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Knowledge, Complexity and Economic Growth: Multi-country Evidence by Development Stages

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This paper analyzes the effects of knowledge spillovers and complexity proxies on the economic growth using the pooled mean group estimator and annual dataset of 86 countries for the period of 1995-2011. Differently, we cluster countries into five groups by development stages, according to the key drivers of their economies. To this end, along with the conventional determinants, we also added foreign direct investment inflows as proxy of potential knowledge spillovers, and economic complexity index that represents overall capabilities of the economy to amass the knowledge and deepen the technology. Results affirm that long-run relationships vary substantially across the country groups. Complexity contributes to the growth most for the countries that are moving into innovation-driven stage while innovation-driven economies seem to have already faced negative consequences of complexity. Adverse effects of FDI inflows indicate possible resource-seeking activities and crowding-out effects for resource-driven and efficiency-driven countries, respectively.

Keywords: *Development Stages, Economic Complexity, GDP Growth, Knowledge Spillover, Pooled Mean Group Estimator.*

Introduction

A number of seminal contributions set theoretical origins of long-run economic growth [1],[2],[3]. Much of attention of studies in the immense literature on the determinants of growth has mainly focused on capital and labor intensities [4],[5],[6],[7],[8]. Some others, on the other hand, have investigated specific factors like financial development, investment, trade and exchange rate, total factor productivity and technological progress, etc. [9],[10],[11],[12]. Besides these economic factors, recent developments in growth theory have underlined the importance of non-economic factors like institutional quality, good governance, political transparency and globalization. In this context, especially the countries that have concentrated on the natural resources based production have been observed to have relatively worse institutions and low integration in the world economy which have hindered this resource-driven economies to have higher growth performances [13],[14],[15].

Trade mechanisms of the growth embody challenges that there is not a certain relationship proven between trade and growth. The neoclassical trade theory, that is closely linked neoclassical growth model, predicted developing countries would gain from the free trade more as they participate in the world trade, i.e. trade openness, with an international division of labor and according to the comparative advantage of production. Moreover, the neoclassical trade theory predicted a convergence trends in growth rates of developed and developing countries in the long-run. Because the last prediction was not supported well by the real data in practice, neoclassical trade theory had been exposed to widespread criticisms that accelerated in 1950s.

Singer [16] and Prebish [17] emphasized what countries specialize in exporting matters for their sustainable gains from the trade and asserted that in the long-run, the terms of trade would develop against the countries who export resource based primary products. At those times, losing side they meant was developing countries and gaining part was industrialized countries. After Nurkse [18] had concluded, a country is poor because it is poor while explaining the ‘vicious circle’ of poverty and stagnation for under-developed countries; Bhagwati [19] pointed out the effect of the trade that can lead to immiserating growth in the long-run because of the deterioration in the terms of trade. This premise seemed to be supported in practice that protectionist instruments in trade were commonly used in those times, especially by slow-growing developing countries.

While growth theories have been attempting to explain the particular conditions of the GDP increases, some East Asia countries have recorded exceptional growth rates gradually since the late 1960s. The growth performances, that were later called 'Asian miracle' [20], had confirmed the contribution of both orthodox and heterodox policies to growth and interested economists in searching whether free market or active states was the driver of these success. These longstanding debate also reflects to studies that they add more indicators of government activities together with their adverse effect, like corruption [21],[22].

Endogenous growth models, pioneered by Romer [23],[24] suggest that research and development sectors create technological innovation using human capital and the existing knowledge. These lead to increasing return in an economy and so enable sustainable economic growth. This is also empirically supported that knowledge is the main driver of productivity rise and economic growth especially in knowledge based developed countries. Thinking their deindustrialization process, this also explains how developed countries keep having sustainable economic growth. This is consistent with global recognition that we live in an information society and knowledge based economy that every economic activities are affected by. One way to measure of knowledge dispersion in an economy is scaling its complexity. The complexity is also affected by foreign direct investment (FDI) activities that create international knowledge networks and carry the knowledge into the host economy. This consequently brings technology diffusion.

In the existing literature, it is well-proven evidence that along with the physical capital, human capital accumulation with its various measurements has significant contribution to growth performance for all countries, regardless in which development stages they are. This is also true for technology adaptation and knowledge dissemination in a society that directly affects overall productivity. Consequently, productivity based sustainable growth is strongly connected with a knowledge based complex economy. Starting from these premises, in this study we examine how the complexity and knowledge spillovers provided by FDIs, affect growth performance for 86 countries. We control the results by development stages of countries following the World Economic Forum's (WEF) five-group development taxonomy [25]. Bu doing so, we also test how economic complexity alters the relationships between GDP per capita and its potential determinants over the development stages. The rest of the study is organized as follows. Next, we present theoretical framework, model and data sets respectively. Then, we introduce the empirical approach and analysis process. After demonstrating empirical results, the study concludes with a discussion.

Theoretical Framework

Economic Complexity and Knowledge Based Growth

Economic complexity approach centers on the knowledge as a main input of the production against the traditional ones that suppose physical capital, natural resources and labor as the core production factors. In fact, the knowledge cannot be measured directly. Rather, we can use specific proxies computable using some visible data related to the 'knowledge economy', which refers to the intellectual capability of an economy with its society to produce science and technology based products. This process requires rapid updates in order to keep up with new technologies that replace the obsolescent ones [26],[27].

Economic complexity is highly related to product diversification in both domestic production and export basket. Krishna and Levchenko [28] highlights that growth trends of poorer countries are more volatile because they specialize in a limited number and volatile sectors. The global and country-specific outlooks of various sectoral and aggregated data confirm that less complex industries are more volatile. The other track of the complexity is the market interactions. Markets allow us to access the vast amount of knowledge that is scattered among the people [29]. In this approach, workers learn the knowledge while producing and consumers do while consuming.

We use the data from atlas of economic complexity index (ECI) [30] initiated by Hausmann et al. [29] who define two kinds of knowledge. The first one, explicit knowledge, can be transferred easily by reading, listening or just observing. However, people need to endeavor systematically to acquire the second one, tacit knowledge. Tacit knowledge is relatively scarce, hard to transfer and required for making more sophisticated and complex products. Hence, tacit knowledge variations among countries also explain growth and development differences in the global economy.

While measuring economic complexity Hausmann at al. [29] start with the diversity, a measure of how many different types of products a country is able to make. They define the economic complexity as a measure

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of the knowledge in a society that is translated into the products it makes. So, complexity capabilities of countries can be scaled by tracking what and how they produce and export. A country is considered 'complex' if it exports not only highly complex products but also a large number of different products. In fact, ECI is a scale gauged using the theory and it ranks countries according to their levels of complexity. It takes into account the average ubiquity of the products that a country exports and the average diversity of the all countries that make those products. ECI centers on both the product complexity and the country complexity. In order to make countries and products comparable, it adopts Balassa's revealed comparative advantage approach, which states a country has revealed comparative advantage in a product if the product's share in the country's exports greater than its total shares in world trade. Consequently, the inference is that countries become more complex as they make and so export products that are more complex (see [29], for further technical details). Table-1 ranks products by their product complexity indexes (PCI) for the year 2014 and in the Harmonized System (HS) 4-digits classification.

Table 1: Most and least complex products, HS-4, 2014

Rank	*HS 4-digit*	*Products*	*PCI*
		Top 10 products by complexity	
1	7805	Lead tubes, pipes and fittings	6.60
2	8444	Machines to extrude, cut manmade textile fibres	5.74
3	9204	Accordions and similar instruments	5.64
4	8457	Machining centers for working metal	5.15
5	8113	Cermets	4.96
6	7507	Nickel tubes, pipes and tube or pipe fittings	4.76
7	2812	Halides and halide oxides of nonmetals	4.71
8	3705	Photographic plates and film, exposed and developed, not motion-picture film	4.64
9	9027	Instruments and apparatus for physical or chemical analysis	4.62
10	9022	Apparatus based on the use of X-rays or of alpha, beta or gamma radiations	4.62

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Bottom 10 products by complexity			
1231	2709	Crude oil from petroleum and bituminous minerals	-3.38
1232	0801	Coconuts, Brazil nuts, and cashew nuts	-3.47
1233	4106	Tanned skins of other animals	-3.57
1234	6704	Wigs etc. of hair etc., human hair articles	-3.64
1235	5310	Woven fabrics of jute or other text bast fiber	-3.73
1236	2609	Tin ores and concentrates	-3.78
1237	0714	Manioc (cassava)	-3.80
1238	2615	Niobium (columbium), tantalum, vanadium or zirconium ores	-3.82
1238	1801	Cocoa beans, whole	-4.60
1240	5303	Jute and other textile fibers	-4.67

Source: Atlas of Economic Complexity [30]

Table-1 illustrates that chemicals and machinery, that embody sophisticated contents from knowledge and skill intensive industries, are among the most complex products. The least complex ones, on the other hand, are mainly raw minerals or simple agro based products that we can name primary products and commodities.

The premise what countries produce and export matters is also supported by the fact that countries with more sophisticated production structure have more sustainable and stable growth paths. This confirms the importance of innovation as one of the engines of the growth [31]. Knowledge based innovative production is also a key pillar of competition in the export-led growth. Exceptional growth trends of East Asia countries since 1970s are presented as the outcome of increases in the human capital stocks and as linked to this, relatively faster technology adaptation [32],[20]. However, this study has other aspect, as well that we also attempt to point out some risks that complexity brings, via the foreign trade channels and

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global production networks. Complex products are commonly made in the global production networks that numerous countries have been contributing in its all production processes, from design to recycle. Here are two important risk can arise: First when a local shock occurs in a country that is in these networks, this can affect other countries fast and easily. This contagion can make countries fragile to the international shocks. Since these risks can be avoided by the repositioning flexibility. The riskier parts come from the characteristics of the complex products that exported mostly by developed countries. These products are generally consumer durables like high-tech electronic devices, together with investment goods, chemicals and machinery. As indicated by Baldwin [33] these group products are postponable. Therefore, when a shock occurs in a market, especially in a large one or in global context at worst, it can suddenly affect the countries that are producing postponable goods because of relatively higher income elasticity. This sudden impact can cause a deviation from the long-run growth trends especially in the developed countries. Hence, the countries that are diversifying export contents are also need to diversify their operation markets in order to minimize locational risks. This is consistent with the observation that countries with more complexity indexes are also the ones that spread their products over more destinations. Therefore, the supplementary part of the complexity is market diversification.

In this study, we get economic complexity to measure the productive knowledge accumulations. It is getting more important than the other production factors like physical capital, labor, and natural resources. This is also a good measure of human capital disperses in the society since conventional measures, like years of schooling and health expenditure or research and development investment are just quantitative measurements that are incapable to capture the qualitative aspects. For example, a traditional resource-driven economy that use traditional production factors also can be investing a high amount in research and development intensively but just for the resource extracting activities that have no linkage to the other industries. In this context, economic complexity not only helps in explaining current income differences of countries, it also predicts future economic growth potentials since the complexity enhances the knowledge accumulation and diversification capabilities. We expect economic complexity that bridges between knowledge and growth has positive coefficients in our model, especially for those countries that have dynamic transformations towards innovation-driven structure.

Microeconomic Origins of Growth: FDI and Knowledge Spillover

In today's world, the only certainty is that there are more changes than ever before and they affect all economic agents, i.e. individuals, firms, governments and institutions, in countries. Hence, knowledge based sectors of a country need to be more updated accordingly to scientific improvements and progressive changes in the global business environment. These linkages can be set by multinational enterprises (MNEs) that have various production stages and/or branches in different countries. Best-fitting data on the international linkages of knowledge spillovers would be those of MNE activities in firm-level. However, this data is available in a very limited number of countries and periods. This unavailability restricts the study to FDI activities. Because FDI flow captures MNEs activities and show general tendencies, this proxy restriction is not a serious problem in our case.

The motives for MNEs, and in a broad definition for FDIs, can differ [34]: i) Resource-seeking FDIs enter a country to have access to specific resources, like natural resources or material inputs. In this sense, factor-driven countries are expected to be pulling this kind of FDIs. ii) Market-seeking FDIs' objectives are to supply goods and/or services in the host market. So, bigger markets are expected to be more attractive in this case. iii) The motivation of strategic asset-seeking FDIs is to acquire assets, such as knowledge or technology in local markets, to accomplish the long-term objectives and to increase their competitiveness in global markets. Innovation-driven economies are targets for these FDIs. Moreover, there are numerous factors pulling or pushing the FDIs like logistics, availability of economies of scale, technological differences are among many others. These factors also have some possible explanations to why developing countries that have a higher marginal return of capital, fail to attract FDI (see Lucas paradox, [35]). Again, our country classification allows us to see these development effects.

Regardless which factor they are motivated by, the majority of evidence in the relevant literature indicates that MNEs proxied by the FDI, are more productive and boost the technology level not only in the developing countries, but also in the developed ones with respect to knowledge spillover effects [36],[37],[38]. These effects can take place directly and/or indirectly [39]. The direct effect occurs when FDI establishes new branches in the host country. Because international firms are expected to have higher productivity level compare to those of locally operating counterparts, new FDI inflows lead to an increase in the overall productivity level of the host country. In this context, as new MNEs import recent machinery and get new license or patents, the latest technologies are introduced to the domestic firms. Moreover, domestic firms, together with their employees, are also forced to compete with the new pressures FDIs bring. This competitive business environment encourages the local companies and employees to enhance activities on skill improvements, know-how, imitation and training that affect overall productivity level of the host economy. This presents microeconomic linkages to macroeconomic growth.

The indirect effects come from three spillover channels: first one is horizontal spillover that occurs when foreign and domestic firms independently operate (inter-firm or arm's length relations) in the same industry or in the same region while second one, vertical spillovers, occur between related domestic and foreign firms (intra-firms relations). In the latter case, domestic firms enjoying the spillovers can be supplier or buyer [34],[39]. Thirdly, spillovers through employment happen when domestic firms hire workers who previously worked for the foreign firms. These spillovers have some explanations to why firms are reluctant in investing formal training since the skills move with the trained employees that can bring extra costs and hereby competitiveness lost. Consequently, arguments on the microeconomic linkages of knowledge and technology spillovers originate from different mechanisms like demonstration/imitation, labor mobility, competition, intra-firm linkages, vertical specialization, skill transfers and training activities accordingly to the interactions between domestic firms and MNEs, i.e. FDI in our case.

These channels also bring a dilemma on the nexus between local entrepreneurial intentions and growth. Spillover effects are also expected to stimulate the local enterprises of new entrepreneurs who have already learned modern business operations by means of imitation, know-how or employee relations, inter-firms linkages, etc., that all in turn improve economic growth. Existing literature on the FDI and entrepreneurship relationships have results indicating both positive effect of knowledge spillovers and dissemination of new technology and negative effects of crowding out domestic entrepreneurship. Some studies suggest that demonstration and/or imitation effects of FDI can create new entrepreneurs and startups. However, studies relative to the relationship between FDI and entrepreneurship have yielded ambiguous results that the net contribution depends on mutual extents of positive technology and spillovers effects and negative crowding-out effects. Furthermore, these net effects can vary over countries and sectors in the same country [40],[38].

FDI and its adverse effects are important since the entrepreneurial activities are considered one of the main engines of economic growth. In this study, we also point to the compensation mechanism of the crowding-out effect. Potential local entrepreneurs can be attracted by higher compensations and better benefits like training, skill improvements, promotion and prestige that MNEs offer. Prestige effect is important especially when foreign firms are well-known worldwide. This can decrease domestic new business startups and so does long-run growth potentials. A worse effect occurs when MNEs acquire monopoly power in the domestic markets, namely labor, factor and goods-service markets that can strictly hinder new entrepreneurial activities setting insuperable entry barriers. Therefore, the effects of FDI activities on the growth are uncertain especially on the growth is uncertain especially on the developing countries, i.e. factor driven-economies in our case.

Model Specification and Data

In this empirical section we assess the effects of economic complexity (EC), human capital (HC) and foreign direct investment (FDI) on economic growth represented by gross domestic product per capita (GDPPC). Other explanatory variables, namely trade openness (TROPEN), physical capital stock (CS), total factor productivity (TFP), oil revenues (OILR) (for the factor-driven and efficiency-driven countries) and oil prices (OILP) (for innovation-driven countries) are also added to the model for a better estimation of coefficients. The linear regression model in a panel framework is specified in the equation-1.

$$\ln GDPPC_{it} = \beta_0 + \beta_1 \ln EC_{it} + \beta_2 \ln HC_{it} + \beta_3 \ln FDI_{it} + \beta_4 \ln TROPEN_{it} + \beta_5 \ln CS_{it} + \beta_6 \ln TFP_{it} + \beta_7 (\ln OILR)_{it} + \beta_8 (\ln OILP)_{it} + \varepsilon_{it} \quad (1)$$

Where, i is the country index we clustered into five groups (i=1…9; 10…21; 22…37; 38…56; 57…86), t is the time index (1995…2011), ε is the error term and βo is a country-specific intercept. All the data variables are converted into natural logarithms (ln) that helps in having a normal distribution and homoscedastic error term. Since cross-section units (N: 86) are numerous than temporal units (T: 17), we have a cross-section dominant (N>T) panel data sets with 1462 observations in total.

One of the key findings in the nexus between growth in real GDP per capita and its determinants is that it is conditional on development stages. This study points out the challenges when using country classifications with respect to their development stages. Cross-country studies seem to be suffering from aggregation biases that make hard to generalize the results. We focus on the complexity and knowledge based determinants of the GDP growth in a holistic approach that are expected to be sensitive to the development stages of the countries. In order to hinder possible biases, we distinguish countries by their development stages, not by the income-level taxonomy. Vazquez and Sumner [41] emphasize the challenges on the use of income per capita as the primary proxy for development level. Their findings reveal that the usual income classification of gross national income per capita (Atlas method) defined by the World Bank is not that effective method to group countries strictly by their prosperities and hence, more adequate and specific indicators are needed to be able to rank countries as low, middle and high income.

Relevant to our case, some studies use for example 'industrialized' and 'developed' or 'high income' countries interchangeably to grade their prosperity, regardless how and where this income originates. One of the reasons for the ambiguity in economic growth literature stems from aggregation biases. This can lead to misleading results on the determinants of growth that, even they are strongly similar in some ways; individual countries can differ considerably in other aspects. For example in 2013, Trinidad and Tobago was a high-income country in terms of World Bank's (WB) classification while it is a developing country for United Nations Industrial Development Organization's (UNIDO) classification, and an

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innovation-driven economy in The World Economic Forum's (WEF) classification. Another example is Greece. It is high income and innovation-driven country in WB's classification and WEF's classification, respectively, but not an industrialized country in UNIDO's classification rather it is among emerging industrial economies. Again, India is among emerging industrial economies in UNIDO's taxonomy for its achievements towards industrialization, especially in those of informatics technologic ones; however, it belongs to factor-driven economies group WEF's classification together with the countries that have natural resource-dominants production structures. This inconsistency is also seen as intertemporal: Because some countries have had considerable changes in the indicators over time, it becomes hard to generalize time series results for the group. Starting from these time and country heterogeneity, we grouped countries by development stages as seen in the Table-2, based on the WEF's classification that fits well our primary intended purposes.

Table 2: Country sample, classifications and economic complexity indexes

Stage-1: Factor-driven (9 countries)	Cameroon (-0.70) {88}, Cote d'Ivoire (-0.98) {98}, India (0.24) {45}, Kenya (-0.67) {87}, Mauritania (-1,63) {119}, Mozambique (-1,15) {106}, Senegal (-0,58) {76}, Tanzania (-1.08) {102}, Zimbabwe (0.88) { 95}.
Key pillars for this group	*Institutions, infrastructure, macroeconomic environment, health and primary education.*
Transition from Stage-1 to stage-2 (12 countries)	Bolivia (-1.22) {107}, Ecuador (-1.10) {104}, Gabon (-1.32) {109}, Honduras (-0.58) {75}, Iran (-0.99) {99}, Kuwait (-0.51) {73}, Moldova (-0.11) {59}, Mongolia (-1.41) {114}, Morocco (-0.60) {78}, Philippines (0.46) {40}, Saudi Arabia (-0.54) {74}, Venezuela (-1.11) {105}.
Stage-2: Efficiency-driven (16 countries)	Bulgaria (0.50) {38}, China (1.10) {19}, Colombia (-0.18) {63}, Dominican Republic (-0.31) {65}, Egypt (-0.17) {61}, Guatemala (-0.36) {70}, Indonesia (-0.02) {56}, Jamaica (-0.35) {68}, Jordan (0.16) {18}, Paraguay (-0.59) {77}, Peru (-0.77) {92}, Romania (0.86) {29}, South Africa (0.00) {55}, Sri Lanka (-0.38) {71}, Thailand (0.94) {26}, Tunisia (0.18) {47}.

Key pillars for this group	*Higher education and training, goods and labor market efficiency, financial market development, technological readiness, market size.*
Transition from Stage-2 to stage-3 (19 countries)	Argentina (-0.22) {64}, Brazil (0.00) {54}, Chile (0.50) {38}, Costa Rica (0.00) {53}, Croatia (0.77) {32}, Hungary (1.49) {9}, Kazakhstan (-0.61) {80}, Latvia (0.60) {35}, Lithuania (0.63) {34}, Malaysia (0.87) {28}, Mauritius (-0.14) {60}, Mexico (1.04) {22}, Panama (0.37) {44}, Poland (0.93) {27}, Portugal (0.57) {36}, Russia (0.05) {50}, Turkey (0.42) { 42}, Ukraine (0.42){43}, Uruguay (0.03) {51}.
Stage-3: Innovation-driven (30 countries)	Australia (-0.63) {82}, Austria (1.70) {6}, Belgium (1.08) {21}, Canada (0.48) {39}, Czech Republic (1.64) {7}, Denmark (1.08) {20}, Estonia (0.94) {25}, Finland (1.60) {8}, France (1.29) {17}, Germany (1.92) {2} Greece (0.21) {46}, Hong Kong (1.22) {18}, Ireland(1.32){16}, Israel (0.98) {23}, Italy (1.35) {15}, Japan (2.21) {1}, Rep. of Korea (1.82) {4}, Netherlands (0.97) {24}, New Zealand (0.10) {49}, Norway (0.71) {33}, Qatar (-0.77) {91}, Singapore (1.40) {12}, Slovak Republic (1.40) {14}, Slovenia (1.46) {11}. Spain (0.82) {30}, Sweden(1.71){5}. Switzerland (1.87) {3}, Trinidad and Tobago (-0.71) {89}, United Kingdom (1.48){10}, United States (1.35) {14 }.
Key pillars for this group	*Business sophistication, innovation.*

Notes: Countries' economic complexity indexes are in the (parentheses) and ranks among 124 countries are in the {curly brackets}.
Source: Adapted from WEF-The Global Competitiveness Report 2014-201, [25] and the Atlas of Economic Complexity [30]

As seen in Table-2, even high economic complexity does not necessarily mean an innovation-based economy in some cases (e.g. Hungary), economic complexity varies in accordance with the country production structures, in general. We use annual data modified from different sources as summarized in Table-3.

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Table 3: Variables, descriptions and sources

Series	***Variables***	***Descriptions***	***Sources***
		Dependent variable	
Real GDP per capita	*GDPPC*	Expenditure-side real GDP per capita. In 2005 US dollar prices.	[42],[43]
		Independent variables	
Economic complexity	*EC*	Economic complexity index. Converted into positive for logarithmic transformation	[30]
Human capital	*HC*	Index of human capital per person, based on years of schooling and returns to education	[42],[43]
Foreign direct investment	*FDI*	FDI inflows per capita. In 2005 US dollar prices.	[44]
Trade openness	*TROPEN*	Percentage share of the sum of imports and exports in GDP	[44]
Physical capital stock	*CS*	Capital stock at constant 2005 US dollars. Per capita	[42],[43]
Total factor productivity	*TFP*	At constant national prices as index, 2005=100	[42],[43]
Oil revenues	*OILR*	Net crude petroleum export value per capita, In 2005 US dollars. Indexed 2005=100	[44]
		Adjusted by the average tariff rates (most favored nation) on the oil.	[46]
Oil prices	*OILP*	International crude oil prices per barrel. In 2005 US dollar prices.	[47]

Method and Empirical Results

In order to determine appropriate analysis procedure to follow, first we checked each series for stationarity using the panel unit root tests of Levin-Lin-Chu [48] and Im-Pesaran-Shin [49]. The first one's null hypothesis of unit root, assumes common unit root processes while latter assumes individual unit root processes. Tests results (see Appendix-1) indicate that the variable have a mixture of orders of the integration, namely I(0) and I(1). Therefore, we follow panel autoregressive-distributed lag (ARDL) approach, proposed by Pesaran et al. [50], since there is no variable with I(2) that would likely generate spurious estimation. In this ARDL (p, q,...,q) framework, that *p* and *q* respectively refer to the lags of the dependent and independent variables, the dynamic panel regression model with respect to theoretical model in equation-1 can be specified for ARDL (1,1,1,1,1,1,1,1,(1)) version as in the equation-2:

$$\begin{aligned}\ln GDPPC_{it} &= \alpha_i + \lambda_i \ln GDPPC_{it-1} + \partial_{10i} \ln EC_{it} + \partial_{11i} \ln EC_{it-1} + \partial_{20i} \ln HC_{it} + \partial_{21i} \ln HC_{it-1} \\ &+ \partial_{30i} \ln FDI_{it} + \partial_{31i} \ln FDI_{it-1} + \partial_{40i} \ln TROPEN_{it} + \partial_{41i} \ln TROPEN_{it-1} \\ &+ \partial_{50i} \ln CS_{it} + \partial_{51i} \ln CS_{it-1} + \partial_{60i} \ln TFP_{it} + \partial_{61i} \ln TFP_{it-1} + \partial_{70i} (\ln OILR)_{it} \\ &+ \partial_{71i} \ln(\ln OILR)_{it-1} + \partial_{80i} (\ln OILP)_{it} + \partial_{81i} \ln(\ln OILP)_{it-1} + \varepsilon_{it}\end{aligned} \quad (2)$$

Related panel-ARDL error correction model can be expressed as in the equation-3:

$$\begin{aligned}D\ln GDPPC_{it} &= \omega_i \big(\ln GDPPC_{it-1} - \delta_{0i} - \delta_{1i} (\ln EC)_{it} - \delta_{2i} (\ln HC)_{it} - \delta_{3i} (\ln FDI)_{it} \\ &- \delta_{4i} (\ln TROPEN)_{it} - \delta_{5i} (\ln CS)_{it} - \delta_{6i} (\ln TFP)_{it} - \delta_{7i} (\ln OILR; \ln OILP) \big)_{it} \\ &- \theta_{11i} D(\ln EC)_{it} - \theta_{21i} D(\ln HC)_{it} - \theta_{31i} D(\ln FDI)_{it} - \theta_{41i} D(\ln TROPEN)_{it} \\ &- \theta_{51i} D(\ln CS)_{it} - \theta_{61i} D(\ln TFP)_{it} - \theta_{71i} D(\ln OILR; OILP)_{it} + \varepsilon_{it}\end{aligned} \quad (3)$$

Where *D* is the first-order difference operator and $\omega_i = -(1-\lambda_i)$ is the error correction term that is expected to be negative for adjustment to long-run equilibrium of *lnGDPPC* after a shock to its determinants. Here, the long-run coefficients are computed by following formulas:

$$\begin{pmatrix} \delta_{0i} = \dfrac{\alpha_i}{1-\lambda_i}; \delta_{1i} = \dfrac{\partial_{10i} + \partial_{11i}}{1-\lambda_i}; \delta_{2i} = \dfrac{\partial_{20i} + \partial_{21i}}{1-\lambda_i}; \delta_{3i} = \dfrac{\partial_{30i} + \partial_{31i}}{1-\lambda_i}; \\ \delta_{4i} = \dfrac{\partial_{40i} + \partial_{41i}}{1-\lambda_i}; \delta_{5i} = \dfrac{\partial_{50i} + \partial_{51i}}{1-\lambda_i}; \delta_{6i} = \dfrac{\partial_{60i} + \partial_{61i}}{1-\lambda_i}; \delta_{7i} = \dfrac{\partial_{70i} + \partial_{71i}}{1-\lambda_i} \end{pmatrix} \quad (4)$$

There are three different models to estimate the parameters: mean group (MG), pooled mean group (PMG), and dynamic fixed effect (DFE). Among these alternatives, Pesaran et al. [50] used the Hausman [51] test in order to determine the best-fitting model to apply. Following Pesaran et al. [50] the maximum lag order was chosen to 1 and all the model evaluations indicate the optimal lag of 1, based on the Schwarz Criterion. One of the advantages of PMG over the DFE is that it can allow the short run dynamic specification to differ among cross-section units. In addition, the Hausman test showed that there was no statistically difference between PMG and MG; hence, we adopted the PMG estimation procedure. PMG estimator tests both the short-run heterogeneity and the long-run homogeneity of the estimated coefficients in a panel framework. Because the PMG estimator assumes the long run parameters are the same across countries we clustered countries into five groups in order to generalize the results for the countries in the same group. Results are reported in Table-4[1].

Table 4: PMG estimation of the long-run determinants of the GDP per capita, one lag ARDL(1,1,1,1,1,1,1,1)

Independent variables	*Stage-1: Factor-driven economies (Group 1)*	*Transition from stage-1 to stage-2 (Group 2)*	*Stage-2: Efficiency - driven economies (Group 3)*	*Transition from stage-2 to stage-3 (Group 4)*	*Stage-3: Innovation - driven economies (Group 5)*
lnEC	0.117 (4.464)**	0.150 (2.515)*	0.169 (1.755	*0.195 (6.396)***	-0.994 (-7.167)*
lnHC	*2.058 (5.060)***	*2.398 (2.895)***	*3.588 (8.133)***	*0.979 (4.024)***	*2.301 (5.178)**

[1] Unreported results including alternative estimators can be obtained from the Author upon request.

lnFDI	-0.005 (-2.959)**	-0.048 (-3.220)**	-0.014 (-5.348)**	0.002 (2.716)*	0.017 (6.846)*
lnTROPEN	-0.169 (-3.702)**	1.241 (3.989)**	-0.006 (-0.227)	0.304 (7.285)**	-0.074 (-0.985)
lnCS	1.247 (15.415)**	3.585 (4.089)**	0.203 (3.019)**	1.666 (11.732)**	0.805 (17.332)**
lnTFP	0.046 (0.458)	0.917 (4.192)**	0.554 (5.628)**	1.074 (9.464)**	-0.123 (-0.596)
lnOILR	-0.007 (-0.031)	0.081 (2.520)*	0.109 (6.604)**	--	--
lnOILP	--	--	--	0.049 (1.173)	0.095 (3.221)**
No. of countries	9	12	16	19	30
Included obs.	144	192	256	304	480

Notes: t-statistics are in the (parentheses). * and ** denotes significance at 5% and 1% level, respectively. Model selection is based on the Schwarz criterion (SIC).

Results seen in the Table-4 confirm that relationships vary substantially across country clusters as expected. Estimations indicate that economic complexity (EC) increases GDP per capita for the group-1, i.e., the factor-driven countries. This is true for group 2 and 4, as well. EC does not have any significant effect on the GDPPC for group-3 countries while it negatively associated with the growth of the innovation-driven countries. Human capital (HC) is the strongest factor contributing to the growth for all groups of the countries in our model. The other one of the variables that has different effects over the country groups is foreign direct investment (FDI). It has slight but significant negative impacts for the first three group countries that can be interpreted as a symptom of the dense of the resource-seeking FDI activities. Rather, its impacts are positive on the last two groups. Again, with group-specific impacts, trade openness (TROPEN) has significant positive effects for only group 2 and group 4, i.e., the countries that are followers of efficiency and innovation-driven countries, respectively. These group countries seem to have export-led growth. As HC, capital stock

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(CS) raises the growth for all country groups. Coefficients for total factor productivity (TFP) are not significant for the factor-driven and innovation-driven countries, while it has positive impacts for the other groups. The variable that we control for the first three groups is oil revenues (OILR). It does not have significant effect for the factor-driven countries. Positive coefficients for group 2 and 3 are consistent with the transition processes of these countries. Not surprisingly, oil prices (OILP) has no significant effect for the countries that are in transition towards innovation. Moreover, OILP seem to be improving the growth performance of the innovation-driven economies.

Short-run coefficients from the estimations of the error correction model reveal that in general, the variables do not have significant effect in the short-run and the ones that have significant impacts remained with the same signs. TFP have positive effects for the country groups except group-2. Error correction terms estimated from the models indicate a slow adjustment to long-run equilibrium. The speeds of adjustments are relatively low (see Appendix-2, for all results). This is expected since many factors that we did not add to our model affect the adjustment process.

Conclusions

Growth performances of countries since 1970s reflect to the fact that what countries produce and export matter for their growth paths. Growth patterns have been differing considerably from those predicted by classical trade theories that assume perfect competition, comparative advantages based on resource endowments, constant returns to scale and perfect specialization. The awareness in the literature has been increasing that more complex and knowledge based production structure can help in having long-term economic growth. Moreover, foreign direct investment and multinational enterprises are affirmed to be fostering the technological deepening and production-upgrading dimension of the complexity. Starting from these premises, this paper purposed to explore how potential knowledge spillovers and economic complexity effect the growth in GDP per capita using the pooled mean group estimator and a dataset of 86 countries clustered into five groups in accordance with the key factors these countries are driven by. To this end, along with the conventional determinants of the economic growth, we also added foreign direct investment inflows per capita as a proxy of knowledge spillover, and economic complexity index that represents the capability of the overall economy to amass the knowledge and deep the technology.

There are several noteworthy findings of the study that, together with relative policy initiatives, can be summarized as followings: Economic complexity foster GDP per capita for the factor driven countries and both transition groups, namely the countries that are in a transition from factor-driven to efficiency-driven and from efficiency-driven to innovation-driven structures. These countries can record higher and sustainable growth rates as they transform their production contents that embody more knowledge and technology. This is also affirmed by the effect of the oil revenues found significantly negative for the factor driven countries. Foreign direct investment that we used as proxy of exogenous knowledge-spillover and technology transfer is found effecting the growth negatively for the efficiency-driven and backwards groups' countries. Even these proxy does not fit well with desired firm-level data we can still suggest these countries to create an investment environment that is attractive for efficiency-seeking investment as well, not only resource-seeking ones. For these, improvements in institutions and infrastructure will be among possible. The other possible reason is that the negative crowding-out effects of the foreign investment can be occurring. For this purpose, micro-level policies in order to stimulate the local entrepreneurial intentions can help reducing the replacement effects of the foreign direct investments.

Even the debates ongoing about the adequacy of the human capital measurements that are just taking the education into account and ignore the quality of education and other human capital indicators like health, science, research and development, etc., this study confirm that human capital is the strongest factor fostering the growth for all countries. Similarly, capital stock raises the growth for all country groups. In this context, traditional approach that formulates production as a function of physical and human capital fits well in these cases. For the factor-driven countries, negative coefficients of trade openness can be explained by excessive export of primary commodities. This evidence keeps the door open to the debates in the literature that trade gains will die out in the long-run for the countries that are excessively dependent on resource export. The variable, oil revenues, does not have a significant impact on the growth for the factor-driven countries. When considered low growth rates of these countries together with the excessive oil export, they seem to be suffering from over-concentrating in the oil extraction that has been investigated by numerous studies related to 'resource curse' and 'Dutch disease'.

Not surprisingly, oil prices (OILP) has no significant effect for the countries that are in transition towards innovation. Moreover, OILP seem to be improving the growth performance of the innovation-driven economies that proves the fact that these countries have production structures with low resource-dependence. In the innovation-driven production structures more contents comes from knowledge and technology not from those of physical capital and natural resources. This finding also has explanation to why the dramatic oil price changes do not reflect to sharp movements in the growths of developed countries as it happened in 1970s. Overall results reveal that technological deepening and upgrading based complexity have different effect over the country groups. Our model seems to be comporting best with the characteristics of the countries that are in a process of transition from efficiency to innovation. Most of these countries are specified as emerging industrial economies for their high shares of manufactures production and export in the world. Their export-led growth performances are supported by their structural changes towards more knowledge and technology complex production. These countries follow the innovation-driven countries as they are followed by the laggards, too.

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Appendix 1: Results of panel unit root tests

Variables	**Levin-Lin-Chu**		**Im-Pesaran-Shin**		**Inference**
	Individual intercept	*Indiv. trend & intercept*	*Indiv. intercept*	*Indiv. trend & intercept*	*5%*
Stage 1: Factor-driven countries (Cross-section 9; N:153)					
lnGDPPC	1.335	0.109	2.356	2.236	I(1)
lnEC	-1.124	-1.815*	-0.715	-0.979	I(0) or I(1)
lnHC	-4.089*	0.998	0.299	2.922	I(0) or I(1)
lnFDI	-1.723*	-1.976*	-1.730*	-2.203*	I(0)
lnTROPEN	0.163	-3.085*	1.451	-2.164*	I(0) or I(1)
lnCS	1.581	-4.841*	3.621	-0.281	I(0) or I(1)
lnTFP	-2.566*	-1.445	-0.977	0.385	I(0) or I(1)
lnOILR	0.857	-8.446*	3.201	-2.713*	I(0) or I(1)
Transition from stage 1 to stage 2 (Cross-section 12; N:204)					
lnGDPPC	-0.289	-1.465	2.312	-0.085	I(1)
lnEC	-4.111*	-4.205*	-2.670*	-3.110*	I(0)
*lnHC***	-0.797	2.696	0.350	5.506	I(1)
lnFDI	-2.425*	0.613	-2.271*	-0.368	I(0) or I(1)
lnTROPEN	-0.938	-2.707*	0.163	-0.233	I(0) or I(1)
lnCS	2.092	-2.379*	5.562	1.923	I(0) or I(1)
lnTFP	1.112	-0.763	1.960	0.523	I(1)

lnOILR	0.989	-9.753*	4.851	-4.288*	I(0) or I(1)
Stage 2: Efficiency-driven countries (Cross-section 16; N:272)					
lnGDPPC	2.358	-1.808*	4.920	-0.133	I(0) or I(1)
lnEC	-2.334*	-5.433*	-1.074	-2.748*	I(0) or I(1)
*lnHC***	-5.612*	0.341	-0.884	4.529	I(0) or I(1)
lnFDI	-3.967*	-4.323*	-4.033*	-0.905	I(0) or I(1)
lnTROPEN	-2.704*	-3.288*	-0.448	-0.844	I(0) or I(1)
lnCS	2.463	-3.411*	6.785	-0.264	I(0) or I(1)
lnTFP	-0.866	-0.693	0.826	0.512	I(1)
lnOILR	1.143	-9.261*	5.602	-4.951*	I(0) or I(1)
Transition from stage 2to stage 3 (Cross-section 19 ; N:323)					
lnGDPPC	-1.333	-0.849	2.818	0.577	I(1)
lnEC	0.136	-2.514*	1.206	-1.502	I(0) or I(1)
*lnHC***	-6.569*	-0.279	-1.487	3.132	I(0) or I(1)
lnFDI	-4.250*	-3.202*	-3.721*	-1.805*	I(0)
lnTROPEN	-1.429	-2.014*	0.171	0.361	I(0) or I(1)
lnCS	-5.251*	-3.242*	2.614	-0.569	I(0) or I(1)
lnTFP	-3.718*	-1.581	-0.094	0.659	I(0) or I(1)
lnOILP	1.117	-5.176*	1.825	-5.162*	I(0) or I(1)
Stage 3: Innovation driven countries (Cross-section 30 ; N:510)					
lnGDPPC	-7.396*	-4.915*	-1.907*	0.029	I(0) or I(1)
lnEC	-2.290*	-5.037*	1.730	-1.340	I(0) or I(1)
*lnHC***	-8.341*	0.618	-1.584	5.708	I(0) or I(1)
lnFDI	-4.670*	-4.753*	-4.437*	-1.693*	I(0)
lnTROPEN	-4.297*	-5.974*	-1.860*	-2.944*	I(0)
lnCS	-8.005*	-2.511*	-0.021	-0.116	I(0) or I(1)
lnTFP	-3.021*	-4.346*	0.337	0.888	I(0) or I(1)
lnOILP	1.519	-3.421*	2.271	-4.780*	I(0) or I(1)

Notes: Optimal lags are selected based on Schwarz information criteria (SC). First-difference unit roots test results, that are not reported in the table in order to save space, indicate there is not any I(2) variable. *Stationary at 5% level. **The unit root tests for the variable lnHC are applied with neither intercept nor trend according to its serial characteristics.

Appendix 2: PMG error correction model estimation and short-run coefficients

Independent variables	*Stage-1: Factor-driven economies*	*Transition from stage-1 to stage-2*	*Stage-2: Efficiency- driven economies*	*Transition from stage-2 to stage-3*	*Stage-3: Innovation- driven economies*
ECM	-0.335 (-4.398)**	-0.012 (-2.362)*	-0.117 (-2.442)*	-0.149 (-2.558)*	-0.116 (-2.952)*
DlnEC	0.035 (1.021)	-0.0007 (-0.013)	-0.129 (-2.042)*	-0.083 (-1.283)	-0.200 (-2.219)*
DlnHC	1.161 (0.477)	5.870 (1.955)	-2.483 (-1.187)	1.674 (1.357)	2.470 (1.160)
DlnFDI	-0.007 (-1.300)	-0.003 (-1.026)	0.004 (0.742)	0.004 (0.893)	0.004 (2.208)*
DlnTROPEN	-0.050 (-0.480)	-0.053 (-0.871)	0.0012 (0.029)	-0.008 (-0.179)	0.137 (3.467)**
DlnCS	0.643 (1.846)	0.731 (1.036)	1.642 (3.697)	1.215 (2.459)*	2.203 (5.161)**
DlnTFP	1.098 (6.864)**	0.897 (3.674)**	0.757 (2.912)	0.895 (4.664)*	1.106 (7.948)**
DlnOILR	-0.015 (-0.997)	0.165 (2.993)**	-0.006 (-0.572)	--	--
DlnOILP	--	--	--	-0.007 (-0.559)	0.008 (0.456)
Constant	-1.303 (-3.030)**	0.589 (0.529)	0.852 (1.500)	-2.231 (-1.603)	-0.189 (-2.875)**
Number of countries	9	12	16	19	30
Included observations	144	192	256	304	480

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Notes: t statistics are in the (parentheses). * and ** denotes significance at 5% and 1% level, respectively. Model selection is based on the Schwarz criterion (SIC).