4	5.4
127	Non–APO	Niger	4.3	4.3	4.2	4.2	4.3	4.4	4.3
128	Non–APO	Nigeria	4.9	4.4	5.1	6.0	6.1	5.9	5.7
129	Non–APO	Norway	6.4	6.5	6.9	7.1	7.1	6.9	6.8
130	Non–APO	Oman	6.0	6.0	6.3	6.6	6.6	6.4	6.2
131	Non–APO	Palestinian Territory, Occupied / West Bank and Gaza	5.0	5.4	5.5	5.5	5.6	5.7	5.6
132	Non–APO	Panama	5.9	5.8	6.0	6.2	6.2	6.3	6.3
133	Non–APO	Paraguay	5.5	5.5	5.2	5.5	5.6	5.7	5.7
134	Non–APO	Peru	5.5	5.6	5.5	5.6	6.0	6.0	6.0
135	Non–APO	Poland	6.1	6.3	6.5	6.6	6.7	6.8	6.8
136	Non–APO	Portugal	6.1	6.2	6.3	6.3	6.3	6.3	6.1
137	Non–APO	Qatar	5.8	5.8	6.5	6.9	7.1	6.8	6.7
138	Non–APO	Republic of Congo	5.2	4.8	5.1	5.4	5.4	4.9	4.9
139	Non–APO	Romania	5.8	6.0	5.9	6.2	6.4	6.5	6.6
140	Non–APO	Russia	6.1	5.7	5.7	6.1	6.5	6.4	6.4
141	Non–APO	Rwanda	5.1	4.5	4.7	4.8	4.9	5.0	5.0
142	Non–APO	Saint Lucia	4.6	4.6	4.6	4.5	4.2	4.0	4.0

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
143	Non–APO	Saint Vincent and the Grenadines	4.4	4.4	4.3	4.0	3.7	3.6	3.6
144	Non–APO	Sao Tome and Principe	3.3	3.1	3.3	3.7	3.5	3.5	3.7
145	Non–APO	Saudi Arabia	6.6	6.6	6.7	7.0	7.2	7.0	6.9
146	Non–APO	Senegal	5.4	5.2	5.3	5.4	5.3	5.4	5.4
147	Non–APO	Serbia	5.9	5.3	5.5	5.8	5.9	6.0	6.0
148	Non–APO	Seychelles		4.2	4.3	4.1	4.1	4.4	4.6
149	Non–APO	Sierra Leone	5.4	5.0	4.5	4.7	4.8	4.8	4.9
150	Non–APO	Slovakia	6.0	6.0	6.2	6.3	6.4	6.3	6.3
151	Non–APO	Slovenia	5.8	5.9	6.0	6.0	6.0	5.9	6.0
152	Non–APO	South Africa	6.3	6.3	6.4	6.5	6.4	6.3	6.3
153	Non–APO	Spain	6.5	6.6	6.7	6.7	6.7	6.7	6.7
154	Non–APO	Sudan	6.5	6.2	6.3	6.2	5.9	5.9	5.8
155	Non–APO	Suriname	4.8	4.6	4.7	4.8	5.0	5.0	4.9
156	Non–APO	Sweden	6.4	6.5	6.7	6.8	6.7	6.7	6.7
157	Non–APO	Switzerland	6.5	6.6	6.7	6.8	6.9	6.9	6.9
158	Non–APO	Syria	5.2	5.1	5.4	6.0	6.1	5.9	6.0
159	Non–APO	Tajikistan	5.9	4.7	4.4	4.7	4.9	5.0	5.2
160	Non–APO	Tanzania	4.8	4.7	4.9	5.0	5.0	5.0	5.0
161	Non–APO	The Bahamas	5.5	5.5	5.7	5.7	5.3	5.1	5.0
162	Non–APO	The Gambia	5.0	4.9	5.0	5.0	4.9	4.9	4.9
163	Non–APO	Togo	4.8	4.7	4.7	4.6	4.4	4.6	4.6
164	Non–APO	Trinidad and Tobago	5.7	5.6	5.9	6.1	6.1	6.4	6.2
165	Non–APO	Tunisia	6.0	6.0	6.1	6.1	6.1	6.1	6.1
166	Non–APO	Turkmenistan	5.8	5.2	5.5	5.6	6.1	6.1	6.2
167	Non–APO	Turks and Caicos Islands				3.4			
168	Non–APO	Uganda	4.9	5.1	5.1	5.1	5.1	5.0	4.9
169	Non–APO	Ukraine	5.9	5.3	5.2	5.6	5.8	5.9	6.0
170	Non–APO	United Arab Emirates	7.0	6.8	7.0	7.1	7.0	7.1	7.1
171	Non–APO	UK	6.6	6.7	6.9	6.9	6.7	6.7	6.8
172	Non–APO	USA	6.9	7.0	7.1	7.1	7.1	7.1	7.1
173	Non–APO	Uruguay	5.7	5.9	5.9	5.8	6.0	6.1	6.1
174	Non–APO	Uzbekistan	6.0	5.8	5.8	5.8	6.1	6.3	6.3
175	Non–APO	Venezuela	6.0	5.9	5.9	6.1	6.3	5.4	5.5
176	Non–APO	Yemen	5.3	5.3	5.7	5.9	6.3	5.6	5.3
177	Non–APO	Zambia	4.7	4.2	4.6	5.0	5.3	5.4	5.4
178	Non–APO	Zimbabwe	6.3	6.0	5.4	4.4	4.6	4.8	4.8

Source: Authors' estimation based on the PWT 9.1 [80].

TABLE 4

TFP2 (RAW DATA) RESULTS FROM PWT 9.1.

	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
1	APO	Bangladesh						5.0	5.0
2	APO	Cambodia	4.5	4.8	4.6	4.7	4.7	4.9	4.8
3	APO	ROC	6.2	6.2	6.3	6.2	6.0	6.0	6.0
4	APO	Fiji	4.6	4.6	4.6	4.4	4.5	4.5	4.4
5	APO	Hong Kong	6.0	6.0	5.9	6.0	5.8	5.7	5.7
6	APO	India	4.8	4.9	4.9	5.0	5.2	5.3	5.3
7	APO	Indonesia	5.4	5.6	5.2	5.1	5.2	5.3	5.3
8	APO	IR Iran	5.4	5.5	5.7	6.0	6.1	5.9	6.0
9	APO	Japan	6.0	6.0	6.0	5.9	5.9	5.9	5.9
10	APO	ROK	5.7	5.8	5.9	5.8	5.9	5.8	5.8
11	APO	Lao PDR						5.1	5.2
12	APO	Malaysia	5.6	5.7	5.6	5.7	5.7	5.7	5.7
13	APO	Mongolia						5.0	5.1
14	APO	Nepal						4.7	4.7
15	APO	Pakistan						5.7	5.7
16	APO	Philippines	5.3	5.4	5.2	5.1	5.2	5.3	5.4
17	APO	Singapore						5.9	6.0
18	APO	Sri Lanka	5.1	5.3	5.2	5.2	5.4	5.6	5.6
19	APO	Thailand	5.3	5.3	5.1	5.3	5.4	5.5	5.5
20	APO	Turkey	6.1	6.2	6.2	6.2	6.2	6.3	6.3
21	APO	Vietnam						5.1	5.1
22	Non–APO	Albania	4.3	4.6	4.7	4.7	5.0	5.1	5.1
23	Non–APO	Algeria	6.0	5.8	5.9	6.0	6.0	5.9	5.9
24	Non–APO	Argentina	5.4	5.7	5.7	5.7	5.8	5.8	5.8
25	Non–APO	Armenia						5.1	5.2
26	Non–APO	Australia	5.9	6.0	6.1	6.1	6.2	6.0	6.0
27	Non–APO	Austria	5.9	5.9	6.1	6.1	6.0	6.0	6.0
28	Non–APO	Bahrain						5.6	5.6
29	Non–APO	Barbados	5.0	5.1	5.1	4.7	4.1	3.8	3.7
30	Non–APO	Belgium	5.9	5.9	6.0	6.0	6.0	5.9	5.9
31	Non–APO	Belize						4.0	4.0
32	Non–APO	Benin	4.6	4.4	4.6	4.7	4.7	4.7	4.7
33	Non–APO	Bolivia	4.8	4.9	4.9	4.9	5.1	5.2	5.2
34	Non–APO	Botswana						5.1	5.1

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
35	Non–APO	Brazil	5.5	5.7	5.6	5.4	5.6	5.6	5.6
36	Non–APO	Brunei Darussalam						5.2	5.1
37	Non–APO	Bulgaria	6.1	5.8	5.6	5.6	5.5	5.5	5.6
38	Non–APO	Burma	4.7	5.0	4.8	4.9	5.3	5.3	5.3
39	Non–APO	Burundi						4.3	4.3
40	Non–APO	Cameroon	5.0	4.9	5.0	4.9	4.9	4.9	4.9
41	Non–APO	Canada	6.0	6.0	6.1	6.1	6.0	5.9	5.9
42	Non–APO	Central African Republic						3.7	3.7
43	Non–APO	Chile	5.6	5.8	5.6	5.7	5.8	5.8	5.8
44	Non–APO	China	4.9	5.0	5.0	5.2	5.3	5.3	5.4
45	Non–APO	Colombia	5.6	5.5	5.4	5.4	5.5	5.5	5.5
46	Non–APO	Costa Rica	5.4	5.5	5.5	5.4	5.5	5.5	5.6
47	Non–APO	Cote d'Ivoire	5.2	5.1	5.2	5.3	5.1	5.2	5.3
48	Non–APO	Croatia						5.4	5.5
49	Non–APO	Cyprus						4.9	4.9
50	Non–APO	Czech Republic						5.5	5.5
51	Non–APO	Democratic Republic of Congo						4.4	4.3
52	Non–APO	Denmark	5.7	5.7	5.8	5.9	5.9	5.8	5.9
53	Non–APO	Dominican Republic	5.3	5.5	5.5	5.4	5.6	5.6	5.7
54	Non–APO	Ecuador	5.3	5.1	5.0	5.2	5.3	5.3	5.2
55	Non–APO	Egypt	5.8	6.0	5.9	5.9	6.0	6.2	6.2
56	Non–APO	El Salvador	5.2	5.3	5.2	5.2	5.2	5.2	5.2
57	Non–APO	Estonia						5.0	5.1
58	Non–APO	Eswatini						4.8	4.9
59	Non–APO	Finland	5.7	5.8	6.0	6.0	5.9	5.9	5.9
60	Non–APO	France	6.2	6.1	6.2	6.2	6.1	6.1	6.1
61	Non–APO	Gabon						5.2	5.1
62	Non–APO	Germany	6.0	6.0	6.1	6.1	6.0	6.0	6.0
63	Non–APO	Ghana	4.7	4.7	4.8	4.7	4.7	4.8	4.8
64	Non–APO	Greece	5.6	5.6	5.8	5.8	5.7	5.5	5.5
65	Non–APO	Guatemala	5.6	5.7	5.6	5.5	5.5	5.5	5.5
66	Non–APO	Haiti						4.2	4.2
67	Non–APO	Honduras	5.2	5.2	5.0	5.0	4.9	4.9	4.9
68	Non–APO	Hungary	5.4	5.5	5.5	5.6	5.6	5.5	5.5

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
69	Non–APO	Iceland						4.6	4.6
70	Non–APO	Iraq	4.8	5.1	5.9	5.8	6.2	6.4	6.4
71	Non–APO	Ireland	5.6	5.8	6.1	6.2	6.0	6.2	6.3
72	Non–APO	Israel						5.9	5.9
73	Non–APO	Italy	6.1	6.1	6.2	6.1	6.1	5.9	6.0
74	Non–APO	Jamaica	4.9	4.9	4.9	4.7	4.5	4.6	4.6
75	Non–APO	Jordan						5.5	5.5
76	Non–APO	Kazakhstan						5.8	5.7
77	Non–APO	Kenya	5.2	5.0	4.9	4.9	5.0	5.0	5.0
78	Non–APO	Kuwait						6.3	6.1
79	Non–APO	Kyrgyz Republic						5.2	5.6
80	Non–APO	Latvia						5.0	5.1
81	Non–APO	Lesotho						4.5	4.5
82	Non–APO	Liberia						3.9	3.9
83	Non–APO	Lithuania						5.4	5.4
84	Non–APO	Luxembourg	5.0	5.0	5.4	5.3	5.2	5.3	5.4
85	Non–APO	Macau						5.8	5.7
86	Non–APO	Malawi	4.6	4.6	4.4	4.4	4.3	4.5	4.4
87	Non–APO	Maldives						4.6	4.6
88	Non–APO	Mali	4.9	5.1	5.2	5.2	5.3	5.3	5.3
89	Non–APO	Malta	4.6	4.5	4.8	4.8	4.7	4.7	4.8
90	Non–APO	Mauritania						4.9	4.8
91	Non–APO	Mauritius	5.3	5.2	5.4	5.2	5.0	5.1	5.3
92	Non–APO	Mexico	6.1	5.9	5.9	5.9	5.8	5.8	5.8
93	Non–APO	Morocco	5.7	5.7	5.6	5.5	5.4	5.4	5.5
94	Non–APO	Mozambique	4.7	4.6	4.8	5.0	4.8	4.7	4.7
95	Non–APO	Namibia						5.4	5.3
96	Non–APO	Netherlands	5.9	5.9	6.1	6.2	6.0	5.9	6.0
97	Non–APO	New Zealand	5.5	5.6	5.7	5.7	5.8	5.9	5.9
98	Non–APO	Nicaragua	4.9	4.9	4.9	4.9	4.8	4.9	4.9
99	Non–APO	Niger	4.2	4.2	4.1	4.1	4.2	4.2	4.2
100	Non–APO	Norway	5.7	5.8	6.1	6.3	6.3	6.1	6.0
101	Non–APO	Panama	5.3	5.3	5.4	5.6	5.5	5.6	5.6
102	Non–APO	Paraguay	5.1	5.0	4.8	5.0	5.1	5.2	5.2

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	APO member	Country name	1991	1995	2000	2005	2010	2015	2017
103	Non–APO	Peru	5.0	5.1	4.9	5.0	5.4	5.4	5.4
104	Non–APO	Poland	5.4	5.7	5.8	5.8	6.0	6.0	6.0
105	Non–APO	Portugal	5.7	5.7	5.8	5.8	5.7	5.7	5.5
106	Non–APO	Qatar						6.3	6.2
107	Non–APO	Republic of Congo						4.5	4.5
108	Non–APO	Romania						5.8	5.9
109	Non–APO	Russia	5.5	5.0	5.0	5.3	5.7	5.7	5.7
110	Non–APO	Rwanda						4.7	4.7
111	Non–APO	Saudi Arabia						6.4	6.3
112	Non–APO	Senegal	5.3	5.0	5.2	5.2	5.1	5.1	5.2
113	Non–APO	Sierra Leone	5.3	4.8	4.3	4.5	4.5	4.6	4.6
114	Non–APO	Slovakia						5.5	5.5
115	Non–APO	Slovenia						5.2	5.2
116	Non–APO	South Africa	5.9	5.8	5.9	5.9	5.8	5.7	5.6
117	Non–APO	Spain	6.1	6.0	6.1	6.0	6.0	6.0	6.0
118	Non–APO	Sudan	6.3	6.1	6.1	6.0	5.7	5.6	5.6
119	Non–APO	Sweden	5.7	5.8	5.9	6.0	5.9	5.9	5.9
120	Non–APO	Switzerland	5.9	5.9	6.0	6.1	6.0	6.1	6.1
121	Non–APO	Syria	4.9	4.8	5.1	5.6	5.6	5.4	5.5
122	Non–APO	Tajikistan						4.3	4.5
123	Non–APO	Tanzania						4.6	4.5
124	Non–APO	The Gambia						4.6	4.6
125	Non–APO	Togo						4.2	4.2
126	Non–APO	Trinidad and Tobago	5.2	5.0	5.2	5.5	5.4	5.7	5.5
127	Non–APO	Tunisia	5.7	5.7	5.7	5.7	5.6	5.5	5.5
128	Non–APO	Uganda	4.6	4.8	4.8	4.8	4.7	4.6	4.5
129	Non–APO	Ukraine						5.2	5.3
130	Non–APO	United Arab Emirates						6.5	6.5
131	Non–APO	UK	6.0	6.1	6.2	6.1	5.9	5.9	5.9
132	Non–APO	USA	6.1	6.1	6.2	6.2	6.2	6.3	6.3
133	Non–APO	Uruguay	5.2	5.3	5.3	5.2	5.4	5.5	5.5
134	Non–APO	Venezuela	5.7	5.5	5.5	5.6	5.7	4.8	4.9
135	Non–APO	Yemen						5.3	5.0
136	Non–APO	Zambia						4.9	4.9
137	Non–APO	Zimbabwe	5.9	5.6	4.9	3.9	4.1	4.2	4.2

Source: Authors' estimation based on the PWT 9.1 [80], Barro and Lee [78], and Lee and Lee [79].

TABLE 5

SYSTEM GMM ESTIMATION RESULTS, LOG DIFFERENCE OF TFP BY COUNTRY GROUP.

	(1) Total countries	(2) APO countries	(3) Non–APO countries
GERD	0.067	−0.013	0.077
	(0.062)	(0.026)	(0.073)
Education/100	0.434	0.099	0.317
	(0.497)	(0.123)	(0.302)
(log) Energy use	−0.141	0.0001	−0.115*
	(0.095)	(0.028)	(0.061)
Trade/100	0.043	0.008	0.066*
	(0.036)	(0.041)	(0.038)
FDI/100	0.040	−0.472*	0.053
	(0.080)	(0.268)	(0.081)
Regulatory quality	−0.009	0.032	−0.012
	(0.116)	(0.049)	(0.130)
Labor freedom/100	0.146	0.100	0.022
	(0.328)	(0.130)	(0.247)
Economic freedom/100	−0.438	−0.011	−0.455
	(0.746)	(0.222)	(0.904)
Corruption/100	0.785*	−0.130	0.817**
	(0.409)	(0.147)	(0.387)
Rule of law	−0.010	−0.002	−0.012
	(0.010)	(0.005)	(0.010)
Political rights/100	0.666*	−0.015	0.549**
	(0.381)	(0.082)	(0.277)
Trust/100	0.103	0.036	−0.071
	(0.405)	(0.059)	(0.401)
Constant	0.557	−0.080	0.631
	(0.503)	(0.218)	(0.521)
Observations	2,101	304	1,797
Number of countries	76	11	65
AR(1)	0.002	0.049	0.001
AR(2)	0.620	0.432	0.912
Sargan	0.990	1.000	0.997

Note: (1) The results are based on one-step system GMM with clustered standard errors (in parentheses). (2) *** represents significant at 1%; ** represents significant at 5%; and * represents significant at 10%. (3) All models include year dummies. (4) AR(1) and AR(2) are tests results for auto-regressive processes of order 1 and order 2, respectively. Sargan test reports the p-values for the overidentification restrictions.
Source: Authors' estimation, based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

TABLE 6

SYSTEM GMM ESTIMATION RESULTS USING PWT 9.1 DATA.

	(1) (log) TFP1	(2) (log) TFP2
(log) (t-1) TFP	0.794*** (0.180)	0.914*** (0.078)
GERD	-0.035 (0.163)	-0.016 (0.051)
Education/100	-0.350 (0.462)	0.013 (0.199)
(log) Energy use/100	-4.335 (12.822)	0.060 (4.720)
Trade/100	-0.205 (0.139)	-0.001 (0.046)
FDI/100	0.301 (0.371)	-0.012 (0.054)
Regulatory quality	0.236 (0.328)	0.010 (0.060)
Labor freedom/100	2.034* (1.052)	-0.094 (0.149)
Economic freedom/100	-0.708 (1.312)	-0.222 (0.360)
Corruption/100	-0.498 (0.895)	0.401** (0.189)
Rule of law/100	1.995 (2.750)	-0.609 (0.639)
Political rights/100	0.151 (0.878)	0.188 (0.254)
Trust/100	0.259 (0.738)	0.223 (0.232)
Constant	0.123 (0.986)	0.534* (0.291)
Observations	2,295	2,052
Number of countries	85	76
AR(1)	0.027	0.018
AR(2)	0.966	0.821
Sargan	0.874	0.795

Note: 1) The results are based on one-step system GMM with the clustered standard errors (in parentheses); 2) *** significant at 1%, ** significant at 5%, * significant at 10%; 3) All models include year dummies; 4) AR(1) and AR(2) are tests results for auto-regressive processes of order 1 and 2, respectively. Sargan test reports the p-values for the over-identification restrictions.
Source: authors' estimation based on the WDI [76], ILO [77], Barro and Lee [78], Lee and Lee [79], UNESCO [38], WGI [37], The Heritage Foundation [39], Transparency International [40], Freedom House [41], and WVS [86] data.

TABLE 7

LABOR PRODUCTIVITY IN 2011 INTERNATIONAL DOLLARS (PPP ADJUSTED) FOR 1991 AND 2017 ALONG WITH THE CORRESPONDING LPI.

	Labor productivity 1991	Labor productivity 2017	LPI (2017 vs 1991)
Argentina	16633	37471	2.25
Australia	59128	96018	1.62
Austria	56707	103543	1.83
Belgium	66663	111771	1.68
Bangladesh	4246	8921	2.1
Bolivia	6027	14087	2.34
Cambodia	2687	6076	2.26
Canada	62478	87138	1.39
Chile	24261	53408	2.2
ROC	47691	95801	2.01
Cote d'Ivoire	6854	11102	1.62
Colombia	18667	27575	1.48
Germany	55824	93328	1.67
Denmark	51019	97982	1.92
Dominican Rep.	14168	35015	2.47
Ecuador	15843	21383	1.35
Spain	50149	90006	1.79
Finland	49993	93791	1.88
Fiji	15690	22147	1.41
France	61476	98713	1.61
UK	49366	87201	1.77
Greece	44577	64999	1.46
Guatemala	11507	17307	1.5
Hong Kong	53591	106906	1.99
Honduras	9036	10174	1.13
Iceland	57078	89211	1.56
Indonesia	8147	23344	2.87
India	3119	15641	5.02
IR Iran	15478	57498	3.71
Ireland	52498	167078	3.18
Israel	57625	78319	1.36
Italy	63762	95350	1.5
Jamaica	12552	19298	1.54

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	Labor productivity 1991	Labor productivity 2017	LPI (2017 vs 1991)
Japan	52244	74784	1.43
Kenya	6419	7463	1.16
ROK	31410	73115	2.33
Lao PDR	2669	12578	4.71
Sri Lanka	10277	35732	3.48
Luxembourg	90390	138440	1.53
Morocco	15855	21986	1.39
Madagascar	2662	3118	1.17
Mexico	34043	42199	1.24
Mongolia	7720	30940	4.01
Mauritius	26788	50913	1.9
Malawi	2530	2579	1.02
Malaysia	23104	55396	2.4
Nigeria	2172	12816	5.9
Netherlands	58487	94301	1.61
Norway	55774	109817	1.97
Nepal	2203	4329	1.97
New Zealand	46524	72533	1.56
Pakistan	9759	16527	1.69
Panama	22220	48317	2.17
Peru	8802	22637	2.57
Philippines	10288	20574	2
Portugal	32743	57429	1.75
Paraguay	9542	17485	1.83
Singapore	45302	128392	2.83
Sierra Leone	4262	4384	1.03
Sweden	51188	96120	1.88
Switzerland	64653	107879	1.67
Syria	3755	19219	5.12
Thailand	9687	29747	3.07
Turkey	33490	79620	2.38
USA	74857	117974	1.58
Vietnam	2896	11507	3.97
Zambia	4472	13402	3
Zimbabwe	13171	3561	0.27

TABLE 8

EFFICIENCY SCORES IN 2011 INTERNATIONAL DOLLARS (PPP ADJUSTED) FOR 1991 AND 2017 ALONG WITH THE CORRESPONDING LPI AND ITS COMPONENTS.

Country	Isocode	Efficiency 1991	Efficiency 2017	Efficiency change	Technology change	Capital deepening	MPI	LPI
Argentina	ARG	0.5707	0.6563	1.15	1.0133	1.9333	1.1653	2.2528
Australia	AUS	0.86	0.7484	0.8702	1.2252	1.5231	1.0662	1.6239
Austria	AUT	0.7838	0.6557	0.8366	1.3635	1.6008	1.1406	1.8259
Belgium	BEL	0.8963	0.669	0.7464	1.4047	1.5992	1.0485	1.6766
Bangladesh	BGD	0.3899	0.3305	0.8475	1	2.4791	0.8475	2.101
Bolivia	BOL	0.4258	0.5275	1.239	1	1.8866	1.239	2.3375
Canada	CAN	0.8329	0.6916	0.8303	1.2204	1.3763	1.0134	1.3947
Switzerland	CHE	0.8242	0.7602	0.9223	1.2984	1.3935	1.1974	1.6686
Chile	CHL	0.6985	0.7368	1.0549	1.0282	2.0296	1.0846	2.2014
Cote d'Ivoire	CIV	0.4332	0.4632	1.0692	1	1.5148	1.0692	1.6197
Colombia	COL	0.5136	0.5094	0.9919	1.0095	1.4753	1.0013	1.4772
Germany	DEU	0.8115	0.73	0.8995	1.2231	1.5195	1.1002	1.6718
Denmark	DNK	0.7519	0.6789	0.9029	1.2984	1.6381	1.1724	1.9205
Domin. Rep.	DOM	0.5481	0.5868	1.0705	1.0163	2.2717	1.0879	2.4714
Ecuador	ECU	0.5058	0.3723	0.7361	1.0137	1.8089	0.7461	1.3497
Spain	ESP	0.7945	0.598	0.7527	1.3197	1.8069	0.9933	1.7948
Finland	FIN	0.682	0.7382	1.0825	1.2239	1.4161	1.3249	1.8761
Fiji	FJI	0.7864	0.5425	0.6899	1	2.0462	0.6899	1.4115
France	FRA	0.8936	0.6609	0.7396	1.322	1.6423	0.9777	1.6057
UK	GBR	0.8303	0.7144	0.8603	1.1835	1.7348	1.0182	1.7664
Greece	GRC	0.6018	0.4224	0.7019	1.3476	1.5415	0.9459	1.4581
Guatemala	GTM	0.6866	0.5157	0.7511	1	2.0024	0.7511	1.504
Hong Kong	HKG	0.9666	0.7482	0.7741	1.2736	2.0234	0.9859	1.9948
Honduras	HND	0.5325	0.3646	0.6846	1	1.6448	0.6846	1.126
Indonesia	IDN	0.5274	0.3697	0.7009	1.0199	4.0078	0.7149	2.8653
India	IND	0.2448	0.3863	1.5782	1	3.1778	1.5782	5.0153
Ireland	IRL	0.8834	1	1.132	1.3846	2.0305	1.5674	3.1826
IR Iran	IRN	0.35	0.6835	1.9526	1.0361	1.8361	2.0232	3.7147
Iceland	ISL	0.7667	0.7545	0.9841	1.1817	1.344	1.1629	1.5629
Israel	ISR	0.8943	0.8365	0.9355	1.0663	1.3625	0.9975	1.3591
Italy	ITA	0.8438	0.5707	0.6763	1.4059	1.5727	0.9508	1.4954
Jamaica	JAM	0.5685	0.3126	0.5498	1.0185	2.7457	0.56	1.5375
Japan	JPN	0.8102	0.713	0.8801	1.1032	1.4743	0.9709	1.4315

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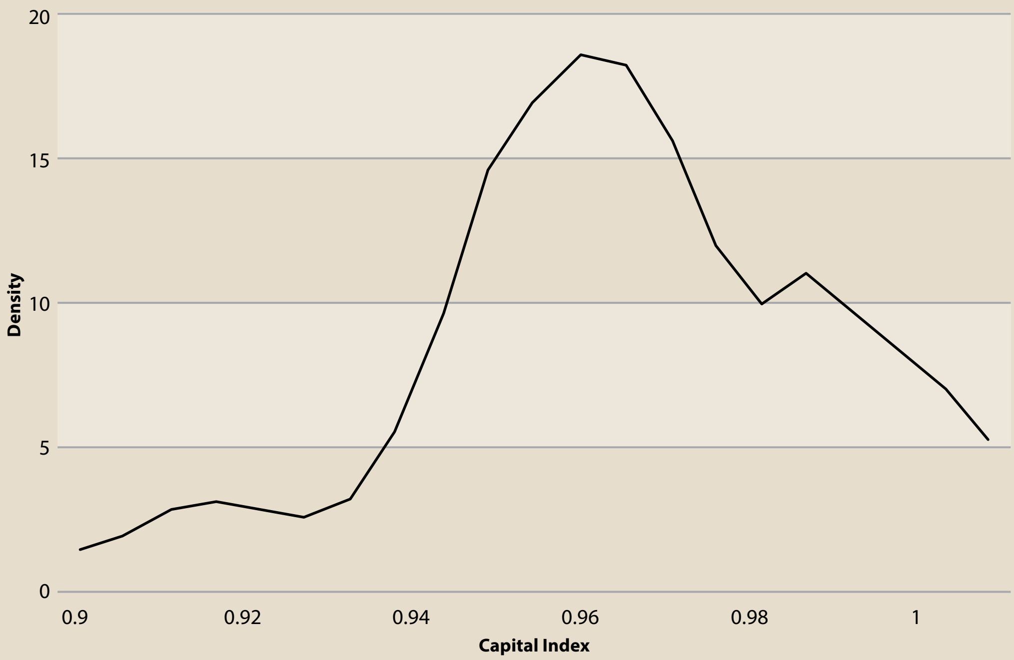
Country	Isocode	Efficiency 1991	Efficiency 2017	Efficiency change	Technology change	Capital deepening	MPI	LPI
Kenya	KEN	0.4306	0.3755	0.8721	1	1.3332	0.8721	1.1627
Cambodia	KHM	0.2541	0.3461	1.3621	1	1.6599	1.3621	2.2609
ROK	KOR	0.6509	0.6929	1.0646	1.0816	2.0215	1.1515	2.3278
Lao PDR	LAO	0.2742	0.4088	1.4908	1	3.1606	1.4908	4.7119
Sri Lanka	LKA	0.504	0.5918	1.1742	1.0171	2.9117	1.1942	3.4771
Luxembourg	LUX	1	0.948	0.948	1.3263	1.2182	1.2573	1.5316
Morocco	MAR	0.5141	0.3678	0.7153	1.0164	1.9072	0.7271	1.3867
Madagascar	MDG	0.4508	0.2179	0.4833	1	2.4232	0.4833	1.1712
Mexico	MEX	0.7437	0.628	0.8445	1.0238	1.4338	0.8646	1.2396
Mongolia	MNG	0.3665	0.5176	1.4121	1.0164	2.7924	1.4353	4.0078
Mauritius	MUS	0.9424	0.6965	0.7391	1.0287	2.4998	0.7603	1.9006
Malawi	MWI	0.3193	0.1969	0.6169	1	1.6523	0.6169	1.0193
Malaysia	MYS	0.5922	0.7637	1.2896	1.0282	1.8082	1.326	2.3977
Nigeria	NGA	0.2205	0.4476	2.0296	1	2.9073	2.0296	5.9005
Netherlands	NLD	0.8735	0.7129	0.8162	1.242	1.5906	1.0137	1.6123
Norway	NOR	0.7478	0.7132	0.9538	1.3486	1.5307	1.2863	1.969
Nepal	NPL	0.282	0.2463	0.8733	1	2.2502	0.8733	1.9652
New Zealand	NZL	0.8199	0.8566	1.0448	1.0519	1.4186	1.099	1.559
Pakistan	PAK	0.6485	0.6406	0.9879	1	1.7143	0.9879	1.6935
Panama	PAN	0.851	0.7136	0.8385	1.0242	2.5319	0.8588	2.1745
Peru	PER	0.4233	0.5047	1.1922	1	2.1572	1.1922	2.5717
Philippines	PHL	0.4889	0.4445	0.9091	1	2.1999	0.9091	1.9998
Portugal	PRT	0.5619	0.4113	0.7319	1.2639	1.8959	0.9251	1.7539
Paraguay	PRY	0.5005	0.452	0.9031	1	2.0292	0.9031	1.8326
Singapore	SGP	0.8381	0.7998	0.9543	1.3473	2.2043	1.2857	2.8341
Sierra Leone	SLE	1	0.2862	0.2862	1	3.5933	0.2862	1.0286
Sweden	SWE	0.74	0.7193	0.9719	1.2509	1.5445	1.2158	1.8778
Syria	SYR	0.4244	0.3763	0.8867	1.0053	5.7412	0.8914	5.1175
Thailand	THA	0.4505	0.4969	1.1029	1.0165	2.7393	1.121	3.0709
Turkey	TUR	0.7301	0.8044	1.1018	1.0464	2.0621	1.1529	2.3775
ROC	TWN	1	0.8772	0.8772	1.0992	2.0833	0.9642	2.0088
USA	USA	0.9906	1	1.0095	1.1814	1.3215	1.1926	1.576
Vietnam	VNM	0.5276	0.4719	0.8944	1	4.443	0.8944	3.9739
Zambia	ZMB	0.2658	0.287	1.0794	1	2.7761	1.0794	2.9966
Zimbabwe	ZWE	1	0.2196	0.2196	1	1.2312	0.2196	0.2704

FIGURE 1

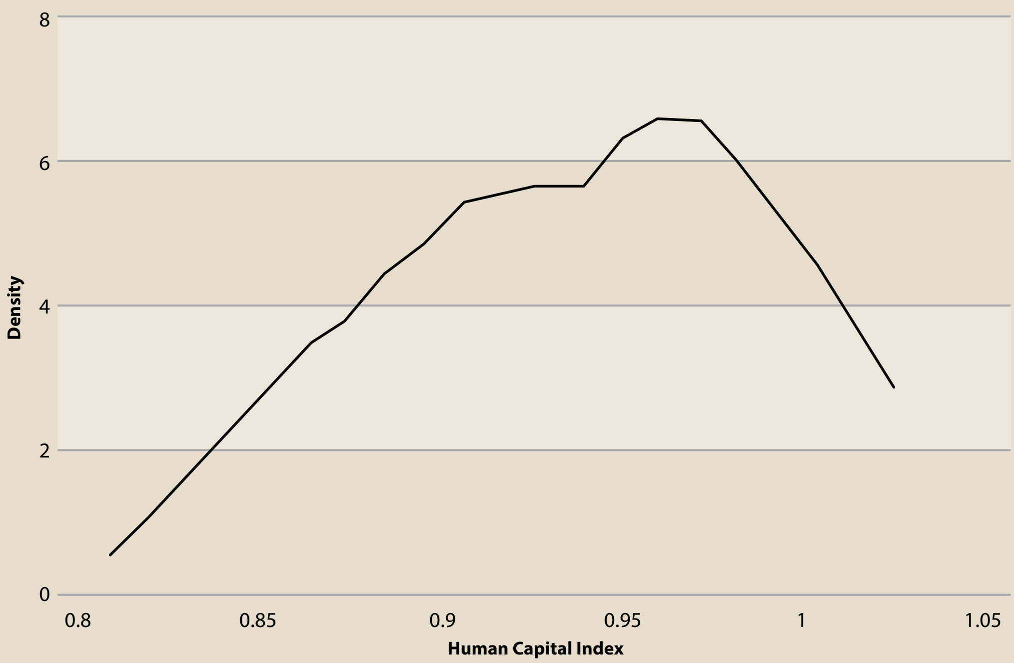
DISTRIBUTION OF THE CAPITAL INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0086

FIGURE 2

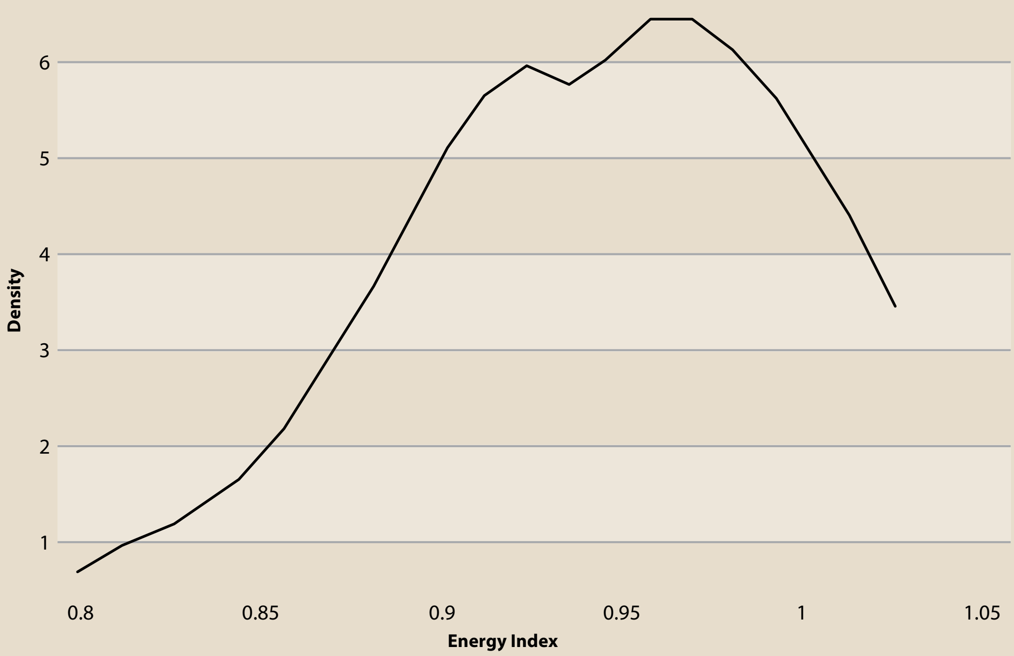
DISTRIBUTION OF THE HUMAN CAPITAL INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0253

FIGURE 3

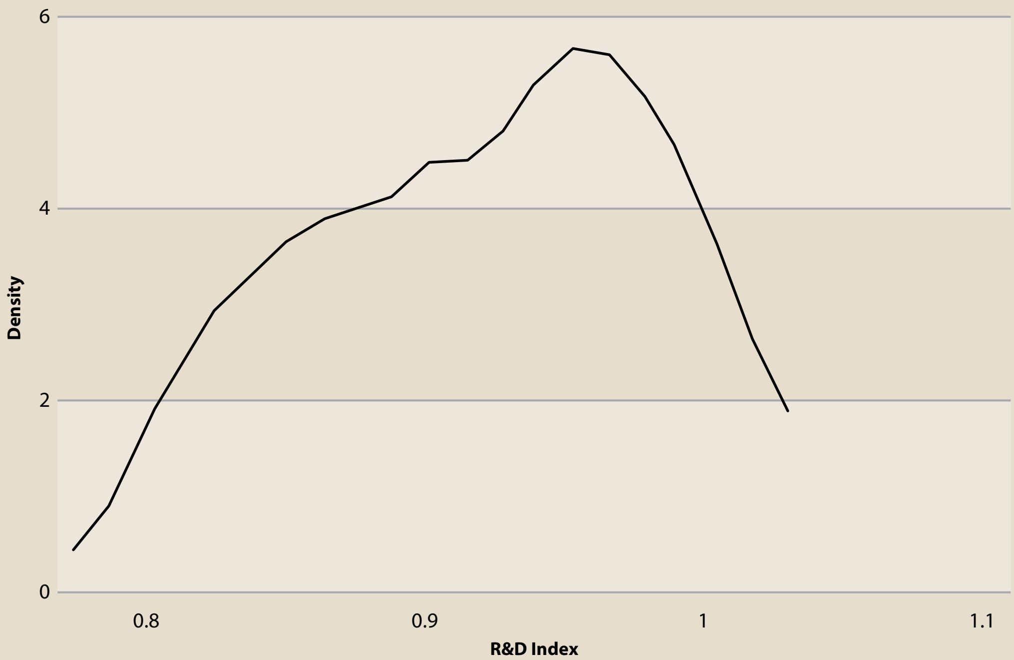
DISTRIBUTION OF THE ENERGY INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0259

FIGURE 4

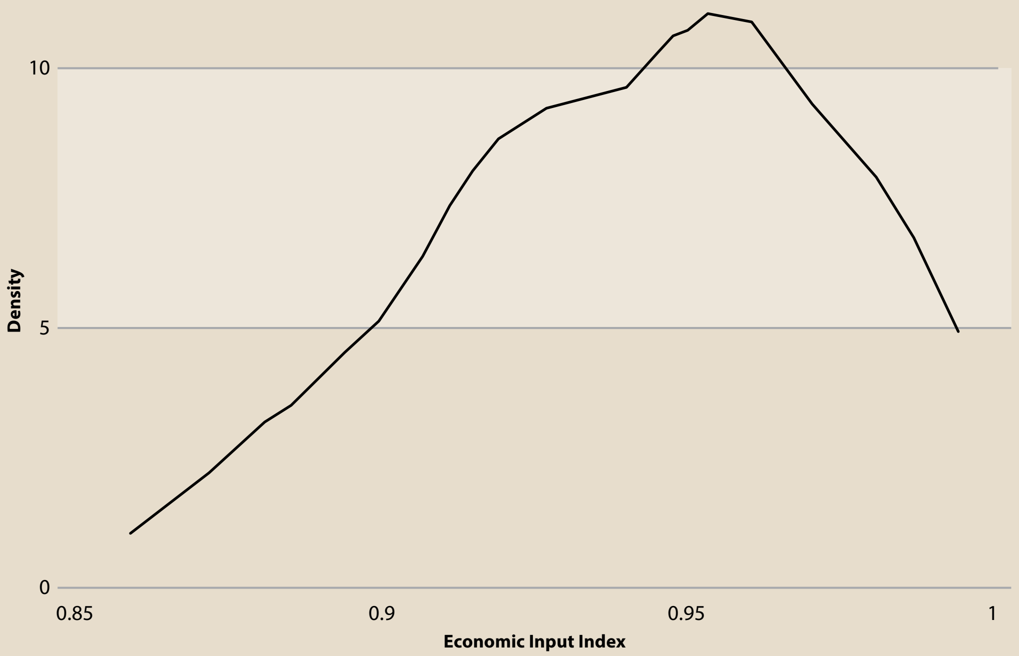
DISTRIBUTION OF THE R&D INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0300

FIGURE 5

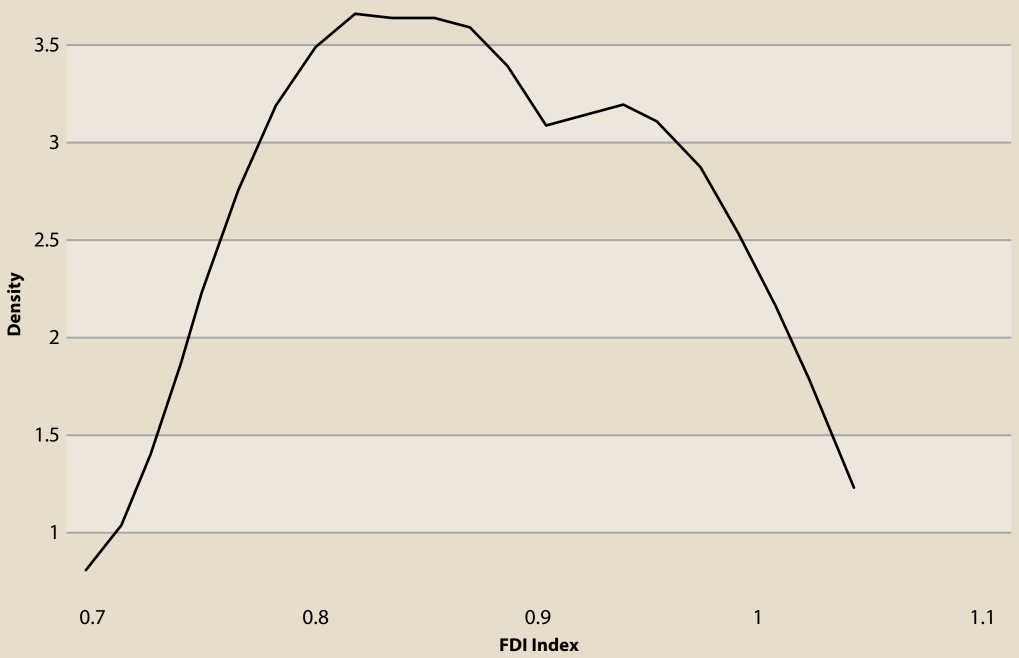
DISTRIBUTION OF THE ECONOMIC INPUT INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0154

FIGURE 6

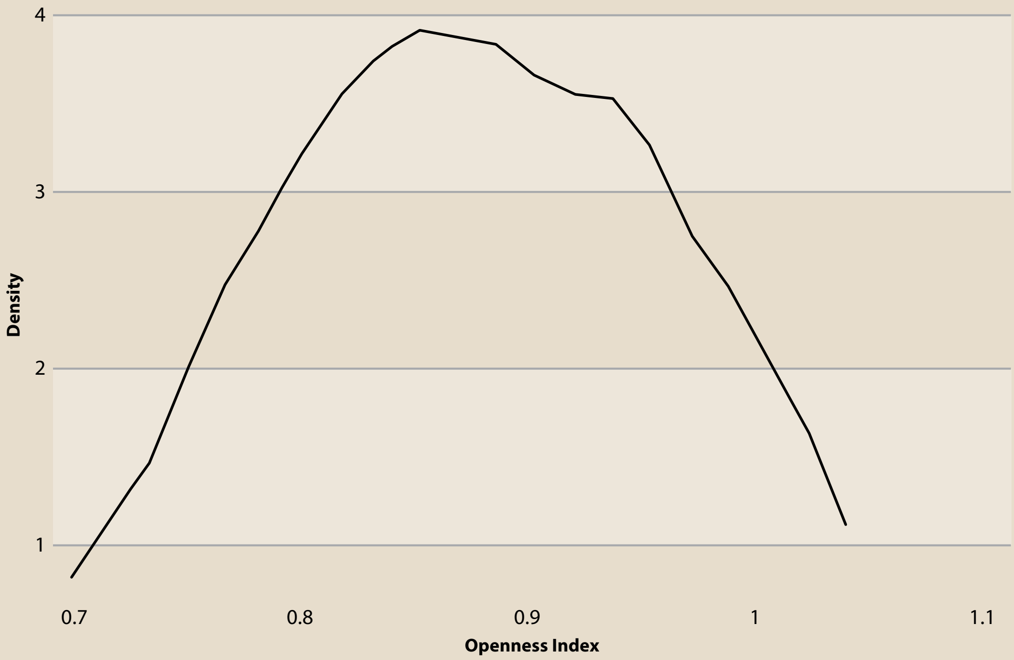
DISTRIBUTION OF THE FDI INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0420

FIGURE 7

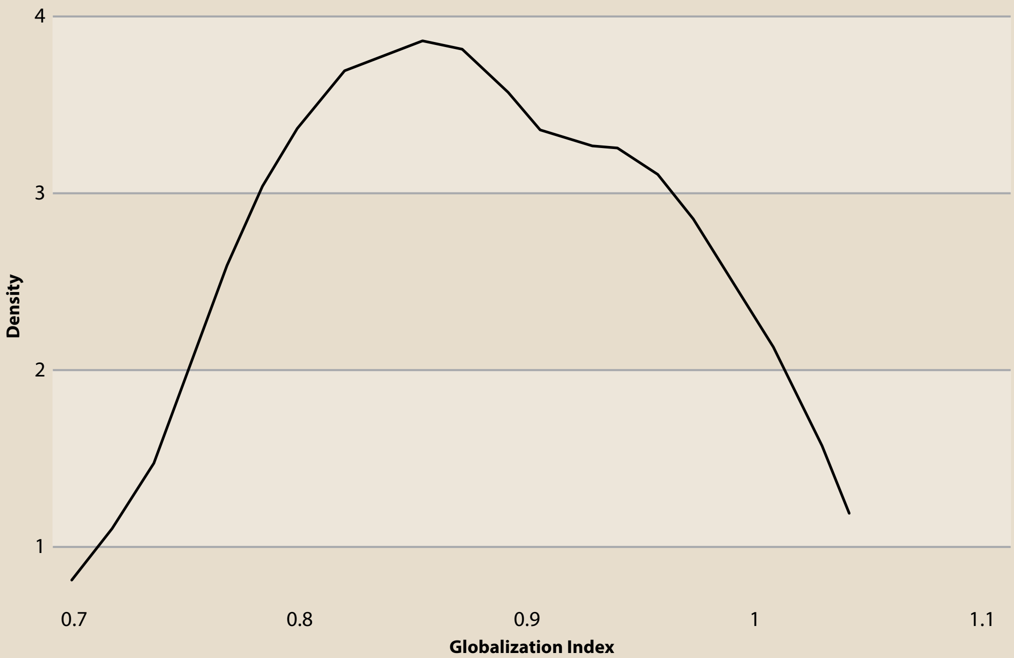
DISTRIBUTION OF THE OPENNESS INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0403

FIGURE 8

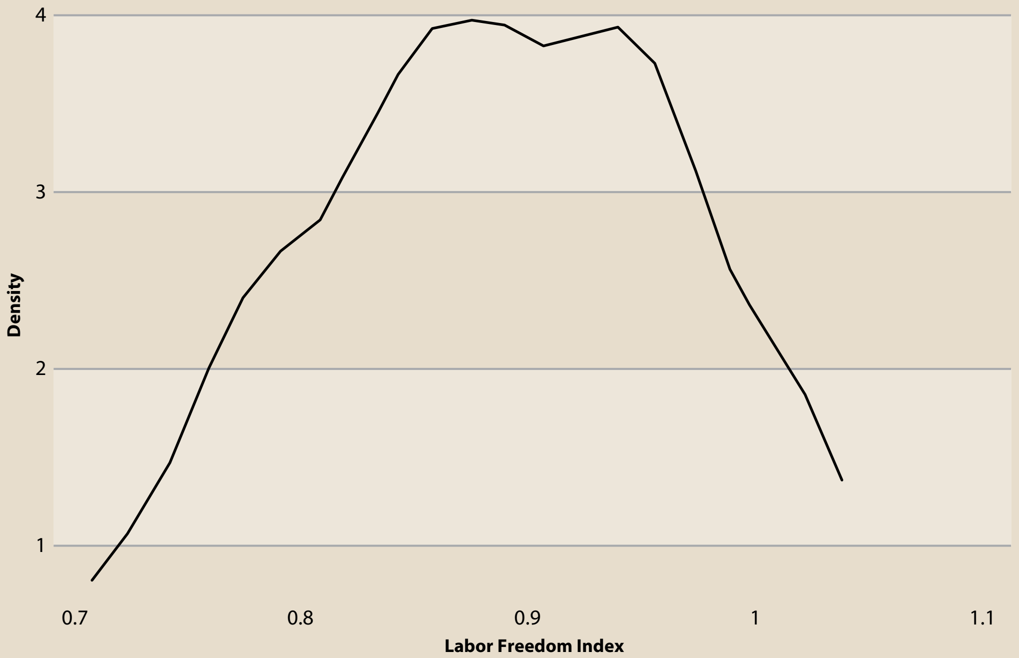
DISTRIBUTION OF THE GLOBALIZATION INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0409

FIGURE 9

DISTRIBUTION OF THE LABOR FREEDOM INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0394

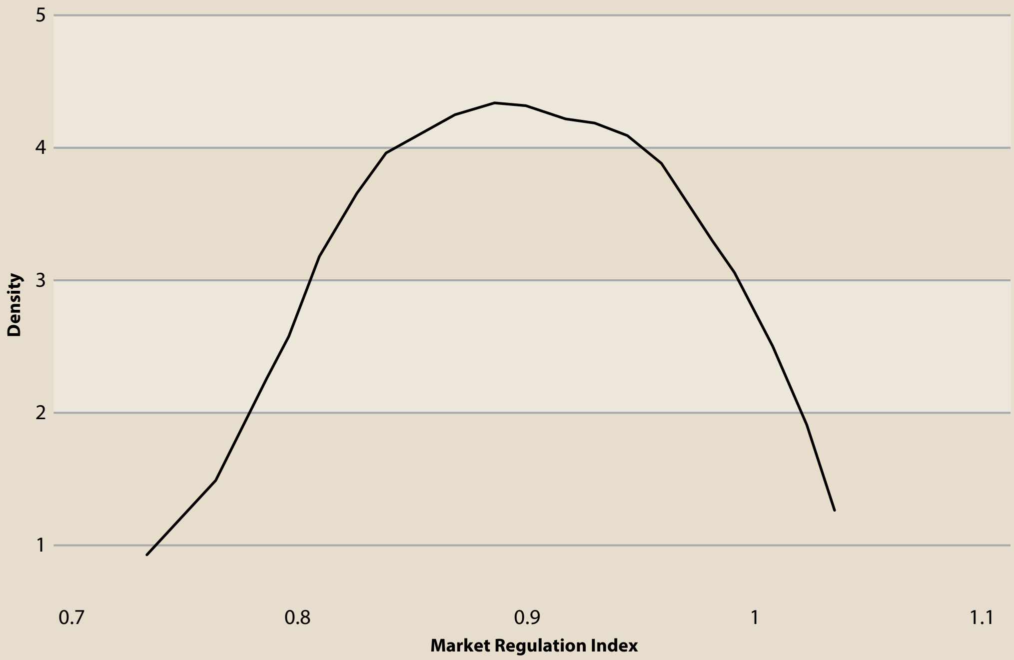
FIGURE 10

DISTRIBUTION OF THE REGULATORY QUALITY INDEX.

Note: Kernel = epanechnikov; bandwidth = 0.0330

FIGURE 11

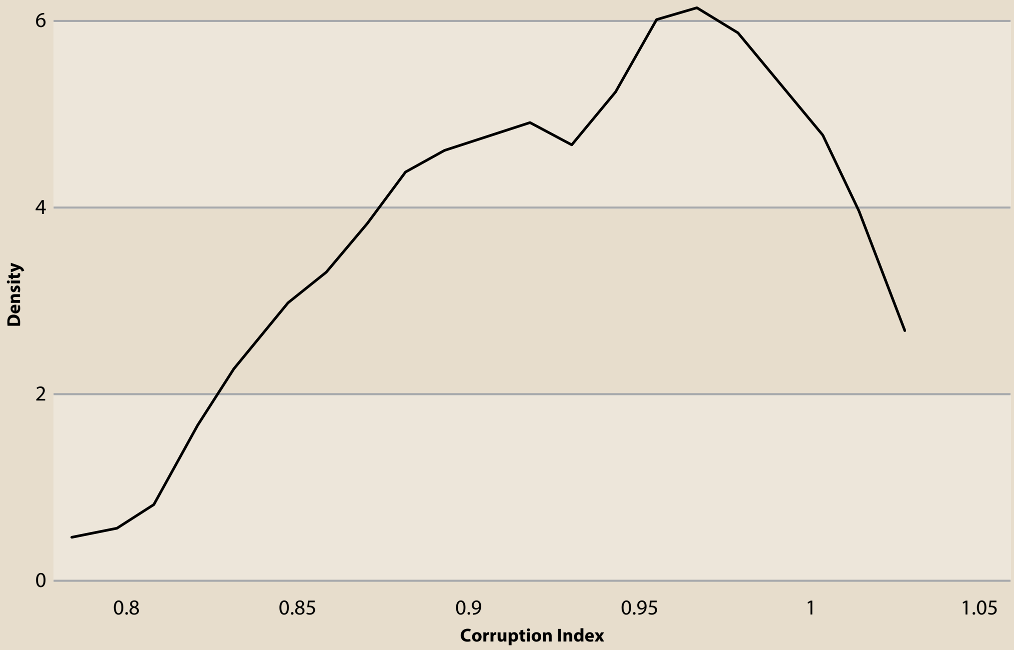
DISTRIBUTION OF THE MARKET REGULATION INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0353

FIGURE 12

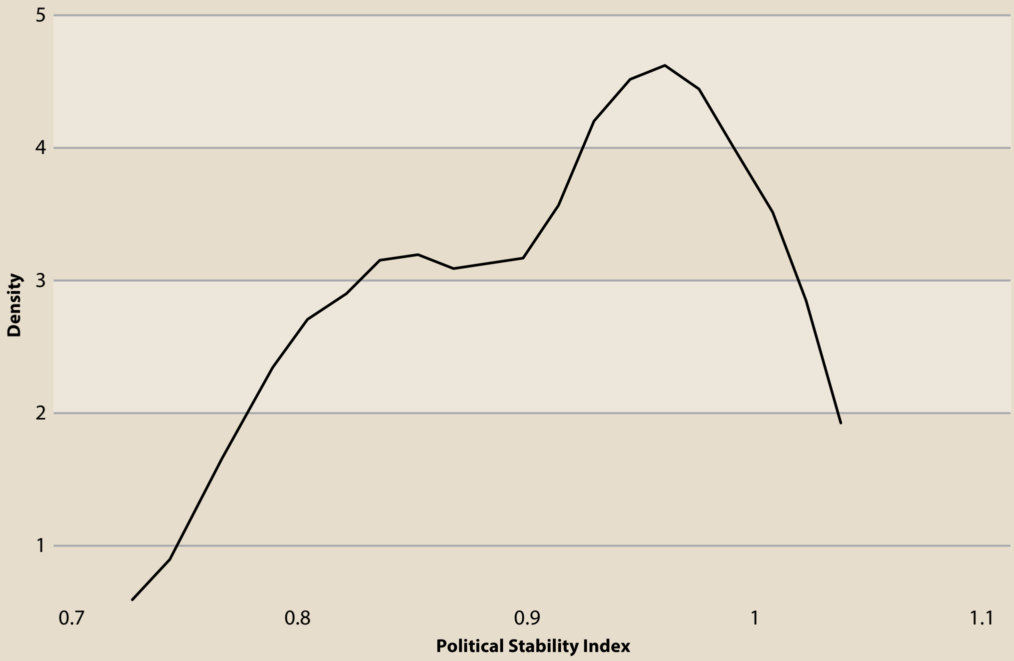
DISTRIBUTION OF THE CORRUPTION INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0279

FIGURE 13

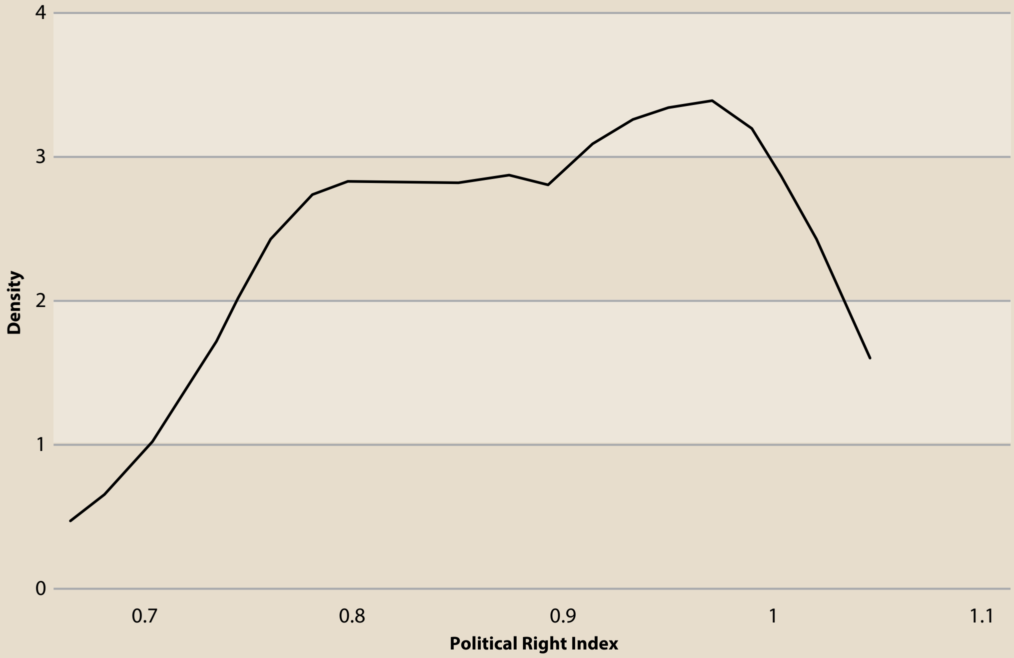
DISTRIBUTION OF THE POLITICAL STABILITY INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0378

FIGURE 14

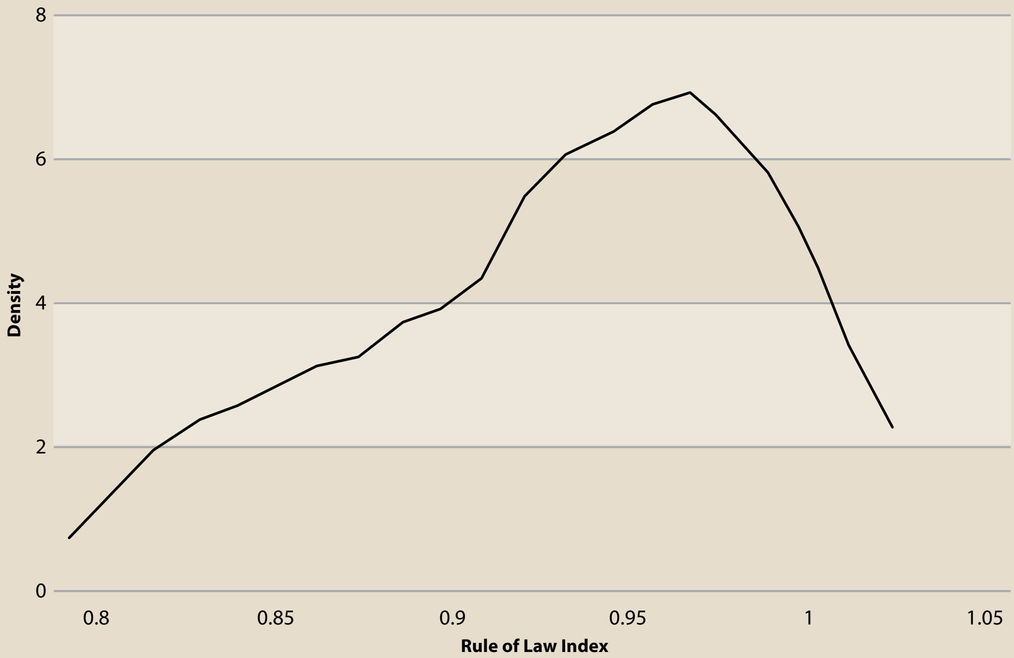
DISTRIBUTION OF THE POLITICAL RIGHTS INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0466

FIGURE 15

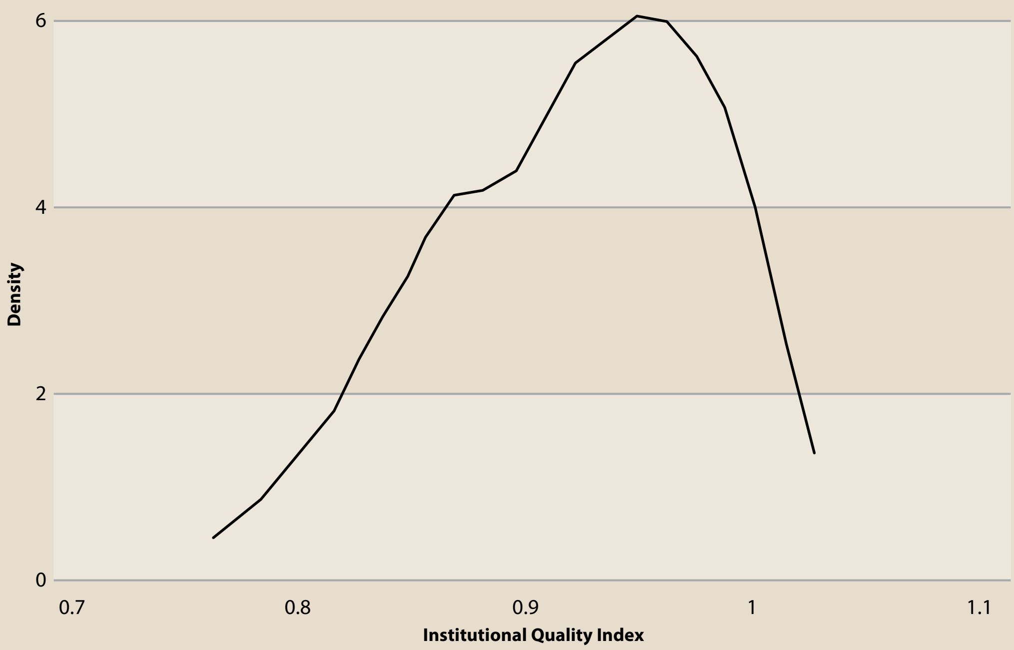
DISTRIBUTION OF THE RULE OF LAW INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0241

FIGURE 16

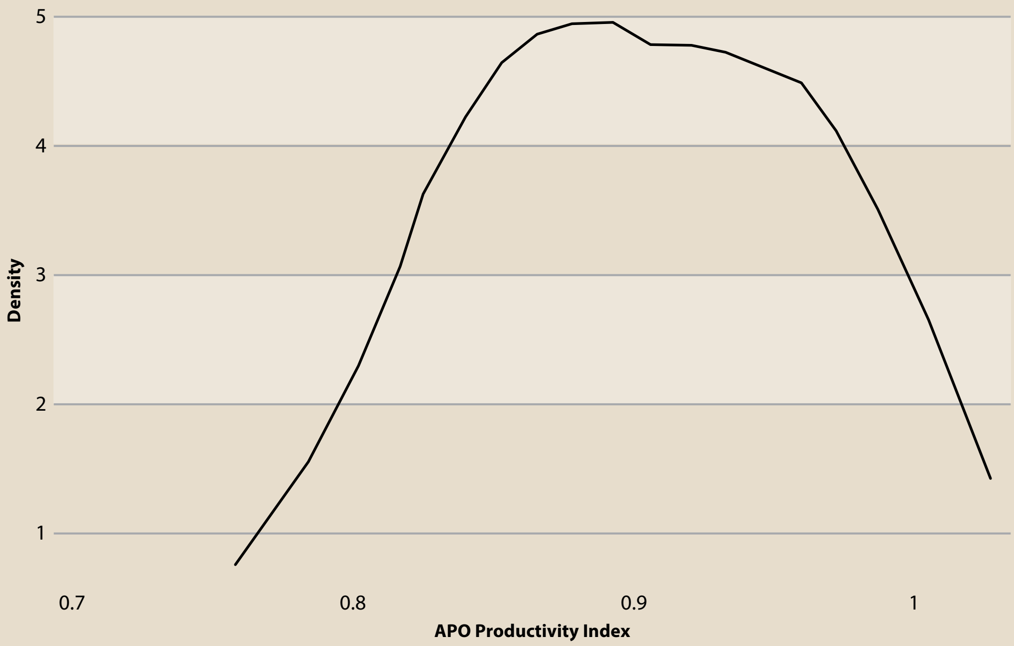
DISTRIBUTION OF THE INSTITUTIONAL QUALITY INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0286

FIGURE 17

DISTRIBUTION OF THE APO PRODUCTIVITY INDEX.



Note: Kernel = epanechnikov; bandwidth = 0.0305

LIST OF TABLES

LIST OF FIGURES

APPENDIX

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