A New Indicator of Economic Complexity to Guide Industrial Policies

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A Praxis submitted to

The Faculty of
The School of Engineering and Applied Science
of The George Washington University
in partial satisfaction of the requirements
for the degree of Doctor of Engineering

January 19, 2018

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Dedication

I would like to dedicate this work to my precious children Khalid, Hana and Wafa, hoping for a more prosperous future for them and their generation.

Acknowledgement

First and foremost I thank Allah, God the almighty.

I would like to thank my loving parents who raised me to value education, I especially thank my mom Hana'a AlZuhair for her endless support and encouragement throughout the years, and my father Dr. Moayyed AlQurtas for his insightful review and valuable critical discussions that helped me in no small part to shape this study.

I would like to also thank my friend Dr. Yaser Faquih for being the first to suggest that I look into the concept of Economic Complexity, and also thank my friend Mr. Khalid AlAseeri for his valuable feedback and comments on the research draft.

And I would like to thank my mentor and advisor His Excellency Mr. Ahmed AlHakbani for his support and guidance, especially during our time together at Saudi Exports Development Authority. Which included introducing me to Mr. Abdulaziz AlRasheed, who is now the deputy minister at the Saudi Ministry of Economy and Planning, whom I also thank for the insightful discussions and workshops with him and his project team from Harvard's Center for International Development.

I also have to thank my advisors Dr. Justin Eggstaff and Dr. Mohammed Islam for their guidance throughout the development of this praxis. And I also appreciate the support of the program directors Dr. Shahram Sarkani, and Dr. Thomas Mazzuchi.

Last and not least, I must thank my dear wife Sana AlAbdullah for her love and support during this journey, and above all her patience.

Abstract

A New Indicator of Economic Complexity to Guide Industrial Policies

The Economic Complexity Index (ECI) is an indicator that can be used by countries with undiversified economies to measure the success of their efforts to grow and diversify their exports, in order to sustain their economic development. However, the index is distorted for countries with undiversified economies that are heavily dominated by a few sectors, such as the case of Saudi Arabia with its oil sector. This study leverages lessons from the economic development literature, and focuses on the export-oriented growth in East Asia, and investigates the role of industrial policies that guide and coordinate the government interventions and initiatives. The study applies lessons from the Economic Complexity framework to overcome the limitation in the Economic Complexity Index. The study then utilizes data analysis techniques to develop a modified ECI utilizing a population-adjusted version of the Revealed Comparative Advantage to normalize countries' exports by their significance, and uses PageRank to capture the product space network information instead of the method of reflection used by ECI which is incompatible with the population-adjusted Revealed Comparative Advantage. The modified ECI can serve as a leading indicator that would allow tracking the success of the economic diversification efforts in countries whose economies are dominated by a few products or sectors, and thereby influence the development of their industrial policies.

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List of Acronyms

CID	The Center for International Development at Harvard University
ECI	Economic Complexity Index
FDI	Foreign Direct Investments
GDP	Gross Domestic Product
PPP	Purchasing Power Parity
RCA	Revealed Comparative Advantage
RPOP	Revealed Comparative Advantage – Per Capita Method
R&D	Research & Development
SOE	State Owned Enterprise
SITC	Standard International Trade Classification

1 Introduction

1.1 The Economic Complexity Index

In 2009, Cesar Hidalgo from the MIT Media Lab and Ricardo Hausmann from Harvard University's Kennedy School of Government published a paper in the Proceedings of the National Academy of Science, where they introduced the Economic Complexity Index (ECI). The paper which was named "The Building Blocks of Economic Complexity", showed the ECI to be highly correlated to income per capita of countries, and highly predictive of their future growth (Hausmann & Hidalgo, 2009). Since then, the ECI gained popularity in the development economics community, and attracted more multi-disciplinary researchers from Harvard and MIT, who worked on developing two editions of "The Atlas of Economic Complexity" which was published by MIT press, in addition to "The Atlas of Economic Complexity" website hosted by the Center of International Development at Harvard University (Center for International Development, n.d.-b).

1.2 The Case of Saudi Arabia

In 1970, Saudi Arabia released its first development plan, which constituted a transformational step in the then young country's economic history, the plan opened with a statement about the Saudi Economy that still echoes today (Central Planning Organization, 1970):

> Dependence on oil is the obverse of the advantages derived from the abundance of oil. Rapid expansion of oil production has provided the Kingdom with both government revenues and foreign exchange to finance development. However, economic growth in Saudi Arabia has been primarily a product of this one sector rather than the substantial development of agriculture, mining and manufacturing that is normally responsible for such growth. Moreover, it has led to the situation where further of the development of the economy over the coming decades is mainly dependent on growth in revenues and foreign exchange earnings from oil; a situation that must gradually be changed by diversifying production, exports, and sources of government revenue. (p. 21)

The relevance of the above statement can be clearly demonstrated through looking at the oil sector contribution to the Saudi Gross Domestic Product (GDP), and the correlation between oil prices and Saudi GDP in the following charts:

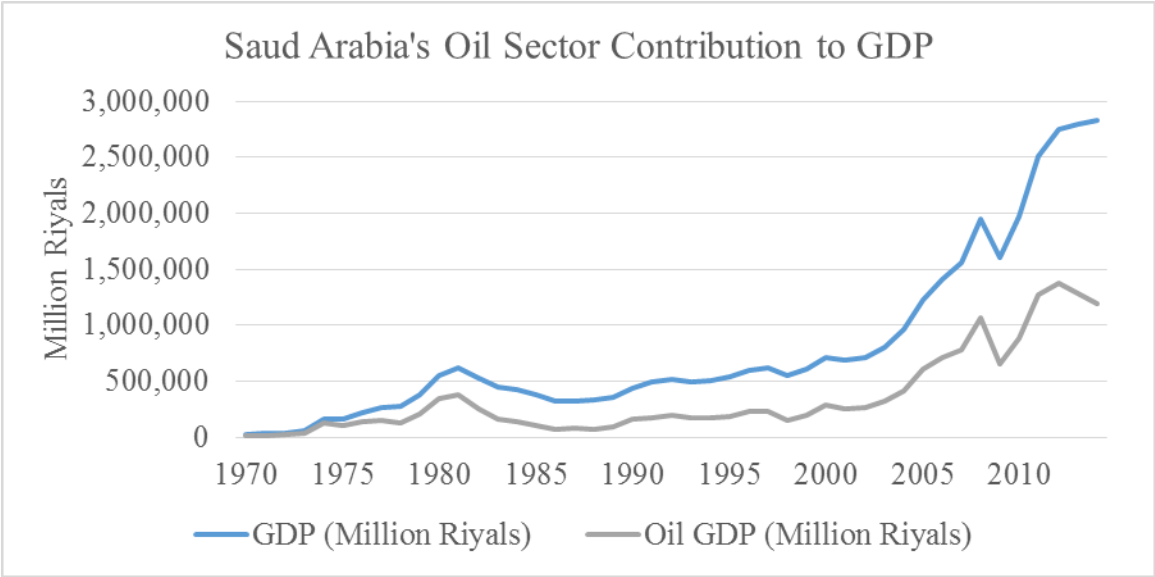

Figure 1-1 Shows the oil sector's contribution to GDP compared with the total GDP, over the years from 1970 to 2014. (Saudi Arabian Monetary Authority, 2016)

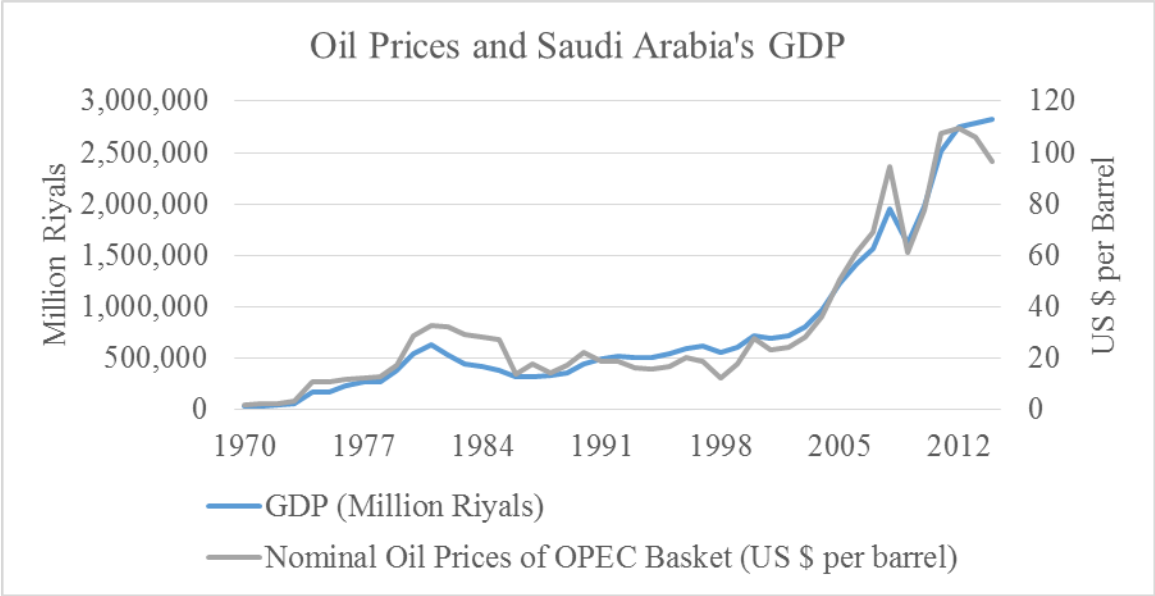

Figure 1-2 Illustrates the high correlation between nominal oil prices and Saudi Arabia's GDP, over the years from 1970 to 2014. (Saudi Arabian Monetary Authority, 2016).

As demonstrated in Figure 1-1 and Figure 1-2, for almost 50 years Saudi Arabia's economic development has relied heavily on oil exports with the oil sector's average contribution to GDP amounting to 43.7% for the years from 1970 to 2014, and with a correlation coefficient of 0.979 between oil prices and Saudi Arabia's GDP (Saudi Arabian Monetary Authority, 2016). While Saudi Arabia had considerably high growth overall, that led it to becoming the twentieth largest economy in 2015 in terms of GDP size according to the World Bank (2017), however it has also left Saudi Arabia's economy vulnerable to oil price cyclicality, with the economy shrinking with the fall of oil prices which is perhaps best illustrated by what happened in the 1980s, and to a lesser degree in the late 2000s as illustrated in Figure 1-2 (Vision 2030, 2017a; World Bank, 2017). There has been a long-standing realization in Saudi Arabia that an oil-based economy is unsustainable over the long-run, which was officially acknowledged as a stated policy objective of reducing the

dependence on oil through economic diversification since the 1970s, however it was not achieved through the development plans (Looney, 1992). Saudi Arabia achieved other objectives through its economic development plans, such as developing its physical infrastructure, but this did not result in attracting the expected private sector investments to sustain diversified economic development (Looney, 1992).

In 2016, Saudi Arabia announced its most ambitious plan for economic diversification as its vision for 2030 (Vision 2030, 2017b). This plan not only intends to remedy the Saudi's economy susceptibility to oil price volatility, but to build a diversified economy that can be sustained even if disruptive innovations displace oil as a major source of world energy or oil eventually runs out. Saudi Arabia's Vision for 2030 has outlined aspirational goals for the diversification of its economy, most importantly for this study are the following goals:

- "To move from our current position as the 19th largest economy in the world into the top 15" (Kingdom of Saudi Arabia, 2016, p. 47)
- "To raise the share of non-oil exports in non-oil GDP from 16% to 50%" (Kingdom of Saudi Arabia, 2016, p. 61)

1.3 Statement of the Problem

Countries with undiversified economies need a robust indicator to measure the success of its efforts to grow and diversify their exports, in order to sustain their economic development. The Economic Complexity Index (ECI) published by Harvard University's Center for International Development (CID) offers the most suitable indicator. Saudi Arabia is working on diversifying its economy beyond reliance on oil, and selected the ECI as one of the metrics to measure the success of the "National Industrial Development

Program", which was launched in 2017 as one of Vision 2030's realization programs (Vision 2030, 2017b). However, when reviewing Saudi Arabia's ECI ranking it appears to be heavily influenced by oil prices in a manner that can distort the results as illustrated in Figure 1-3.

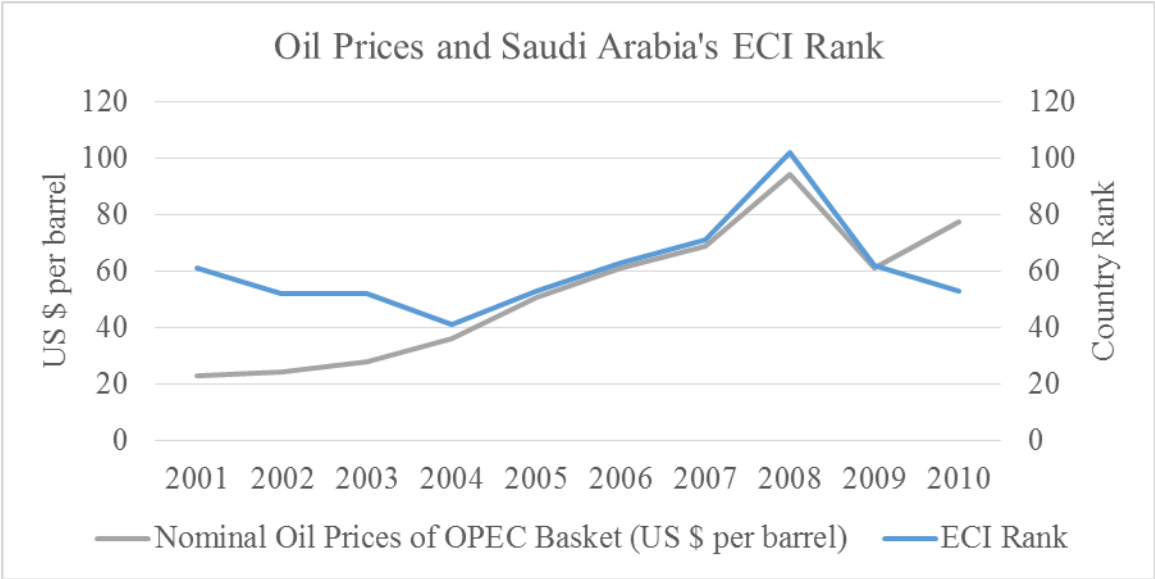

Figure 1-3 Illustrates the high correlation between oil prices and Saudi Arabia's ECI Ranking, as oil prices go up Saudi Arabia is ranked worse in ECI, the ranking axis was reversed for illustration purposes. (Center for International Development, n.d.-a; Saudi Arabian Monetary Authority, 2016).

1.4 Approach

Since the "National Industrial Development Program" will utilize the Economic Complexity Index (ECI) as an indicator of the success of the program, this study attempts to leverage the research on industrial policies and economic complexity to support the Vision 2030 goals of Saudi Arabia. This will include investigating the suitability of the ECI as leading indicator for industrial development, and developing a modified indicator

that is better suited for undiversified economies, including Saudi Arabia. As the choice of the indicator will eventually influence product development decisions, as countries such as Saudi Arabia work towards improving their ranking, and thereby their economic diversification; as indicated by the popular statement by Kaplan & Norton (1992) "What you measure is what you get" (Kaplan & Norton, 1992, p. 71).

1.5 Organization of the Document

This document is organized as six chapters. The first chapter is an introduction for the study, providing some background which highlights the motivation behind it, and states the problem and approach used, in addition to its limitations. The second chapter is a literature review of the relevant research body, including a section on industrial policies, a detailed example of the South Korean experience with industrial policies, and ends with an overview of the Economic Complexity framework. The third chapter outlines the specific research questions that the study will attempt to answer. The fourth chapter describes the research methodology and how the results will be evaluated. The fifth chapter will discuss and validate the results of the study. The sixth and final chapter will discuss the conclusions and recommendations based on this study.

1.6 Purpose

This study will investigate how the Economic Complexity framework can influence the selection of a robust indicator to track the progress of industrial policies to diversify economies. This will in turn support the efforts of the various government agencies, and facilitate their coordination. The study will use Saudi Arabia as a case study, to illustrate how this indicator can be utilized towards achieving economic diversification, and more specifically its export diversification efforts.

1.7 Scope and Limitations

This study will investigate the suitability of the ECI as an indicator to track the progress and success of industrial policies, using Saudi Arabia as a case study. It will modify the index to avoid the distortionary effect of oil price fluctuations on Saudi Arabia's ranking. The study will illustrate how the selected index can be used to influence specific industrial policies and decisions. However, this study does not give specific recommendations for which industries and products to promote, as this is beyond the scope of this study. This study is also limited to product exports, and does not cover service exports. The study will not provide detailed recommendations for Saudi Arabia's industrial policy, it will only highlight the importance of having one, and outline some of the success factors for industrial policies based on lessons from the East Asian model.

2 Literature Review

This study attempts to understand how governments can contribute to economic growth and diversification, and more specifically through exports growth. It will provide a discussion on the different views of the role of government in economic development and the need for industrial policies and how they were instrumental in the East Asian miracle, then provide an account of South Korea's experience with industrial polices as a leading successful example, and conclude with a discussion on the Economic Complexity framework and the role that export diversification plays in economic development.

2.1 Industrial Policy

This section will start with a brief outline of the classical views on the role of governments in economic development, then provide an argument for the need of an industrial policy, followed by giving a brief overview of the different types of industrial policies. It will also provide a high-level introduction into the experiences of several East Asian countries with industrial policies, and outline some success factors based on the research that covers their experiences. The section will also discuss industrial policies' role in creating export-oriented growth. Finally, the section will conclude with some specific criticisms of industrial policies regarding the creation of clusters, stimulating innovation and harnessing competition, and attempt to address them and show the complementarity of industrial policies to all of them.

2.1.1 Government Role in Economic Development

There has been a lot of research in the economic literature to explain economic growth, and especially periods of accelerated development, however there are no easy answers or a single theory to explain all episodes of the frequently occurring growth

acceleration, as some researchers found that between 1957 and 1992 there were 83 episodes of sustained economic growth of at least 3.5% for at least 8 years (Hausmann, Pritchett, & Rodrik, 2005). When it comes to the government role in leading or stimulating economic growth, the literature differentiates between two broad schools. The first focuses on free market forces and has its origins in Adam Smith's invisible hand, and views the role of government in economic development to be simply stepping aside and leaving the economy to market forces (Stiglitz, 1996). The second school is on the opposite extreme, and views economic development to be a government function that is conducted through central planning, yet this school failed to have any clear successful countries that followed its model, and therefore has largely faded away (Stiglitz, 1996).

The free market school is perhaps best represented by the "Washington Consensus", which was coined to describe the prevailing view of Washington DC based international institutions, including the World Bank and the International Monetary Fund, in addition to the central economic agencies of the U.S. government, which focuses on financial and trade liberalization, privatization and deregulation; however the term is now widely used to describe neoliberal and market fundamentalist policies (Williamson, 2000). Countries that attempted to implement "Washington Consensus" policies have failed to achieve the economic growth it promised, thus giving further evidence for the argument that the invisible hand controlling the market does not exist in the real world or it is paralyzed, (B. Greenwald & Stiglitz, 1987; Mukand & Rodrik, 2005).

Therefore, it is easy to conclude that the reality is different from what both schools suggest, as researchers found that almost all industrializations were through mixed economies, that did not strictly follow one of these schools, as they were countries with

governments that intervened and played an active role in the economy to complement markets and protect infant industries (Chang, 2003; Stiglitz, 1996).

2.1.2 The Need for an Industrial Policy

While both schools on either end of the government intervention spectrum failed to provide a sure success recipe for economic development, as discussed in the previous sub-section 2.1.1; various countries have achieved success through policy experimentation, and some even became regional role models for neighboring countries to follow their examples, while countries that have no successful regional model to follow usually struggled (Mukand & Rodrik, 2005). Research has shown that government policies can help countries get out of having a low-tech equilibrium, when they lack the economies of scale to develop the intermediate products domestically; in these situations government incentives can help in stimulating the economy to move into a new high-tech equilibrium, through developing new sectors that the market forces fail to cultivate on their own (Rodrik, 1996). Researchers have found that comparative advantages of nations are dynamic and not static, therefore continuing to focus efforts only on exploiting existing comparative advantage is suboptimal (Cypher & Dietz, 1998; Bruce Greenwald & Stiglitz, 2006). Focusing on the development of the industrial sector through industrial policy can be beneficial for the economy as a whole, as it has the maximum potential learning spillovers to the traditional sectors, even if the country does not develop a comparative advantage in the industrial products (Greenwald & Stiglitz, 2006). Since it is difficult to predict the comparative advantage of a country in new products that were never manufactured there before, entrepreneurs that pioneer producing them will discover their cost structures through learning by doing (Hausmann & Rodrik, 2003). Since other firms can imitate the

pioneers without enduring the discovery process and costs, and they can do it more efficiently through the spillover learning from the pioneers' experiences and mistakes, therefore the potential pioneers can get discouraged from entering into such economic activities and prefer to be followers instead; this in turn can cause economies to stagnate and get stuck, unless their governments intervene to support pioneering firms that provide positive externalities (Hausmann & Rodrik, 2003; Wagner & Zahler, 2015; Wu, Ma, & Shi, 2010). This support can be a form of the widely used infant industry protection, which traditionally aims to allow the new industries to grow and no longer require protection; however if conducted properly and targeted towards industries with high positive externalities and learning spillover effects, then it can potentially allow the economy to have a faster growth trajectory even if these infant industries never fully grow up and continue to consume government support (Stiglitz, 2015).

2.1.3 Types of Industrial Policy

The coordination of government interventions to change the economic structure towards improving the manufacturing sectors in order to stimulate higher economic growth can be called an "industrial policy" (Pack, 2000). Some researchers differentiate between two types of industrial policies, vertical industrial policy which targets specific industrial sectors with government intervention, and horizontal industrial policy which aims at improving the overall business environment (Holz, 2011; Lazzarini, 2015). This study focuses on the first type when discussing industrial policies, as horizontal industrial policies are less controversial among economists and are not suspected of introducing market distortions, as opposed to the vertical industrial policies that target specific sectors (Lazzarini, 2015). However, while industrial policies are widely debated and inherently

risky, they appeared to have succeeded in creating the East Asian Miracle (Rodrik, 1996; Stiglitz, 1996).

From an engineering management perspective, industrial policies deserve further research as a strategic management topic, affecting the competitive advantage of firms (Lazzarini, 2015). In addition, industrial policies have a great impact on innovation and entrepreneurship, technological catch-up, technology transfer and commercialization, and capability accumulation, which have been addressed in both the engineering management and economics academic literature; including a number of articles focused on the experiences of the East Asian countries (Autio, Hameri, & Nordberg, 1996; Liu, 1998; Lynn, 2000; Martinsons, 1998; Stiglitz, 2015; van der Heiden, Pohl, Mansor, & van Genderen, 2016a).

2.1.4 East Asian Miracle

Perhaps the most successful countries in conducting industrial policies were those in East Asia, as they succeeded in playing a positive role to promote industrial diversification and achieved high economic growth, they are therefore are called the East Asian miracle countries and include Japan, South Korea, and Taiwan among other countries (Amsden, 1994; Lall, 1994; Stiglitz, 1996). While some economists from the free market school attempted to attribute the success of the East Asian model to following the Washington Conesus recommendations, the reality is different as proof of active government intervention is prevalent, therefore these explanations seem to be a simple case of confirmation bias (Amsden, 1994; Nickerson, 1998).

Instead, economists find several explanations why these industrial policies worked, which are summarized as the following success criteria:

1- Complementing, regulating and enhancing existing markets in addition to creating new markets, rather than replacing them (Rodrik, 1996; Stiglitz, 1996)
2- Moving the economy to a high-tech equilibrium, through experimentation to discover the country's dynamic comparative advantages (Rodrik, 1996).
3- Accumulating human capital through investments in education (Stiglitz, 1996).
4- Attracting foreign investments that are conducive for technology transfer (Stiglitz, 1996).
5- Adapting and learning from mistakes, as the economies evolve and mature, governments interventions and policies must change accordingly (Stiglitz, 1996).
6- Giving and withdrawing support from firms based on their performance (Pack, 2000).
7- Focusing on future oriented analysis of their dynamic comparative advantage, as it can facilitate economic growth beyond what free trade can offer (Cypher & Dietz, 1998).
8- Hiring government employees that possess superior technical and analytical capabilities (Lazzarini, 2015).
9- Directing support towards export-oriented industries, and promoting exports (Stiglitz, 1996).
10- Enhance cooperation between industry and government agencies (Stiglitz, 1996).

2.1.5 Export-Oriented Growth

Industrial policies in the East Asian model focused heavily on export promotion, while in Latin America in the 1960s and 1970s focused on import substitution industrialization (Hausmann & Rodrik, 2003). And where the export-oriented growth of East Asia largely succeeded, import substitution industrialization is largely considered a failure, and by the 1970s a consensus emerged in favor of export promotion over import substitution policies, despite the conclusion by some researchers of the lack of concrete evidence of causality between export promotion strategies and growth (Jung & Marshall, 1985; Pack, 2000).

The export-oriented industrialization in the East Asian model encouraged competition not only in protected domestic markets, but in international markets as well (Pack, 2000). And since the majority of the emerging economies' domestic markets are too small to reap the benefits of competition on firm performance, therefore the industrial policy should force firms with targeted support to compete in international markets (Aghion et al., 2015).

While the inward and outward orientation of the industrial policies of the two models are not the only determinants of success, as the East Asian model was also more balanced in providing promotional support and having the discipline to withdraw it when needed (Hausmann & Rodrik, 2003). However, the outward focus on export promotion played a major factor, as it provided governments with clear performance criterion to offer and direct their support, as success in competing with foreign products in international markets meant that these firms were efficient and more economically viable (Stiglitz, 1996). In addition, export orientation provides other spillover benefits from operating in

international markets, these generally include having higher levels of R&D, innovation and product differentiation that are required to stay competitive (Cruz-Cázares, Bayona-Sáez, & García-Marco, 2013).

2.1.6 Industrial Policies and Clusters

Some criticism of industrial policy seems to be directed at vertical industrial policies that target specific sectors, rather than horizontal industrial policies, as in the literature discussing the creation of clusters of interconnected firms which compete amongst themselves, and benefit from linkages that complement each other in close geographical vicinity which maximizes spillover effects (Porter, 2000). These critics argue that the government's role in the support of clusters should not be attempting to create new ones without competitive assets to build on, rather it should focus its policy efforts on nurturing emerging and existing clusters and allow them to develop and upgrade as the economy matures (Porter, 2000). However, such policies can be labeled as horizontal industrial policies, and while they are aimed towards supporting clusters that exploit existing comparative advantages, they can be further complimented with vertical industrial policies that provide support and subsidies to specific firms or industries within clusters to maximize their positive externalities on neighboring firms (Lazzarini, 2015; Rodríguez-Clare, 2007). Therefore, cluster promotion should not be considered an alternative to industrial policy, rather it should be one component of it, as it complements several of the success criteria outlined previously, as successful clusters tend to be very attractive for foreign direct investments and promote exports, in addition to playing a positive role in enhancing cooperation between government agencies and industry (Porter, 2000).

2.1.7 Industrial Policies and Innovation

While free market advocates claim that it is more conducive for innovation, researchers have shown that import restrictions or export subsidies in some contexts can improve the innovation climate, especially if they are directed to support leaders and pioneers in specific industries and products (Hausmann, Hwang, & Rodrik, 2007). Furthermore, transformative innovations and inventions are sometimes the result of the free market competition, and sometimes achieved by government financing and even monopolies as exemplified by the role that Bell Labs played in introducing the information theory, the C programming language and the UNIX computer operating system (Stiglitz, 2015).

2.1.8 Industrial Policies and Competition

Another criticism directed towards industrial policies is that they diminish competition, as firms start to depend on government support, and allows the government to pick winners (Aghion et al., 2015). However, these effects can be avoided through the design of a proper industrial policy, accordingly governments should avoid "picking winners" to provide with targeted support (Greenwald & Stiglitz, 2006). And research has shown that industrial policies that offer government support to more competitive sectors, and foster higher levels of competition and entrepreneurship have greater success, and therefore a positive impact on productivity and firm performance when the support is given in the form of subsidies or tax breaks (Aghion et al., 2015). In addition, outward-oriented industrial policies, which force firms to compete through exporting in international markets mitigate these risks, as firms become subjected to tougher competition with specific performance targets (Aghion et al., 2015; Chang, 1993).

2.2 South Korea's Experience with Industrial Policies

The previous section 2.1 gave an overview of industrial policies, and how they were instrumental in allowing the East Asian Miracle countries to achieve export-oriented growth, this section will take South Korea as a specific case for further investigation.

2.2.1 Dynamic Comparative Advantage

When South Korea started on its amazing economic development journey, it went against the Washington Consensus and was even declined loans from the World Bank (Chang, 1993; Williamson, 2000). As South Korea ignored the free market doctrine that advocated that it should focus on exploiting its static comparative advantage, which was growing rice and instead focused on industrialization (Greenwald & Stiglitz, 2006; Stiglitz, 2011). As Stiglitz (2011) puts it:

"Had Korea allowed market forces on their own to prevail, it would not have embarked on its amazing development successes. Static efficiency entailed that Korea produced rice; indeed the country might today have been among the most efficient rice farmers - but it would still be a poor country.": (Stiglitz, 2011, pp. 232–233).

South Korea implemented trade restrictions which enabled it to develop its industrial sector, which has higher economic spillovers to other sectors, and benefited from learning by doing to understand and develop its dynamic comparative advantage (Greenwald & Stiglitz, 2006). South Korea's success in its industrial policies allowed its comparative advantage to eventually change from agriculture to industry, and therefore no longer required the same level of government intervention, and was redirected to maximize learning spillovers and innovation (Stiglitz, 2015).

2.2.2 Industrial Upgrading

South Korea's industrial policy focused on import substitution in the early 1960s, following in the footsteps of many governments that initiated such policies since the 1950s, based on the perception that industry was superior to agriculture (Mah, 2007; Pack, 2000). South Korea's first five year plan from 1962 to 1966 focused on basic industries, which included cement, fertilizers and oil refining (Chang, 1993). The focus of South Korea's industrial policy changed in 1964 to focus on exports, starting with labor intensive light industries where South Korea had a comparative advantage in exports, and then during the second five year plan from 1967 to 1971 it designated different priority sectors of chemicals, steel and machinery (Chang, 1993; Mah, 2007). In the third and fourth five year development plans, spanning the period from 1972 to 1981, South Korea's industrial policy had its heavy and chemical industries (HCI) drive, which targeted six strategic industries, adding non-steel metals, shipbuilding, and electronics, to the second five year plan's three targeted industries (Chang, 1993; Mah, 2007). In the fifth and sixth five year plans South Korea continued to target sectors, however its industrial policy became more horizontal in scope and encouraged R&D, and introduced a number of high-tech industries, during the period of 1982 to 1991 (Chang, 1993; Mah, 2007). South Korea also created the Economic Planning Board, which was led by the deputy prime minister and in charge of both government planning and budgeting, thus eliminating the traditional conflict between the ministry of finance which focuses on short-term stability and the ministry of industry that focuses on long-term investments (Chang, 1993).

2.2.3 Export Promotion

South Korea's focus on export promotion was popularized with a promotional campaign and the slogan "Export Number One", and evident through the established Korea Trade-Investment Promotion Agency (KOTRA), and holding monthly export promotion meetings in the "export situation" room, which was next to the Minister of Commerce and Industry's office, and of which South Korea's president received briefings about the quarterly export target achievement (Mah, 2007; Westphal, 1990). Government subsidies and support given to firms in infant industries was based on both export potential and based on performance and meeting export targets, this was facilitated through strictly mandated regular reporting to the government, which provided further information that facilitated informed decision making to guide future interventions (Chang, 1993; Lee, 1997).

When South Korea changed its focus from import substitution to export promotion it built on top of its earlier policies, rather than dismantling them, as it continued to protect infant industries supported during the import substitution regime, while promoting exports (Lee, 1997). South Korea also capitalized on its earlier learning-by-doing during the previous period, and exploited its import substitution industries for intermediate inputs to its export oriented industries, and its experiences as a military contractor in South Korea and Vietnam for the success of its later major construction contracts (Westphal, 1978). This achieved high complementarity of its inward and outward focused strategies and long-term focus on development and industrial upgrading, through utilization of a wide array of mechanisms including utilizing foreign direct investments to facilitate technology transfer and enforce local content provisions in major projects (Chang, 1993; Westphal, 1990).

In that vein, South Korea implemented “infant industry export”, through subsidies and price discrimination; this helped Korean industries to learn by doing and mature over time with the phased liberalization that offered producers clear market expectations of when and how markets will be opened up to imports (Lee, 1997). And while South Korea protected its industries from foreign competition, it encouraged domestic competition between them, while stepping in at times to protect against what it considered excessive competition (Chang, 1993; Lee, 1997).

2.2.4 Learning from the South Korean Model

South Korea’s industrial policy was managed by highly competent public agency staffed with skilled bureaucrats, and since South Korea has an ethnically homogenous population this helped further reduce the political considerations that can distort the industrial policy (Hodler, 2009; Mah, 2007). South Korea’s government agencies were sometimes better informed and more skilled than their counterparts in the private sector (Chang, 1993). These characteristics allowed South Korea’s industrial policy to be adaptable, to respond to changing market conditions, and benefit from the earlier learning by doing (Mah, 2007). The South Korean government took a phased approach, as it provided the infrastructure required for economic development, and supported the strategically important industries by targeting only a small number of industries at a time (Mah, 2007; Westphal, 1990).

However, it is important to note that the mechanisms and incentives that South Korea utilized during its economic development have mostly been prohibited or regulated by the World Trade Organization (WTO), therefore it would be challenging for other countries to replicate its experience under the current WTO system (Mah, 2007, 2010).

2.3 Economic Complexity and the Product Space

This section will turn to the Economic Complexity literature to investigate how countries can use it to direct their industrial policies in the current globalization era, and how they should select specific industries and products to provide targeted support.

2.3.1 Export Diversification

While the classical economist David Ricardo advocated that countries should specialize in their exports to exploit their comparative advantage, researchers have found a robust correlation between export diversification and level of income in countries (Cadot, Carrère, & Strauss-Kahn, 2011). Additionally, the more sophisticated the goods that a country produces, the better it performs in economic growth, therefore policies should focus on industrial upgrading of products to promote diversification into higher quality products (Hausmann et al., 2007). Countries achieve this diversification into higher sophistication of products through the accumulation and combination of the accumulated capabilities (Hausmann & Hidalgo, 2009). These capabilities are implicitly represented by the product space of a country, as each product requires a specific set of capabilities to produce it (Hausmann & Hidalgo, 2009).

2.3.2 The Product Space

The product space is the network of the export products, with products visualized as being interconnected based on their similarity, which is measured through the proxy of their co-exportation likelihood, and therefore implies that they share some of the capabilities required to produce them (Hausmann & Hidalgo, 2011). The product space network is illustrated in the following figure:

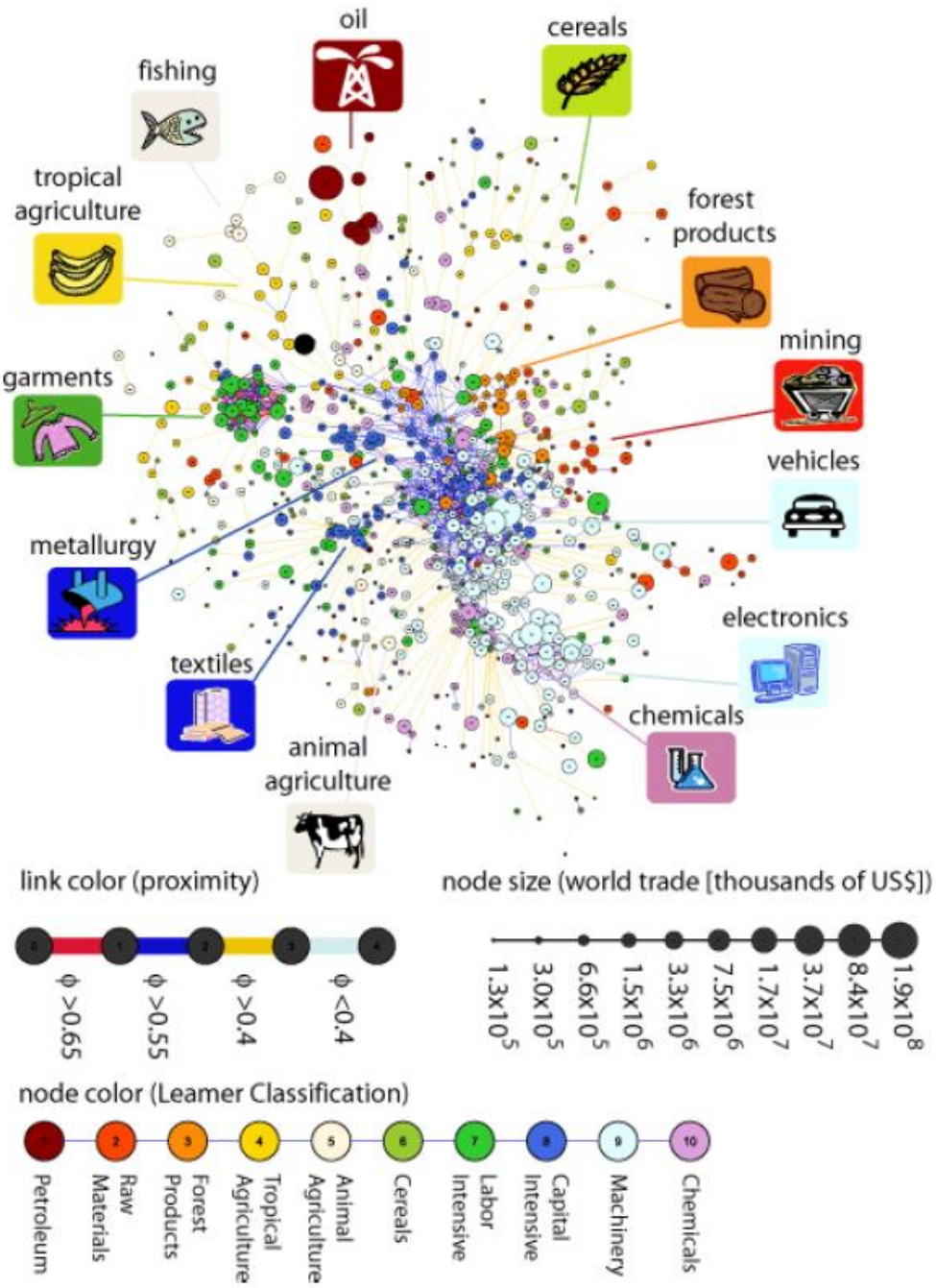

Figure S7. Final version of the product space in which node size represents its world trade, node color shows its classification as proposed by Leamer and link color indicates a range in the proximity values.

Figure 2-1 The Product Space (Hidalgo, Klinger, Barabási, & Hausmann, 2007)

Countries that have a good product space network, means that they currently produce a large number products or can potentially produce a large number of adjacent products, utilizing a combination of the capabilities required to produce the nearby products (Hausmann & Hidalgo, 2011). This explains why some countries get stuck in their economic diversification and growth efforts, since due to their current product space, they cannot easily move into other products due to their low diversity of capabilities, which does not benefit a lot from adding other capabilities that do not synergize with the existing set to introduce new products (Hausmann & Hidalgo, 2011).

2.3.3 Economic Complexity Index

Hausmann & Hidalgo (2009) introduced the Economic Complexity Index (ECI) to measure the level of sophistication of the country's production capabilities. This is achieved through the method of reflections that combines information from the export diversification of a country and the ubiquity of its exports (Hausmann & Hidalgo, 2009). To control for the size of the economy the Economic Complexity Index uses the Revealed Comparative Advantage (RCA), which normalizes the country's export volume of a product with the size of its exports, compared to the total volume of the world's exports of that product compared with the total world trade volume (Hausmann & Hidalgo, 2009). The RCA is expressed as follows:

$$\mathrm{RCA}_{cp} = \frac{X_{cp} / \sum_c X_{cp}}{\sum_p X_{cp} / \sum_p \sum_c X_{cp}} \qquad (2\text{-}1)$$

Where X_{cp} represents how much country c exported of product p, and an RCA value of 1 represents the threshold of whether a country exports its fair share of the world market of that product (Hausmann & Hidalgo, 2009).

Through creating a bipartite network connecting countries to products, an adjacency matrix is defined as $M_{cp} = 1$ where $RCA_{cp} \geq 1$, and $M_{cp} = 0$ otherwise (Hausmann & Hidalgo, 2009). The diversification of a country is then defined as number of products that it exports more than its fair share of in the world markets, and calculated as the sum of M_{cp} for all products, this is represented as the following:

$$k_{c,0} = \sum_{p} M_{cp} \tag{2-2}$$

and the ubiquity of a product is number of countries that export more than their share fair of that product in world markets, and calculated as the sum of M_{cp} for all countries, this is represented as follows:

$$k_{c,1} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} k_{p,0} \tag{2-3}$$

the average ubiquity that country c exports is defined as follows:

$$\mathrm{k_{p,0}} = \sum_{c} M_{cp} \tag{2-4}$$

and the average diversification of countries exporting product p is defined as follows:

$$k_{p,1} = \frac{1}{k_{p,0}} \sum_{c} M_{cp} k_{c,0} \tag{2-5}$$

this process is then repeated using their method of reflections to get the generalized measures of diversification, which incorporates the information of the ubiquity of products and the level of diversification of the countries that produce them (Hausmann & Hidalgo, 2009, 2011). The index shows that while two countries can export the same number of products, the country that exports products similar to more diversified countries is ranked higher than the country that exports products that are similar to less diversified countries (Hausmann & Hidalgo, 2009).

The Economic Complexity Index was tested and proved to highly correlate with the initial level of income per capita and countries, and to be predictive of long-term future economic growth, and even outperforms other similar indices (Hausmann & Hidalgo, 2009).

2.3.4 Capability Accumulation

Governments have various ways of introducing new capabilities and thereby products, they can utilize industrial policies can create state owned enterprises (SOEs) to stimulate expansion in the product space, through both backward linkages or forward linkages, and the performance of SOEs would be judged not solely on their financial performance but also on their positive externalities and spillover effects (Holz, 2011). Although this form of government intervention has often been called state-capitalism and performed poorly, governments can intervene through more modern forms than the traditional SOE model, including having minority or even majority shares in a publicly listed company, or through strategic involvement through state-owned banks, these various models have performed differently in various countries and industries, and a significant share of them were successful (Musacchio, Lazzarini, & Aguilera, 2015).

Another popular method of accumulating capabilities is attempting to attract foreign direct investments (FDI), research has shown that FDI leads to productivity spillovers and through backward linkages, however when these firms have partial foreign ownership it leads to even higher productivity spillovers (Javorcik, 2004). In order to achieve successful international technology transfer through FDI, countries must have absorptive capacity allowing them to utilize and exploit the technologies commercially, this takes place formal mechanisms such as contractual clauses in addition to other various

informal mechanisms (Ernst & Kim, 2002; van der Heiden, Pohl, Mansor, & van Genderen, 2016b). The absorptive capacity of countries required to assimilate foreign technology significantly increases with the percentage of population aged 20 to 24 that are enrolled in higher education, and with having high levels of technological resources through R&D spending (Cruz-Cázares et al., 2013; Gousty, Pigeyre, & Thieblemont, 1984).

2.3.5 Economic Complexity Implications on Industrial Policy

Industrial policy should focus on promoting industries that are close to the existing capabilities within a country, thus moving to close by opportunities in the product space to maximize the potential of success, while further jumps away in the product space are more challenging to succeed (Hidalgo et al., 2007).

Furthermore, since export diversification is an important policy indicator, the Economic Complexity Index can serve as method to track and manage level and sophistication of a country's economic and export diversification efforts, and use the product space to guide its selective interventions (Cadot et al., 2011; Hidalgo et al., 2007).

3 Contribution

This study contributes to the body of knowledge through applying lessons from industrial policies and the Economic Complexity framework towards developing an leading indicator to measure the success of industrial policies. Accordingly, it discusses the suitability of the Economic Complexity Index (ECI) to track the progress and success of undiversified countries' economic and export diversification efforts, and attempts to discover any limitations with it and how it can be modified to address them, using Saudi Arabia as a case to test the modified index.

3.1 Research Question

The question can be framed as follows:

Is the Economic Complexity Index (ECI) suitable for tracking the progress of economic diversification efforts, and can it be modified to overcome its limitation, which is the influence of price fluctuations on the ranking of countries that are dominated by a few sectors?

The question will address Saudi Arabia's progress economic diversification as represented by its ranking in ECI. This will investigate how and why oil price fluctuations impact Saudi Arabia's ranking, and how another index can be constructed based on the lessons from the Economic Complexity framework while avoiding this limitation for undiversified economies, including Saudi Arabia. This will be tested with the following hypothesis:

Hypothesis I

A modified version of the Economic Complexity Index (ECI) outperforms it in terms of correlation with income per capita.

In order to test this hypothesis, this study will investigate several modifications for the ECI, based on lessons from the literature review and ensuring its compatibility with Saudi Arabia's economy. The null hypothesis and alternative hypothesis will be formulated as follows:

- H_0: The Economic Complexity Index (ECI) has a higher correlation with GDP per capita better than the modified Economic Complexity index.
- H_1: The modified index has higher correlation with GDP per capita better than the Economic Complexity index (ECI).

This will be tested through linear regression on historical data, with the log of GDP per capita as the dependent variable, and using the ECI and its variants alternating as predictors.

Hypothesis II

A modified version of the Economic Complexity Index (ECI) outperforms it as a predictor for future long-term economic growth.

In order to test this hypothesis, this study will investigate several modifications for the ECI, based on lessons from the literature review and ensuring its compatibility with Saudi Arabia's economy. The null hypothesis and alternative hypothesis will be formulated as follows:

- H_0: The Economic Complexity Index (ECI) predicts economic growth better than the modified Economic Complexity index.

- H_1: The modified index predicts economic growth better than the Economic Complexity index (ECI).

This will be tested through linear regressions on historical data, with the long term economic growth as the dependent variable, and using the ECI and its variants alternating as predictors, while controlling for the initial level of development of the country, through adding the initial GDP per capita as an independent variable. The long term economic growth will be defined as the average economic growth over periods of 5, 10, and 20 years.

4 Methodology

This study will utilize the Economic Complexity framework to construct a new index and test it through analyzing Saudi Arabia's ranking, as a case for an undiversified country whose economy is dominated by a few sectors. This will include reviewing the evolution of Saudi Arabia's product space and the change in its ranking in the Economic Complexity Index, and the adverse impact that oil price fluctuations causes them. Then the study will introduce several alternatives for the ECI, through modifying it, and constructing different indicators based on the lessons provided by the Economic Complexity framework.

4.1 Research Goals

This study attempts to provide a robust alternative for the Economic Complexity Index, to be used as a lead indicator to track the success of the economic diversification efforts for countries whose economies are dominated by a few products or sectors, without being adversely impacted by price fluctuations in these sectors, such as the impact of oil price fluctuations on the Saudi Arabian economy. The proposed indicator needs to have comparable performance in predicting long-term economic growth, in addition to a strong correlation with income per capita. To maximize the usefulness of the indicator, it should be an international ranking indicator, and not a Saudi Arabia specific index, as economic diversification is a moving target since other countries continue their development efforts.

4.2 Research Method

The study uses data analysis and network analytics techniques to construct an international ranking index for Economic Complexity from the world trade data. The data for the rankings were prepared and analyzed through building an R program using RStudio®. The study will start by reconstructing the ECI, and using it to predict initial GDP

per capita and future economic growth using linear regressions. The study will then proceed to modify the index through trial and error, and test each new version to ensure that it retains its predictive power while overcoming the influence of oil prices over it. The study will also review the rankings produced by the new version of the index and compare them to the original ECI rankings, to ensure that they hold valuable information about the economic development and diversification of the ranked countries. The linear regression results will be evaluated and compared through their adjusted R2 scores while making sure the coefficients are significant, to ensure that the modifications maintain the validity of the original ECI. Then the results of the new rankings will reviewed, to make sure that they make sense and rank developed and diversified economies higher than developing economies. If the modified ECI passes both of these tests, the study will make sure that this solves the problem for undiversified economies by testing it on Saudi Arabia's ranking and comparing it to fluctuating oil prices as presented in Figure 1-3. Finally, residual analysis will be performed on the regression models to ensure the linearity of the regressions, through validating that the residuals are normally distributed and homoscedastic. The regression results will be presented using a standard organization used by Hausmann & Hidalgo (2009) as described in Figure 4-1:

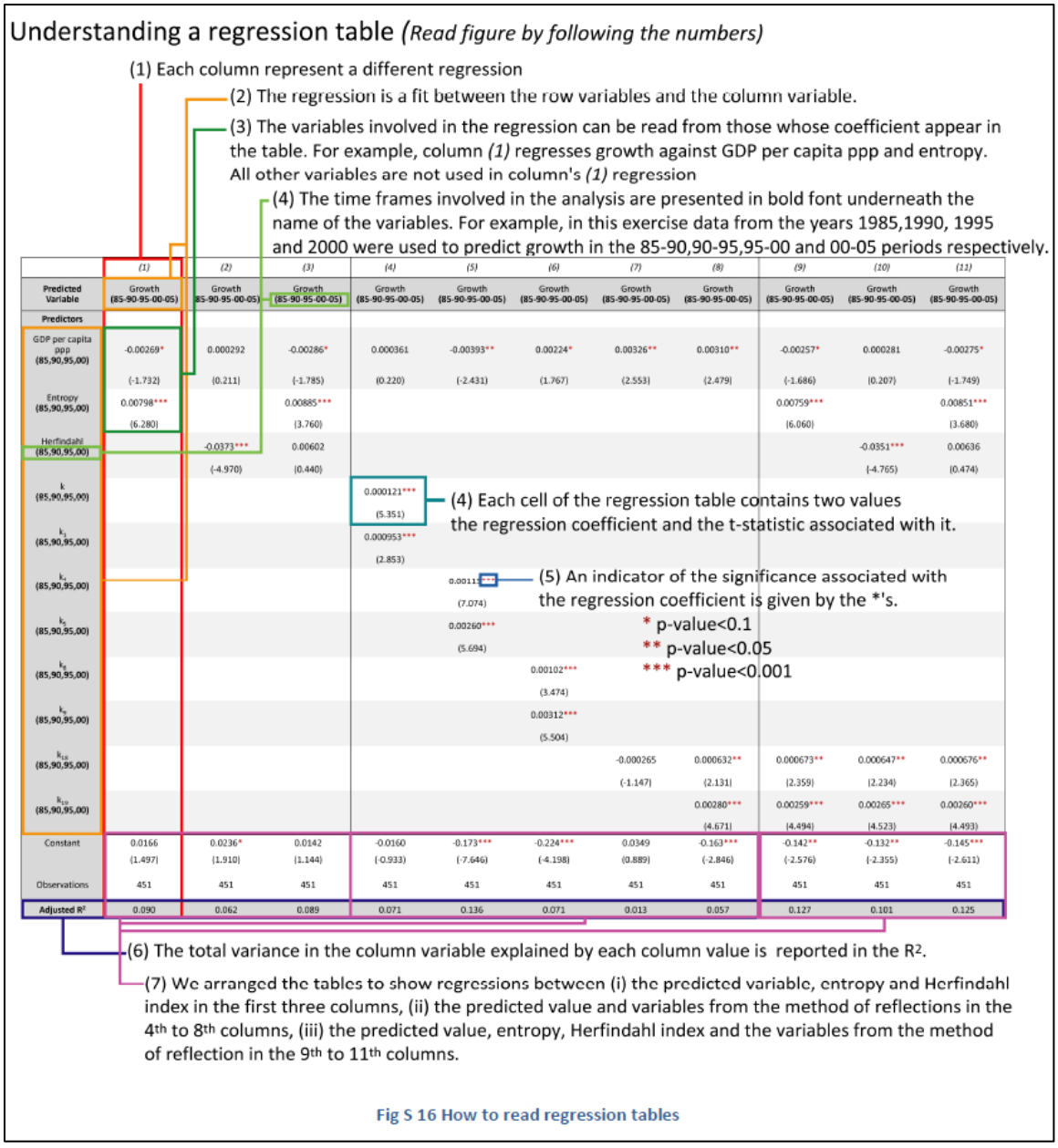

Fig S 16 How to read regression tables

Figure 4-1 How to read regression tables (Hausmann & Hidalgo, 2009)

4.3 Datasets Descriptions

This section will provide brief descriptions of the datasets used, and highlight important details about how they were used.

4.3.1 World Trade Data

The world trade data used are encoded in the 4-digit Standard International Trade Classification (SITC) revision 2, and retrieved from MIT's Observatory of Economic Complexity ("SITC4 REV. 2 (1962 - 2014) - Product Trade by Year and Country," n.d.), this dataset combines the classic world trade dataset (Feenstra, Lipsey, Deng, Ma, & Mo, 2005) which covers the years 1962 to 2000 and was used in Economic Complexity research (Hausmann & Hidalgo, 2009; Hidalgo et al., 2007), with more recent world trade data from United Nations COMTRADE for the years 2001 to 2014. The world trade dataset has 5,108,305 observations of 7 variables, and is provided in the following format (shown are the first 5 observations):

Table 4-1 The Structure of the Raw World Trade Dataset. ("SITC4 REV. 2 (1962 - 2014) - Product Trade by Year and Country," n.d.)

year	origin	sitc	export_val	import_val	export_rca	import_rca
1962	AGO	6940	1000	225000	0.004771	NULL
1962	AGO	7000	2000	2069000	0.00268	NULL
1962	AGO	7130	4000	1047000	0.004889	NULL
1962	AGO	7244	2000	383000	0.002133	NULL
1962	AGO	7271	1000	161000	0.006328	NULL

Following are brief descriptions of the dataset's variables:

- year: the first variable is the year of the trade flow
- origin: the second variable is the origin country of the data flow, encoded in three letter abbreviations, the dataset contains observations for 250 countries

- sitc: the third variable is the type of the product traded, encoded in SITC revision 2 classification codes
- export_val: the fourth variable is the total value of the country's exports of a specific product for that year
- import_val: the fifth variable is the total value that a country imports from a specific product in the specified year
- export_rca: the sixth variable is the country's Revealed Comparative Advantage (RCA) for that export product in a specific year; this variable is unused and replaced by a calculated RCA
- import_rca: the seventh variable is similarly calculated for the country's imports of that product; this variable is unused and dropped from the dataset in this research

4.3.2 Penn World Tables (PWT)

The most widely used dataset for income comparisons across time and countries is the "Penn World Tables" (PWT) dataset, which avails Gross Domestic Product (GDP) per capita adjusted for purchasing power parity (Johnson, Larson, Papageorgiou, & Subramanian, 2013). I will use in this study version 7.1 providing data for 189 countries and territories for 61 years from 1950 to 2010. The dataset contains 11,590 observations of 36 variables, it is provided in the following format (shown are the first 5 observations of the select variables):

Table 4-2 The Structure of the Penn World Table (Heston, Summers, & Aten, 2012)

isocode	year	POP	rgdpl
AFG	1950	8150.368	NA
AFG	1951	8284.473	NA
AFG	1952	8425.333	NA
AFG	1953	8573.217	NA
AFG	1954	8728.408	NA

Following are brief descriptions of the selected dataset's variables:

- isocode: is the three letter code representing the country or territory
- year: is the year of the observation
- POP: is the total population of the country or territory in the specified year, measured in 1000s
- rgdpl: is one of the GDP per capita measures provided by the PWT dataset, it is uses the Laspeyres method to adjust for purchasing power parity (ppp) and measured in constant 2005 international dollar per person (2005 I$/person)

The population and GDP per capita data used in this study, are the variables described above. Additionally GDP growth is calculated as the percentage of annual change in GDP per capita for a country.

4.3.3 Saudi Data

The Saudi Arabian Monetary Authority publishes the annual statistics dataset (Saudi Arabian Monetary Authority, 2016), this study uses the 2016 version contains several relevant statistical tables. The first table used provides the Saudi GDP in Saudi Riyals, broken down by sector for the years from 1970 to 2014 and an initial estimate for 2015. This provided in the following statistical table (shown are the first 5 records):

جدول رقم (5) : الناتج المحلي الإجمالي حسب القطاعات التنظيمية بأقيام المنتجين بالأسعار الجارية
TABLE (5): GROSS DOMESTIC PRODUCT BY INSTITUTIONAL SECTORS

(AT PRODUCERS' VALUES AT CURRENT PRICES)

(مليون ريال) (Million Riyals)

السنة Year	القطاع النفطي Oil Sector	القطاع الغير نفطي Non-Oil Sector		الناتج المحلي الإجمالي ماعدا رسوم الإستيراد GDP Excluding Import Duties	رسوم الإستيراد Import Duties	الناتج المحلي الإجمالي GROSS DOMESTIC PRODUCT	معدل النمو % Growth rate %
		القطاع الخاص Private Sector	Government Sector القطاع الحكومي				
1970	10390	8903	4619	23912	286	24198	19.9
1971	17031	9755	5078	31864	373	32237	33.2
1972	22450	11425	5740	39616	440	40056	24.3
1973	33217	14809	6896	54921	483	55404	38.3
1974	126320	26078	8376	160774	442	161216	191.0

Figure 4-2 Shows the structure of the Saudi GDP breakdown statistical table. (Saudi Arabian Monetary Authority, 2016)

The dataset also includes nominal and real oil prices in US dollars for the exports of the Organization of Petroleum Exporting Countries (OPEC), from the years from 1970 to 2015. This provided in the following statistical table (shown are the first 5 records):

جدول رقم (10) : الأسعار الاسمية والحقيقية للنفط
(سنة الأساس عام 2005)
Table (10): NOMINAL AND REAL OIL PRICES
(Base Year 2005)

(دولار أمـريكي للبرميـل) (In U.S.$ per Barrel)

السنة Year	الأسعار الاسمية للنفط NOMINAL OIL PRICE			الأسعار الحقيقية للنفط* REAL OIL PRICE*		
	العربي الخفيف Arabian Light	بحر الشمال (برنت) North Sea (Brent)	سلة أوبك OPEC BASKET	العربي الخفيف Arabian Light	بحر الشمال (برنت) North Sea (Brent)	سلة أوبك OPEC BASKET
1970	1.30	2.23	1.67	9.07	15.55	11.67
1971	1.65	3.21	2.03	10.62	20.66	13.07
1972	1.90	3.61	2.29	10.66	20.26	12.88
1973	2.70	4.25	3.05	12.62	19.86	14.26
1974	9.76	12.93	10.73	41.19	54.56	45.26

Figure 4-3 Shows the structure of the oil prices statistical table. (Saudi Arabian Monetary Authority, 2016)

The nominal oil prices are used in this study, as all trade flow values and Saudi GDP figures are nominal as well.

Finally, this dataset provides annual oil exports of Saudi Arabia in million barrels for the years 1962 to 1995. This provided in the following statistical table (shown are the first 5 records):

جدول رقم 3 (أ) : صادرات المملكة من النفط الخام حسب الجهات

Table 3(a): SAUDI EXPORTS OF CRUDE OIL BY DESTINATION

(Million Barrels) (بملايين البراميل)

السنة Year	أمريكا الشمالية North America	أمريكا الجنوبية South America	أوروبا الغربية Western Europe	الشرق الأوسط Middle East	إفريقيا Africa	آسيا والشرق الأقصى Asia and Far East	اوقيانوسيا Oceania	المجموع Total
1962	--	--	180.92	--	--	--	--	501.30
1963	--	--	199.74	--	--	--	--	544.83
1964	--	--	247.71	--	--	--	--	587.21
1965	--	--	301.09	--	--	--	--	678.83
1966	--	--	404.54	--	--	--	--	829.31

Figure 4-4 Shows the structure of the Saudi oil exports statistical table. (Saudi Arabian Monetary Authority, 2016)

4.3.4 CID's Economic Complexity Rankings

The Center for International Development at Harvard University publishes the annual rankings based on the Economic Complexity (Center for International Development, n.d.-a), their Atlas of Economic Complexity website avails the full rankings for 124 countries from 1995 to 2014 for download. The dataset includes 2460 observations of 6 variables, and is provided in the following format (shown are the first 5 observations):

Table 4-3 the Structure of the Economic Complexity Ranking Dataset (Center for International Development, n.d.-a)

rank	abbrv	country	eci_value	delta	year
1	JPN	Japan	3.097456	0	1995
2	DEU	Germany	2.645996	0	1995
3	CHE	Switzerland	2.463272	0	1995
4	SWE	Sweden	2.344447	0	1995
5	AUT	Austria	2.297525	0	1995

Following are brief descriptions of the dataset's variables:

- rank: the international ranking of a country in a specific year based on its Economic Complexity
- abbrv: the three letter abbreviation of the country's name
- country: the full name of the country
- eci_value: the normalized value of the Economic Complexity Index
- delta: the change in country's ranking from the prior year
- year: the year for the observation ranking

The Atlas of Economic Complexity website also provides aggregate values of exports in billion US dollars, which will be utilized for analyzing Saudi Arabia's ranking (Center for International Development, n.d.-b).

5 Results

5.1 Data Analysis

This section will utilize the datasets described in the previous section 4.3, to investigate the reason behind the influence of oil prices on Saudi Arabia's ranking in the Economic Complexity Index published by the Harvard University's Center for International Development, which was illustrated in Figure 1-3 (Center for International Development, n.d.-a). Then the section will describe the trial and error process followed to construct an alternative index.

5.1.1 RCA Limitations

Looking at Saudi Arabia's ranking in 2007, 2008 and 2009 I found that it fluctuated heavily, dropping 31 ranks from 71 in 2007 to 102 in 2008 and then rising 40 ranks to 62 in 2008 (Center for International Development, n.d.-b). To investigate the reason behind this fluctuation, I constructed the following table, to combine Saudi Arabia's ranking in Economic Complexity with oil prices, in addition to its total value of exports and number of unique products exported in six selected years from 2004 to 2008. This table is shown below:

Table 5-1 Comparing Changes in ECI Ranking of Saudi Arabia with Oil Prices, Diversity and Value of Exports (Center for International Development, n.d.-b; Saudi Arabian Monetary Authority, 2016; "SITC4 REV. 2 (1962 - 2014) - Product Trade by Year and Country," n.d.)

Year	ECI Rank	Oil Prices (US $)	Diversity	Exports (billion US $)
2004	41	36.05	719	98.3
2005	53	50.64	730	158
2006	63	61.08	744	189
2007	71	69.08	740	190
2008	102	94.45	723	277
2009	62	61.06	727	152

While the drop in ranking from 2007 to 2008 coincides with a 46% increase in the value of Saudi exports, the number of different products exported also had a 2% decrease from 740 to 723. Similarly the major increase in the ranking from 2008 to 2009 coincides with a 45% decrease in the value of Saudi exports, while the number of different products exported by Saudi Arabia had a 1% increase from 723 to 727. However, when looking at the 12 ranks drop from 2004 to 2005, which also coincides with a 61% increase in the value of Saudi exports, the number of products also increased by 2% from 719 to 730. While two out of the three episodes discussed can be due to the change in Saudi Arabia's export diversity, however the first episode from 2004 to 2005 cannot be, furthermore all three changes in ranking coincide with much larger change in the exports value and oil prices than they do with changes in diversity. This led me to compare Saudi Arabia's product space in the years 2004 and 2005, and the years 2007 and 2008, which are displayed in Figure 5-1 and Figure-5-2 below.

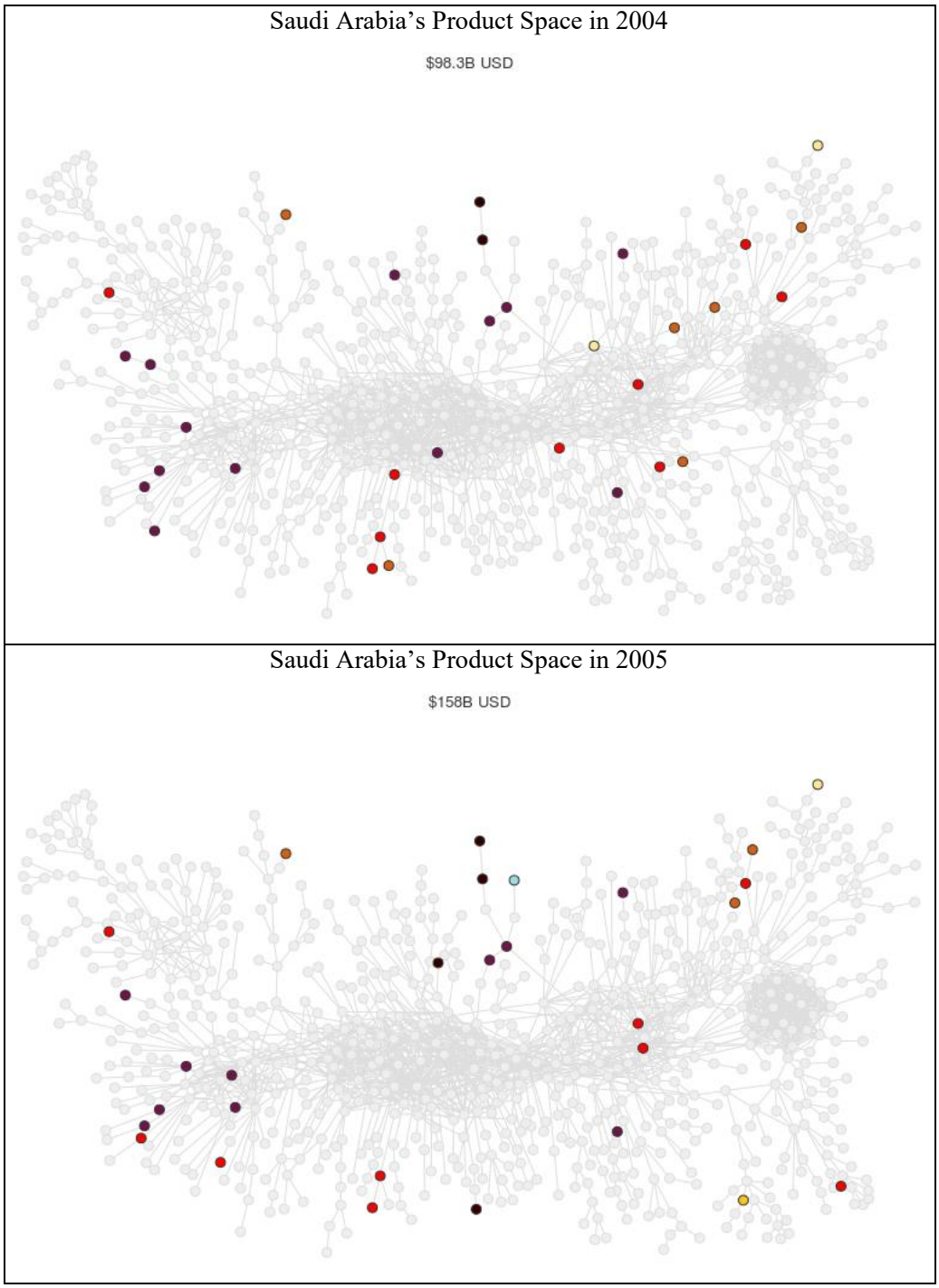

Figure 5-1 Illustrates the decline in Saudi Arabia's product space with the increase in the total value of Saudi exports from 2004 to 2005. (Center for International Development, n.d.-b)

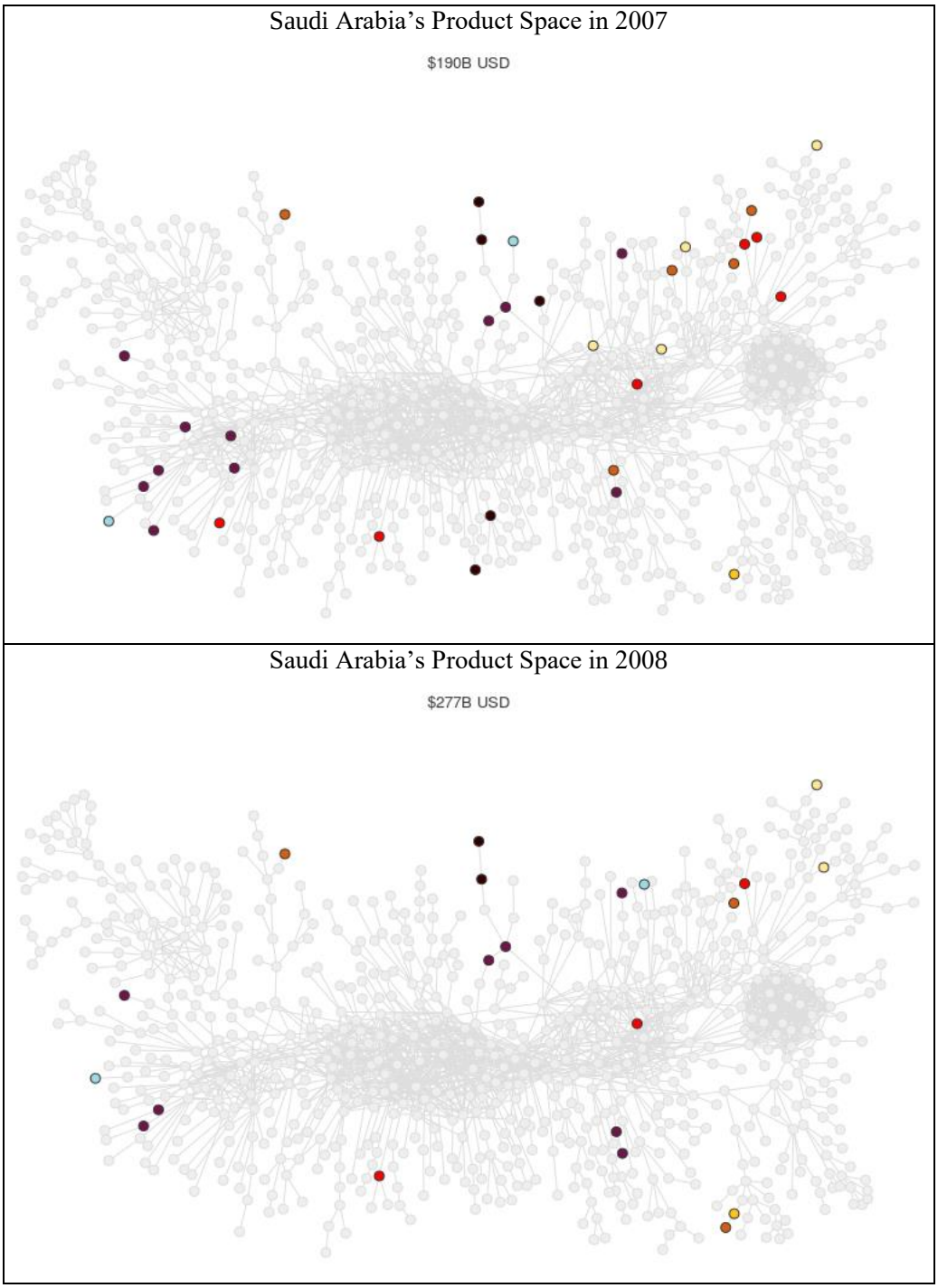

Figure-5-2 Illustrates the decline in Saudi Arabia's product space with the increase in the total value of Saudi exports from 2007 to 2008. (Center for International Development, n.d.-b)

While the decrease in the diversity of Saudi products from 2004 to 2005 coincides with a 2% increase in the number of products that Saudi Arabia exports, Figure 5-1 shows that Saudi Arabia has fewer products in its product space decreasing by 9% from 32 to 29. Figure-5-2 provides a clearer illustration, as the product space has 38% fewer products in 2008 than 2007 dropping from 34 to 21, while it had only 2% decrease in diversity. The reason for this discrepancy between the number of products calculated in the product diversity column in Table 5-1, and the number of products shown in Figure 5-1 and Figure-5-2, is due to the use of the Revealed Comparative Advantage (RCA) to filter the significant exports of a country, as the colored nodes in the previous figures represent products that Saudi Arabia has an RCA of 1 or higher in.

As illustrated in equation (2-1), RCA normalizes the product exports of a country, by the total value of its exports, and the total value of the worldwide exports of that product. Accordingly if a product holds a significant share of a country's exports it can heavily impact the RCA of its other exports based on its value. I illustrate this with the following hypothetical example of a country that produces three products with the same volumes in two years, while the price of the product with the largest share in its export basket changing.

Table 5-2 Hypothetical Example illustrating the Effect of Price Changes on the Reveled Comparative Advantage (RCA) of a Country's Product Exports

Year	Exporter	Product	Export Volume (tons)	Unit Price ($ per ton)	Export Value ($)	Percentage of Exports (%)	Share of World Trade (%)	RCA
2015	Country	Product A	10	50	500	49.26%	1.00%	1.00
		Product B	10	50	500	49.26%	1.00%	1.00
		Product C	15	1	15	1.48%	1.50%	1.49
		Total			1,015		1.00%	
	World	Product A	1,000	50	50,000	49.50%		
		Product B	1,000	50	50,000	49.50%		
		Product C	1,000	1	1,000	0.99%		
		Total			101,000			
2016	Country	Product A	10	50	500	48.54%	1.00%	0.99
		Product B	10	50	500	48.54%	1.00%	0.99
		Product C	15	2	30	2.91%	1.50%	1.49
		Total			1,030		1.01%	
	World	Product A	1,000	50	50,000	49.02%		
		Product B	1,000	50	50,000	49.02%		
		Product C	1,000	2	2,000	1.96%		
		Total			102,000			

The previous example shows that, holding everything else constant, a one US dollar increase in the price of Product C changed the number of products where the country has RCA above the threshold of 1 from three products to one product only. While the country's export performance overall improved in the year 2016, as its share of total world exports increased from 1% to 1.01%. While the previous example does not detail all conditions where price fluctuations can adversely impact the RCAs of a country, especially since it does not factor in demand and supply and price elasticity dynamics, it just illustrates that

under certain conditions there can be such an effect. Since the real economy is much more complicated and everything else cannot be held constant, the next table shows what really happened to the RCA Saudi Arabia's exports of oil and two other products in 2004 and 2005:

Table 5-3 Saudi Arabia's RCAs of Oil and Two Select Exports in 2004 and 2005 ("SITC4 REV. 2 (1962 - 2014) - Product Trade by Year and Country," n.d.)

Year	Exporter	Product	Export Value ($)	Percentage of Exports (%)	Share of World Trade (%)	RCA
2004	Saudi Arabia	Crude Petroleum (3330)	74,831,799,824	73.89%	15.14%	12.03
		Blown Glass (6643)	8,151,060	0.01%	1.32%	1.05
		Synthetic Fibers (2665)	79,324,499	0.08%	1.85%	1.47
		Other	26,361,976,856			
		Total	101,281,252,239		1.26%	
	World	Crude Petroleum (3330)	494,266,626,879	6.14%		
		Blown Glass (6643)	615,240,071	0.01%		
		Synthetic Fibers (2665)	4,294,391,345	0.05%		
		Other	7,547,976,741,705			
		Total	8,047,153,000,000			
2005	Saudi Arabia	Crude Petroleum (3330)	105,117,402,027	75.21%	15.30%	9.96
		Blown Glass (6643)	10,328,469	0.01%	1.51%	0.99
		Synthetic Fibers (2665)	63,163,016	0.05%	1.37%	0.89
		Other	34,582,682,766			
		Total	139,773,576,278		1.54%	
	World	Crude Petroleum (3330)	686,949,649,926	7.55%		
		Blown Glass (6643)	681,879,040	0.01%		
		Synthetic Fibers (2665)	4,598,483,924	0.05%		
		Other	8,409,134,987,110			
		Total	9,101,365,000,000			

Table 5-3 shows that Saudi Arabia had products with RCA higher than 1 in 2004, which signifies that Saudi Arabia produced more than its fair share of these products in world markets. And while the export value of "Blown Glass" increased in 2005 over the 2004 value, and Saudi Arabia's share of the world market of "Blown Glass" increased from 1.32% to 1.51%, the RCA of "Blown Glass" dropped below 1, this is due to the total value of Saudi exports increasing by 38%, which was mainly driven by the increase of Saudi oil

exports, as the “Crude Petroleum” exports increased in value by 40% and reached 75.21% of the total value of Saudi exports in 2005. This increase in the value of Saudi oil exports can be explained by the increase of both the oil prices and the volume of Saudi oil exports from 2004 to 2005, as oil prices increased by 40% from 36.05 to 53 dollar per barrel, and the volume of Saudi exports increased by 6% from 2,487 to 2,631 million barrels.

This leads me to conclude that the reason behind Saudi Arabia’s ranking fluctuation in the Economic Complexity Index in correlation with oil prices, as illustrated in Figure 1-3, is due to its reliance on the Reveled Comparative Advantage to determine which products represent significant exports of a country. However, in the case of Saudi Arabia using the RCA can have misleading conclusions about the diversification of its exports, since it is still highly dominated by oil, which can potentially distort the results of RCA normalization.

5.1.2 ECI without RCA

Since the RCA distorts Saudi Arabia’s ranking with oil price fluctuations, I attempted to re-construct the Economic Complexity Ranking without using the RCA normalization. In order to achieve that, I created an R program to calculate the Economic Complexity Index, as described in its original formulation (Hausmann & Hidalgo, 2009). This program used the world trade data provided by the dataset described in sub-section 4.3.1, since it contains observations for more countries and years than the dataset used in the original Economic Complexity paper. It was combined with the PWT 7.1 dataset described in sub-section 4.3.2 since it also contains observations for more countries and years than the dataset used in the original paper. However, GDP per capita calculations vary significantly between datasets and different versions of the PWT, as one study found that 24 out of 104 countries had robust numbers (Johnson et al., 2013). Therefore, in order

to obtain comparable results with the Economic Complexity Index, I filtered the dataset to retain only the 128 countries used by Hausmann & Hidalgo (2009) in the original paper that introduced ECI (Hausmann & Hidalgo, 2009).Then I ran the regressions described in section 3.1, for both the calculated ECI with and without RCA normalization, and compare it with the results of the ECI (designated as $K_{c,18}$) in (Hausmann & Hidalgo, 2009).

Table 5-4 Regression Coefficients for Income Comparing ECI with and without RCA

	(1)	(2)	(3)
Predicted Variable	Log GDP per capita ppp (2000)	Log GDP per capita ppp (2000)	Log GDP per capita ppp (2000)
Predictors			
Calculated ECI (2000)	491.1 *** (12.01)		
Calculated ECI without RCA (2000)		2.9863 *** (9.122)	
ECI from original research, Table S 6 –column 8 (Hidalgo et al., 2007)			392.6*** (11.99)
Constant	-82755.4 *** (-12.01)	6.5917 *** (28.372)	-63581 *** (-11.99)
Observations	127	127	125
Adjusted R2	0.5319	0.3949	0.535

Table 5-5 Regression Coefficients for 20 Year Growth Comparing ECI with and without RCA

	(1)	(2)	(3)
Predicted Variable	Growth (85,05)	Growth (85,05)	Growth (85,05)
Predictors			
GDP per capita ppp (1985)	-0.0000007 * (2.542)	-0.00000044 * (-2.047)	-0.0047 (-1.478)
Calculated ECI (1985)	0.6084 *** (4.914)		
Calculated ECI without RCA (1985)		0.03465 *** (5.812)	
ECI from original research, Table S 7 – column 7 (Hidalgo et al., 2007)			0.401 *** (3.453)
Constant	-101.70 *** (-4.914)	0.0018 (0.596)	-69.21 *** (-2.94)
Observations	108	108	97
Adjusted R2	0.1936	0.2495	0.202

Table 5-6 Regression Coefficients for 10 Year Growth Comparing ECI with and without RCA

	(1)	(2)	(3)
Predicted Variable	Growth (85-95-05)	Growth (85-95-05)	Growth (85-95-05)
Predictors			
GDP per capita ppp (1985,1995)	0.0000001598 (0.975)	0.0000001558 (0.95)	0.00310 ** (2.188)
Calculated ECI (1985,1995)	-0.004565 *** (-3.634)		
Calculated ECI without RCA (1985,1995)		0.01113 *** (3.677)	
ECI from original research, Table S 8 – column 7 (Hidalgo et al., 2007)			-0.000660 *** (-3.577)
Constant	0.7766 *** (3.725)	0.01338 *** (5.194)	0.102 *** (3.107)
Observations	235	235	221
Adjusted R2	0.05119	0.05243	0.068

Table 5-7 Regression Coefficients for 5 Year Growth Comparing ECI with and without RCA

	(1)	(2)	(3)
Predicted Variable	Growth (85-90-95-00-05)	Growth (85-90-95-00-05)	Growth (85-90-95-00-05)
Predictors			
GDP per capita ppp (85,90,95,00)	0.0000001720 (1.256)	0.0000001334 (0.982)	0.00326** (-2.553)
Calculated ECI (85,90,95,00)	0.001378 ** (2.85)		
Calculated ECI without RCA (85,90,95,00)		0.01589 *** (4.387)	
ECI from original research, Table S 9 – column 7 (Hidalgo et al., 2007)			-0.000265 (-1.147)
Constant	-0.2088 ** (-2.611)	0.01085 *** (4.155)	0.0349 (0.889)
Observations	471	471	451
Adjusted R2	0.01664	0.03909	0.013

The previous results presented in Table 5-4, Table 5-5, Table 5-6 and Table 5-7 corroborate the results that Hausmann & Hidalgo (2007) produced, which are

presented in column 3, while calculated ECI is presented in column 1 and ECI without normalization is presented in column 3. Henceforth, the calculated ECI using RCA normalization will be used as the benchmark to compare other indices against in this study. It is important to note that the results of the calculated ECI, and the ECI presented by Hausmann & Hidalgo (2009) differ slightly due to the different variations and revisions of the datasets used in this study. Next, I will compare the top 5 rankings produced by the calculated ECI with and without RCA normalization:

Table 5-8 Economic Complexity Ranking with RCA Normalization for 2010

Rank	Country
1	Japan
2	Germany
3	Korea, Rep.
4	Sweden
5	Finland
6	Austria
7	Czech Republic
8	Singapore
9	United Kingdom
10	United States

Table 5-9 Economic Complexity Ranking without RCA Normalization for 2010

Rank	Country
1	United States
2	Italy
3	China
4	Spain
5	Germany
6	India
7	United Kingdom
8	Australia
9	Austria
10	Netherlands

From Table 5-8 and Table 5-9 I found that while the ECI without RCA normalization gave encouraging regression results, the rankings themselves appear to be less useful, as they do not take into account the comparative advantage of the various exports, or the countries' shares of them in world markets, and thereby the significance of the exported products in the countries' export baskets. This led to interesting results giving higher rankings to large emerging economies, such as China outperforming Germany and India outperforming the United Kingdom in 2010, as shown in Table 5-9. This led me to conclude that another method of normalization is required, which I explored next.

5.1.3 ECI Using Normalized by Population

Since normalization by total exports using RCA leads to the problems illustrated in 5.1.1 in the case of Saudi Arabia, I attempted to construct another ECI using population for normalization instead of total exports value. This attempts to determine the revealed comparative advantage per capita, which is referred to as RPOP (Stuart Russell, Carla Tokman, Douglas Barrios, & Matt Andrews, 2016). Similar to the RCA equation (2-1), the RPOP can be expressed as follows:

$$\mathrm{RPOP}_{cp} = \frac{X_{cp}/Z_c}{\sum_c X_{cp} / \sum_c Z_c} \qquad (5\text{-}1)$$

Where X_{cp} represents how much country c exported of product p, Z_c represents the population of the country, and an RPOP value of 1 represents the threshold of whether a country exports its fair share of the world market of that product (Stuart Russell et al., 2016).

Testing the ECI constructed using RPOP yielded the following results:

Table 5-10 Regression Coefficients for Income Comparing ECI with RCA and RPOP

	(1)	(2)
Predicted Variable	Log GDP per capita ppp (2000)	Log GDP per capita ppp (2000)
Predictors		
Calculated ECI (2000)	491.1 *** (12.01)	
Calculated ECI with RPOP (2000)		1340.63 *** (16.86)
Constant	-82755.4 *** (-12.01)	-546291.27 *** (-16.8)
Observations	127	127
Adjusted R2	0.5319	0.6921

Table 5-11 Regression Coefficients for 20 Year Growth Comparing ECI with RCA and RPOP

	(1)	(2)
Predicted Variable	Growth (85,05)	Growth (85,05)
Predictors		
GDP per capita ppp (1985)	-0.000000688 * (2.542)	-0.000000711 ** (-2.912)
Calculated ECI (1985)	0.6084 *** (4.914)	
Calculated ECI with RPOP (1985)		1.348 *** (5.874)
Constant	-101.70 *** (-4.914)	-555.3 *** (-5.874)
Observations	108	108
Adjusted R2	0.1936	0.2534

Table 5-12 Regression Coefficients for 10 Year Growth Comparing ECI with RCA and RPOP

	(1)	(2)
Predicted Variable	Growth (85-95-05)	Growth (85-95-05)
Predictors		
GDP per capita ppp (1985,1995)	0.0000001598 (0.975)	0.000000155 (0.945)
Calculated ECI (1985,1995)	-0.004565 *** (-3.634)	
Calculated ECI with RPOP (1985,1995)		0.001944 *** (3.687)
Constant	0.7766 *** (3.725)	-0.7871 *** (-3.600)
Observations	235	235
Adjusted R2	0.05119	0.05271

Table 5-13 Regression Coefficients for 5 Year Growth Comparing ECI with RCA and RPOP

	(1)	(2)
Predicted Variable	Growth (85-90-95-00-05)	Growth (85-90-95-00-05)
Predictors		
GDP per capita ppp (85,90,95,00)	0.0000001720 (1.256)	0.0000001681 (1.228)
Calculated ECI (85,90,95,00)	0.001378 ** (2.85)	
Calculated ECI with RPOP (85,90,95,00)		-0.0008294 *** (-2.985)
Constant	-0.2088 ** (-2.611)	0.3626 ** (3.150)
Observations	471	471
Adjusted R2	0.01664	0.01826

As demonstrated in Table 5-10, Table 5-11, Table 5-12 and Table 5-13 the ECI using RPOP normalization outperforms RCA, as can be observed through comparing column 2 with column 1 respectively. The top 10 countries are shown in the following table:

Table 5-14 Economic Complexity Ranking with RPOP Normalization for 2010

Rank	Country
1	Japan
2	Korea, Rep.
3	Samoa
4	Norway
5	Finland
6	Barbados
7	Czech Republic
8	Malta
9	Slovak Republic
10	Slovenia

As shown in Table 5-14, the ECI with RPOP shows interesting results including having small countries such as Samoa, Barbados and Malta in the top 10 countries. This required further investigation which is perhaps best illustrated by examining Germany's ranking in 2010. While Germany was the third largest exporter in 2010, following China and the United States, and also ranked second in the ECI with RCA, it ranked 26th in the ECI with RPOP. This prompted me to investigate further the effects of using the method of reflection with RPOP normalization, as Germany ranked second in diversity of products where it has an RPOP above or equal 1, with 711 products out of 773 in 2010. However, since this is represents a significant proportion of the total products it exports, it distorted the higher reflections. While this effect did not take place when using an RCA of 1 or higher, since Germany ranked first with only 361 products, which means significantly fewer countries would share its exports. In the following tables, I attempt to illustrate how RPOP threshold of 1 distorts the results of the method of reflection, leading to a much lower ranking for Germany than justified. This will compare the method of reflection results with RCA and RPOP normalizations in Table 5-15 and Table 5-16 respectively.

Table 5-15 Method of Reflection with RCA Illustration for the Year 2010

	1		2		3			4	
Rank	Country	Diversification, number of products with RCA>=1 ($K_{c,0}$)	Country	Ubiquity, number of countries exporting products in 1 ($K_{c,1}$)	Country	Average diversification of countries in 2 ($K_{c,2}$)		Country	ECI ($K_{c,18}$)
1	Germany	361	Japan	15.6696	Japan	207.309		Japan	173.5978
2	Italy	352	Singapore	16.81553	Germany	206.9612	…	Germany	173.5971
3	Spain	337	Korea, Rep.	17.85294	Czech Republic	202.0575		Korea, Rep.	173.5969
4	United States	318	Germany	18.31025	Italy	201.6519		Sweden	173.5969
5	China	283	United Kingdom	18.32609	Austria	201.6381		Finland	173.5969

Table 5-16 Method of Reflection with RPOP Illustration for the Year 2010

	1		2		3			4	
Rank	Country	Diversification, number of products with RPOP>=1 ($K_{c,0}$)	Country	Ubiquity, number of countries exporting products in 1 ($K_{c,1}$)	Country	Average diversification of countries in 2 ($K_{c,2}$)		Country	ECI ($K_{c,18}$)
1	Nether-lands	712	Niger	23.42857	Japan	440.5397		Japan	401.9346
2	Germany	711	India	26.8	Korea, Rep.	431.7167	…	Korea, Rep.	401.9346
3	Austria	644	Burkina Faso	27.75	Finland	424.1428		Samoa	401.9346
4	Italy	605	Malawi	27.91803	Czech Republic	424.1155		Norway	401.9345
5	Singapore	600	Mongo-lia	27.95556	United States	422.1091		Finland	401.9345

From Table 5-15 and Table 5-16, it is easy to see that Germany is punished for having high diversification when using the method of reflection with RPOP normalization. This prompted me to investigate the effect of setting a threshold of 1 for RPOR, and if it has a similar distribution as the RCA:

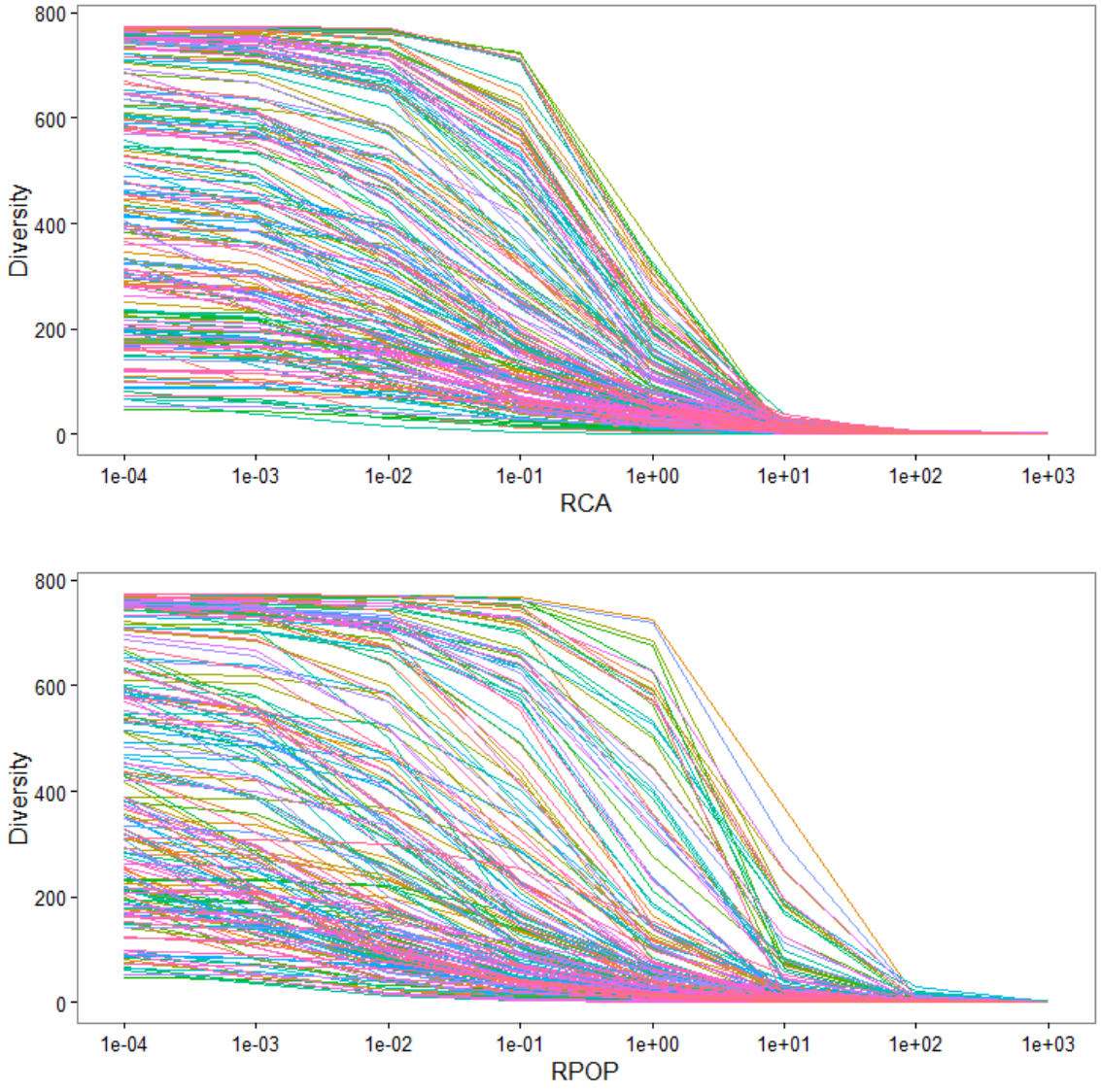

Figure 5-3 Diversification ($K_{c,0}$) as a function of RCA and RPOP cutoffs

Figure 5-3 clearly demonstrates that the distribution of RPOP across thresholds is different form RCA, while RCA converges significantly using a threshold of 1, RPOP still

has a high number of products, and potentially using a threshold of RPOP >=10 can work with the method of reflection, however there is no theoretical justification to set that threshold, therefore I turn in the next sub-section to investigating a different method of capturing the product space network information in the index.

5.1.4 Alternative to the Method of Reflection

An alternative way to capture the product space information, is using one of the most widely used network analytics methodologies, namely PageRank which is used to determine the most important nodes in a network, based on its connections (F. Chung, 2014; Hu, Tian, Liu, Liang, & Gao, 2012). PageRank can be formally defined as follows:

$$PR(A) = (1 - d) + d(\frac{PR(T1)}{C(T1)} + \cdots + \frac{PR(Tn)}{C(Tn)}) \qquad (5\text{-}2)$$

Where PR(A) is the PageRank of page A, and d is damping factor with a default value of 0.85, and pages T1 to Tn are the pages that link to page A, and C is the number of outgoing links from the page(Brin & Page, 1998). The PageRank was calculated in R based on the product space built using all products without any normalization, using the igraph package in R, which provides a methodology to calculate PageRank for undirected graphs (Csardi & Nepusz, 2006). In this context, the PageRank score of a product would represent how large the spillover effects to other close by products would be, as captured by the network connections created by co-exportation data. I proceeded to construct an index based on the summation of the PageRank value for all products exported by a country, and another version which only sums up the products that country has a revealed comparative advantage in, measured by RPOP higher or equal to a threshold of 1. Following are the regression tables produced:

Table 5-17 Regression Coefficients for Income Comparing PageRank with and without RPOP

	(1)	(2)	(3)
Predicted Variable	Log GDP per capita ppp (2000)	Log GDP per capita ppp (2000)	Log GDP per capita ppp (2000)
Predictors			
Calculated ECI (2000)	491.1 *** (12.01)		
PageRank (2000)		3.4245 *** (8.937)	
PageRank with RPOP (2000)			3.7743 *** (12.58)
Constant	-82755.4 *** (-12.01)	6.0168 *** (20.260)	7.750 *** (77.13)
Observations	127	127	127
Adjusted R2	0.5319	0.385	0.5553

Table 5-18 Regression Coefficients for 20 Year Growth Comparing PageRank with and without RPOP

	(1)	(2)	(3)
Predicted Variable	Growth (85,05)	Growth (85,05)	Growth (85,05)
Predictors			
GDP per capita ppp (1985)	-0.000000688 * (2.542)	-0.000000385 (-1.799)	-0.0000003687 (-1.205)
Calculated ECI (1985)	0.6084 *** (4.914)		
PageRank (1985)		0.03201 ** (5.516)	
PageRank with RPOP (1985)			0.02929 ** (2.874)
Constant	-101.70 *** (-4.914)	0.003437 (1.183)	0.01549 *** (7.140)
Observations	108	108	108
Adjusted R2	0.1936	0.2309	0.08038

Table 5-19 Regression Coefficients for 10 Year Growth Comparing PageRank with and without RPOP

	(1)	(2)	(3)
Predicted Variable	Growth (85-95-05)	Growth (85-95-05)	Growth (85-95-05)
Predictors			
GDP per capita ppp (1985,1995)	0.0000001598 (0.975)	-0.0000003947 * (-2.046)	-0.0000005515 (-1.949)
Calculated ECI (1985,1995)	-0.004565 *** (-3.634)		
PageRank (1985,1995)		0.03123*** (5.378)	
PageRank with RPOP (1985,1995)			0.0325 *** (3.244)
Constant	0.7766 *** (3.725)	0.005145 (1.574)	0.01929 *** (9.288)
Observations	235	235	235
Adjusted R2	0.05119	0.1084	0.04072

Table 5-20 Regression Coefficients for 5 Year Growth Comparing PageRank with and without RPOP

	(1)	(2)	(3)
Predicted Variable	Growth (85-90-95-00-05)	Growth (85-90-95-00-05)	Growth (85-90-95-00-05)
Predictors			
GDP per capita ppp (85,90,95,00)	0.0000001720 (1.256)	-0.0000004187 ** (-2.660)	-0.0000006027 * (-2.531)
Calculated ECI (85,90,95,00)	0.001378 ** (2.85)		
PageRank (85,90,95,00)		0.0369 *** (6.968)	
PageRank with RPOP (85,90,95,00)			0.03651 *** (4.027)
Constant	-0.2088 ** (-2.611)	0.0009359 (0.297)	0.01913 *** (10.423)
Observations	471	471	471
Adjusted R2	0.01664	0.09359	0.03307

From Table 5-17, Table 5-18, Table 5-19 and Table 5-20 I found that PageRank as presented in column 2 outperforms column 1, which is the ECI with RCA in all growth regressions, while performing lower than it in the income per capita. While PageRank with

RPOP presented in column 3 outperforms ECI with RCA in income per capita and 5 year growth predictions only. The regression performance is evaluated in terms of the adjusted R2 scores, while ensuring the coefficients are significant. I then proceeded to generate the top 10 rankings for both methods for 2010:

Table 5-21 PageRank Ranking for 2010

Rank	Country
1	United States
2	China
3	Italy
4	Germany
5	United Kingdom
6	Spain
7	India
8	Australia
9	Austria
10	Netherlands

Table 5-22 PageRank Ranking with RPOP for 2010

Rank	Country
1	Netherlands
2	Germany
3	Austria
4	Italy
5	Singapore
6	Denmark
7	Sweden
8	United Kingdom
9	Spain
10	Czech Republic

The ranking results from the PageRank presented in Table 5-21 appear to be misleading, since this methodology does not normalize for the size of the exports or how significant they are. Accordingly, I found that large emerging countries such as China and India outperform more industrialized advanced European economies. While the PageRank with

RPOP method produces more meaningful results while favoring smaller population countries, as shown in Table 5-22, as the top 10 are mostly European countries with the exception of Singapore which ranks at number 5. In the next sub-section, I test the robustness of these results and compare the 5 ranking methods examined with a few more variations.

5.2 Results Comparison and Robustness

While the results of the regression tests in the previous sub-sections 5.1.2, 5.1.3, and 5.1.4 do not offer clearly the best index that can be used for ranking, I added a few other variations of the rankings such as measuring the diversity of exported products, measuring the diversity that the countries have RCA or RPOP above the threshold of 1, and PageRank of all products with RCA above the threshold of 1. Below is a summary comparison table:

Table 5-23 Regression Results for Select Years in Dataset (Measured by Adjusted R2)

	Ranking Method	Income (2000)	20 Year Growth (1985)	10 Year Growth (1985,1995)	5 Year Growth (85,90,95,00)
1	ECI without RCA	0.3949	0.2495	0.0524	0.0391
2	ECI with RCA	0.5319	0.1936	0.0512	0.0166
3	ECI with RPOP	0.6921	0.2534	0.0527	0.0183
4	Diversity	0.3910	0.2291	0.1066	0.0918
5	Diversity with RCA	0.2589	0.1378	0.0751	0.0524
6	Diversity with RPOP	0.5541	0.0798	0.0401	0.0326
7	PageRank	0.3850	0.2309	0.1084	0.0936
8	PageRank with RCA	0.2584	0.1369	0.0747	0.0525
9	PageRank with RPOP	0.5553	0.0804	0.0407	0.0331
	Number of observations	127	108	235	471

While the results summarized are not conclusive, I proceeded to test the robustness of the regression results by checking the residuals of the original ECI with RCA and the PageRank with RPOP, as displayed in the following charts:

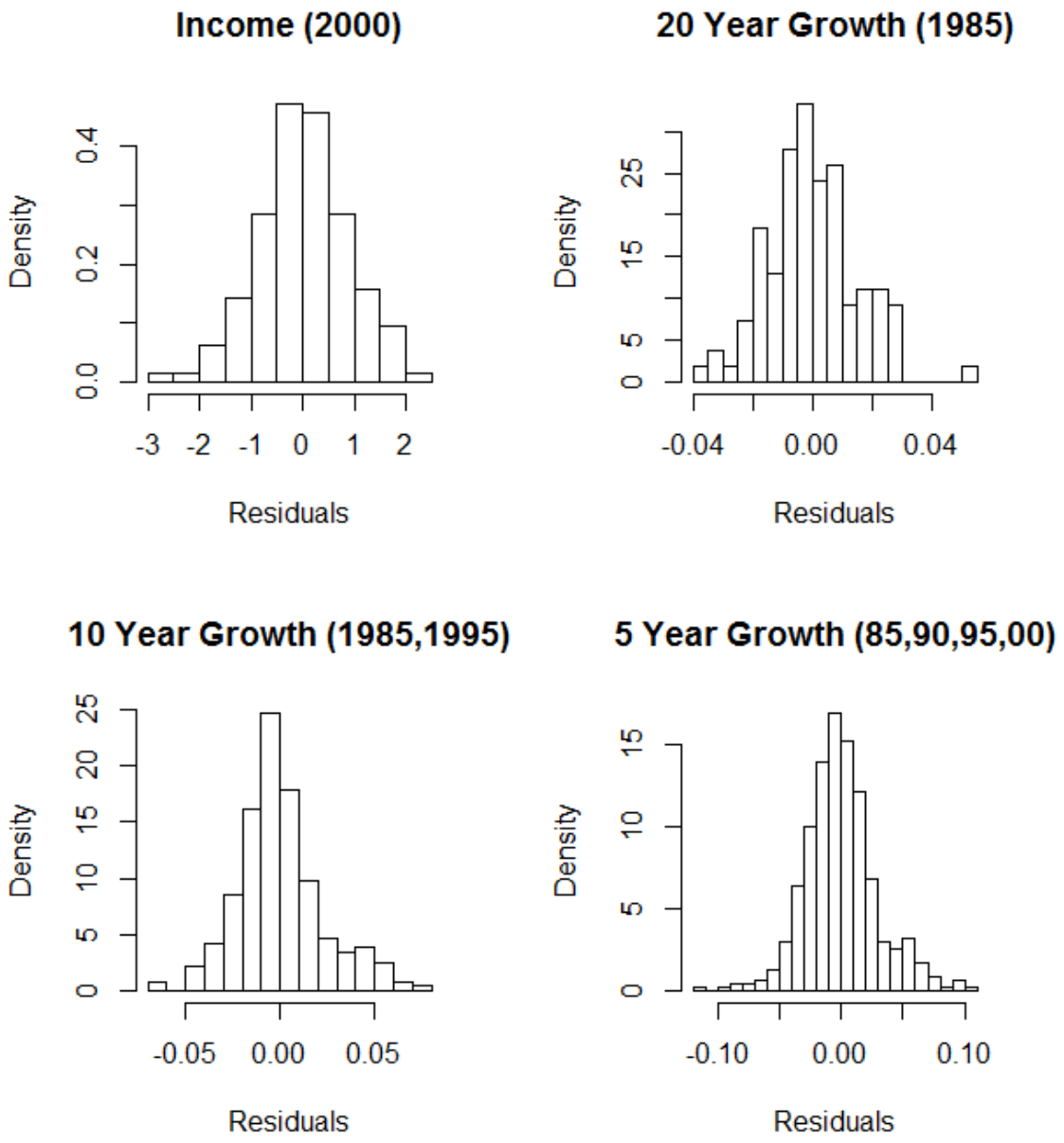

Figure 5-4 Histograms of Residuals from ECI with RCA regressions

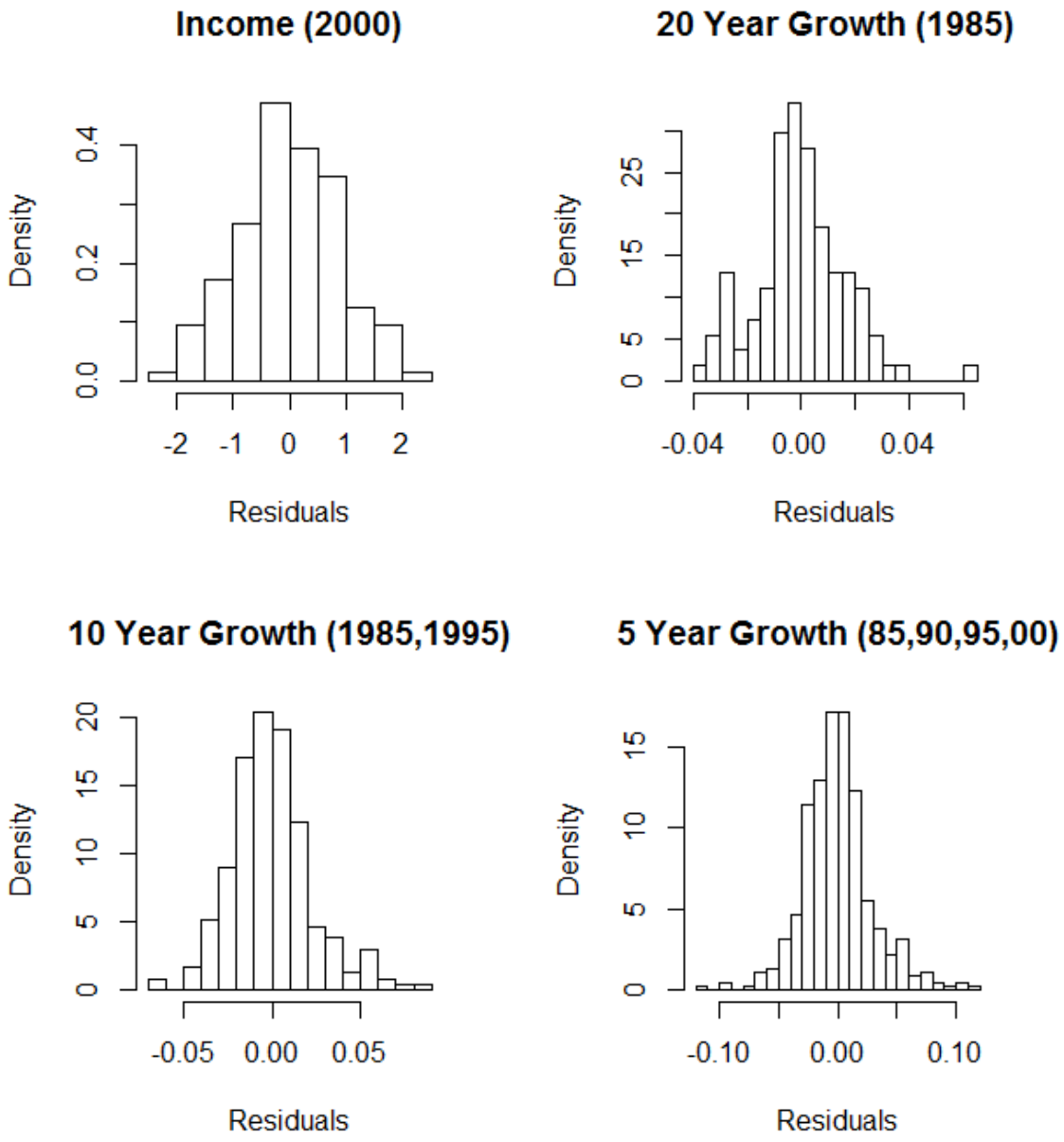

Figure 5-5 Histograms of Residuals from PageRank with RPOP regressions

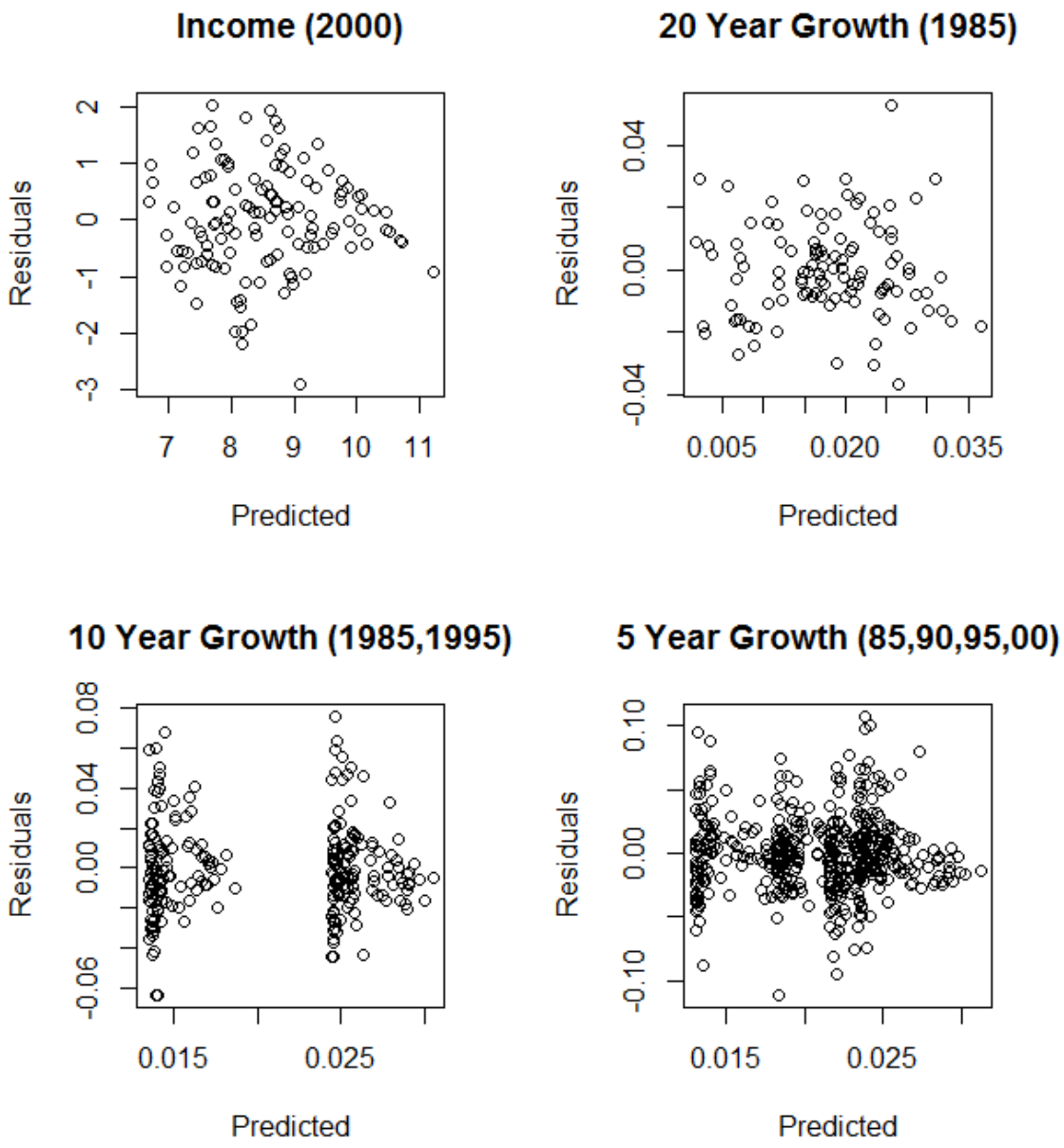

Figure 5-6 Scatter plots of Residuals from ECI with RCA regressions

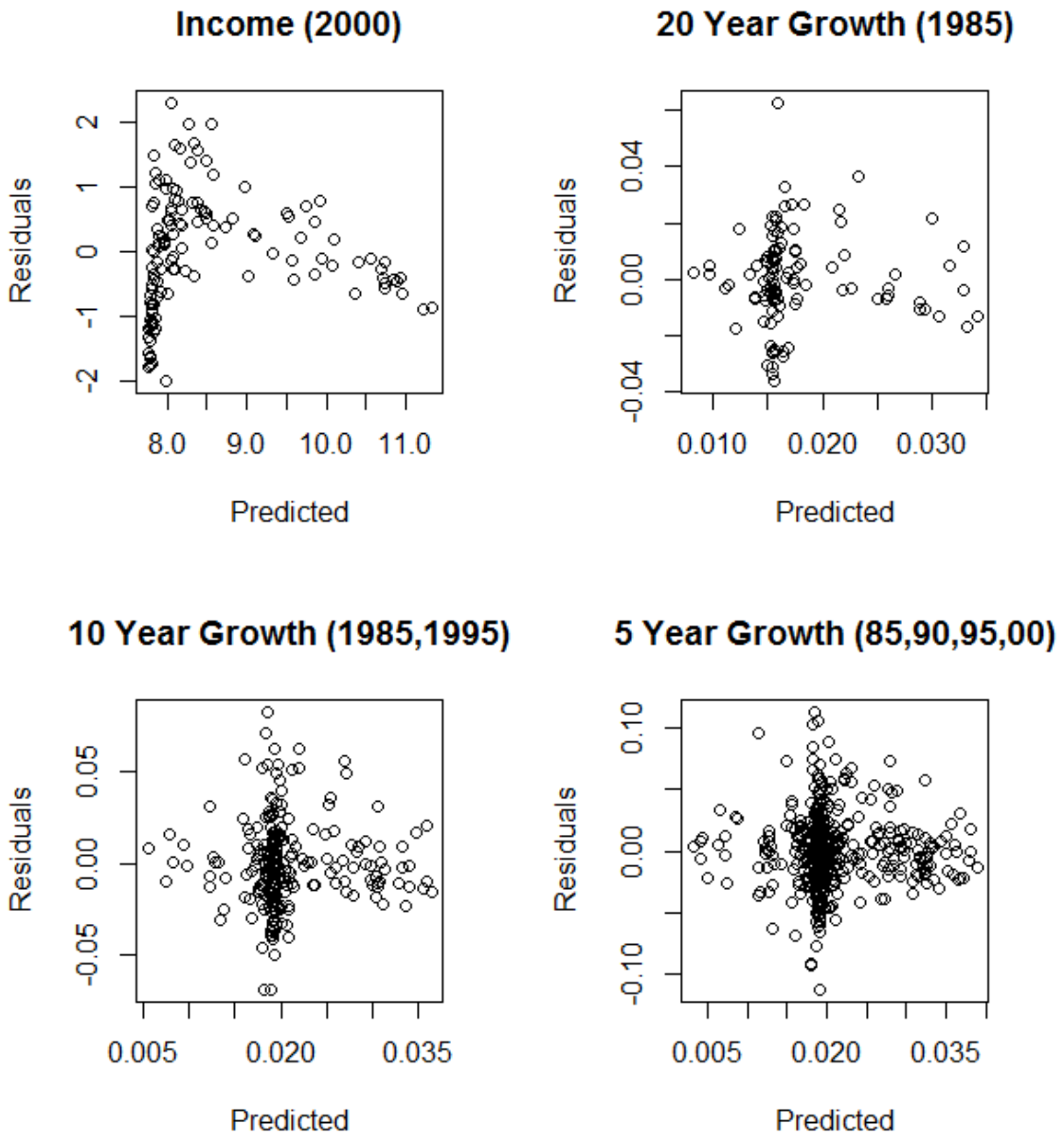

Figure 5-7 Scatter plots of Residuals from PageRank with RPOP regressions

From the previous figures, I found that while the residuals of both methods' regressions are reasonably normally distributed, while the PageRank with RPOP

regressions' residuals displayed in Figure 5-6 appear to exhibit heteroscedasticity, so I linearize the PageRank with RPOP using a log transformation, which produced the following regression results:

Table 5-24 Regression Results of Linearized PageRank with RPOP (Measured by Adjusted R^2)

Ranking Method	**Income (2000)**	**20 Year Growth (1985)**	**10 Year Growth (1985,1995)**	**5 Year Growth (85,90,95,00)**
ECI with RCA	0.5319	0.1936	0.0512	0.0166
PageRank with RPOP	0.5553	0.0804	0.0407	0.0331
Log of PageRank with RPOP	0.7777	0.1976	0.0895	0.0768

From Table 5-24, the linearized PageRank with RPOP appears to perform better than both the PageRank with RPOP and the ECI with RCA, so I proceed to check the residuals of this version in the following charts:

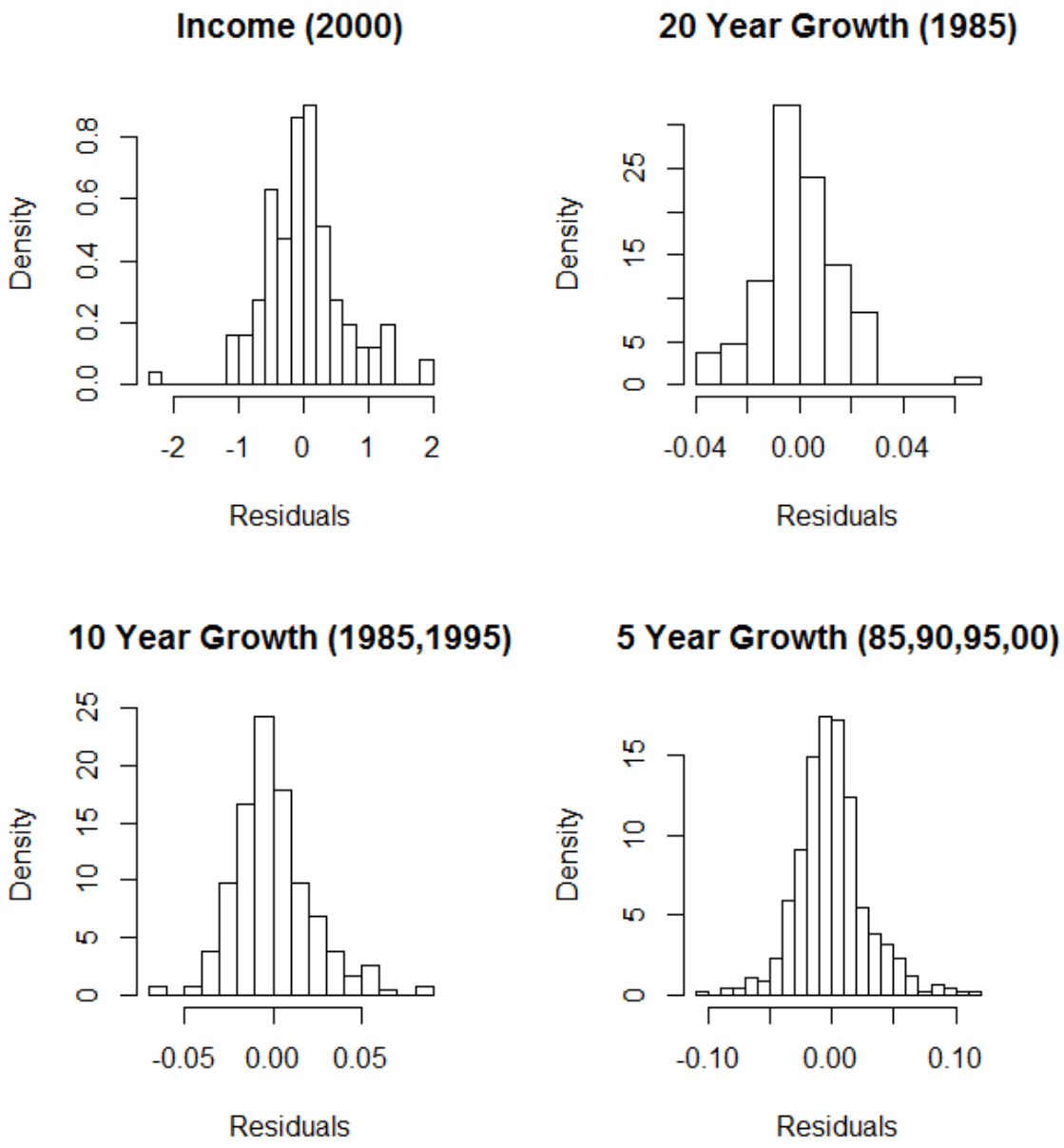

Figure 5-8 Histograms of Residuals from Linearized PageRank with RPOP regressions

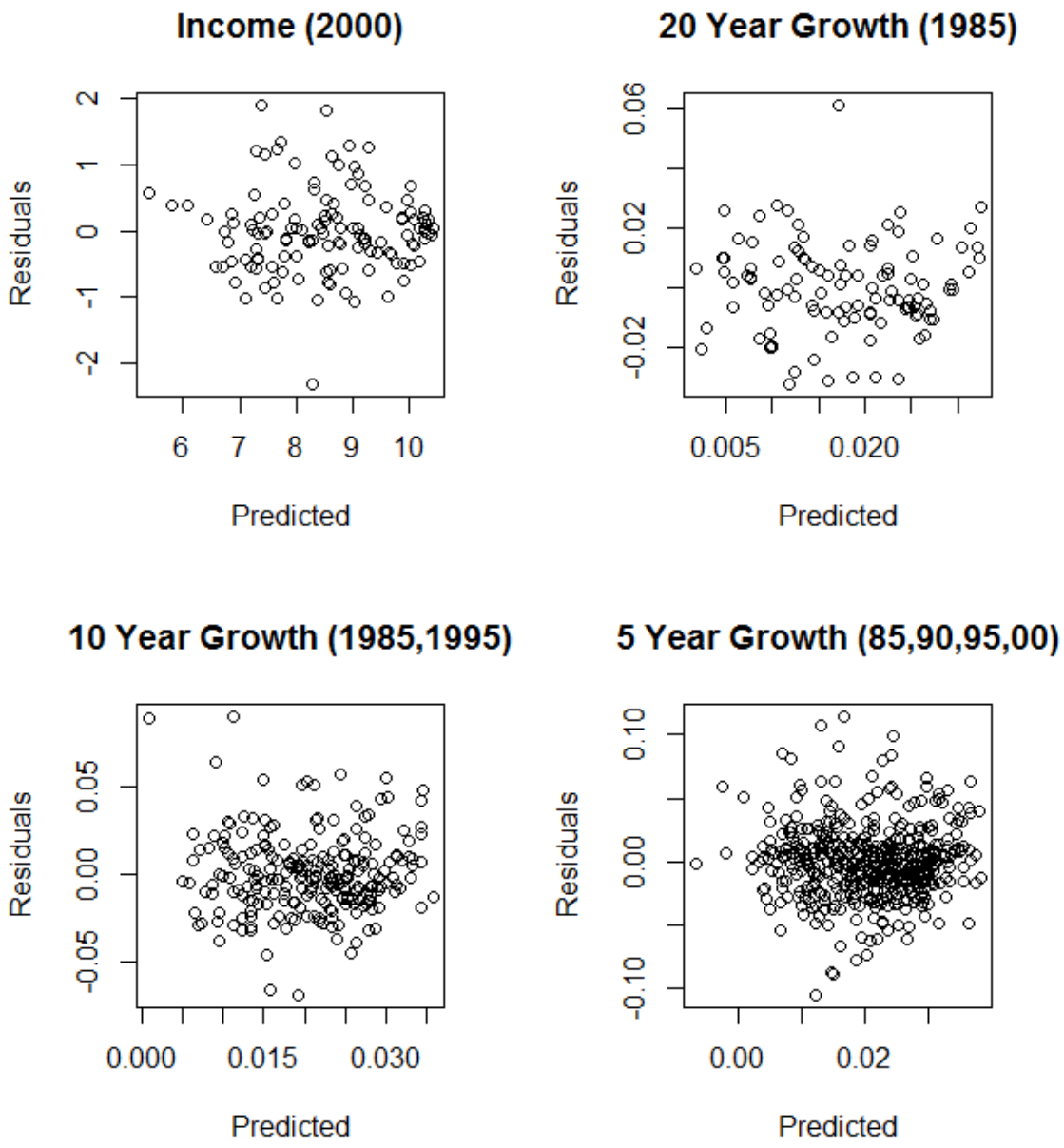

Figure 5-9 Scatter plots of Residuals from Linearized PageRank with RPOP regressions

From the previous charts, it shows that the residuals of the linearized PageRank with RPOP are reasonably normally distributed as demonstrated in Figure 5-8, and the linearization did not affect the normality of the errors compared to Figure 5-5, as they

appear to be reasonably normally distributed. However, the linearization of PageRank with RPOP eliminated the heteroscedasticity shown in Figure 5-7, as the scatterplots in Figure 5-9 display no apparent patterns for the distribution of the residuals, so they can be considered homoscedastic. This validates the linearity of the regressions' results of PageRank with RPOP, and coupled with the fact that they have higher adjusted R2 than the original ECI, this method appears to offer a viable alternative.

Next, I proceeded to test the robustness of the results using the other years available in the dataset, and not limiting the study to the years selected previously. Below is the comparison table of the adjusted R^2 values for the results:

Table 5-25 Regression Results for All Years in Dataset (Measured by Adjusted R^2)

	Ranking Method	Income (1962-2010)	20 Year Growth (1962-1990)	10 Year Growth (1962-2000)	5 Year Growth (1962-2005)
1	ECI without RCA	0.0354	0.0100	0.0016	0.0003
2	ECI	0.0262	0.0183	0.0280	0.0181
3	ECI with RPOP	0.0272	0.0103	0.0062	0.0070
4	Diversity	0.4049	0.1593	0.0898	0.0606
5	Diversity with RCA	0.2943	0.1174	0.0628	0.0352
6	Diversity with RPOP	0.5128	0.0679	0.0378	0.0219
7	PageRank	0.3967	0.1736	0.1098	0.0772
8	PageRank with RCA	0.2922	0.1303	0.0735	0.0425
9	PageRank with RPOP	0.5145	0.0741	0.0436	0.0263
	Number of observations (except 3)	5490	2966	4192	4827
	Number of observations (3)	5483	2959	4185	4820

The results in Table 5-25 show that both PageRank with RPOP in row 9 significantly outperform ECI with all its variations and the simpler measures of diversification ($K_{c,0}$), and while PageRank without RPOP in row 7 has better results for

growth predictions, the actual rankings are less relevant. As the overall results of PageRank with RPOP seemed acceptable, since they outperform the benchmark ECI in row 2, I proceeded to compare the rankings of Saudi Arabia with oil prices, similar to Figure 1-3, in the following chart:

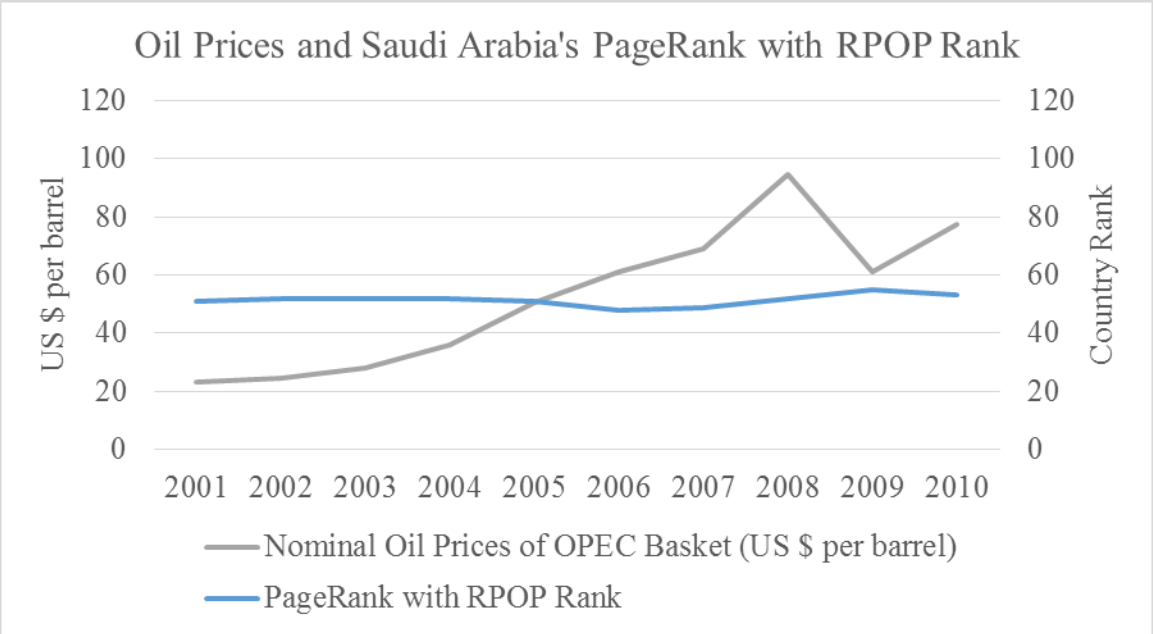

Figure 5-10 Illustrates independence between oil prices and Saudi Arabia's PageRank with RPOP Ranking, and the stability of its performance. (Saudi Arabian Monetary Authority, 2016).

From Figure 5-10, it is clear that the rankings of Saudi Arabia are much more stable using PageRank with RPOP and independent from oil price fluctuations, as compared with the ECI with RCA as shown in Figure 1-3. As the PageRank with RPOP ranking of Saudi Arabia had a correlation coefficient of -0.005 with oil prices over the period from 2001 to 2010 with a standard deviation of 1.86, while the ECI ranking as published by CID had a

correlation coefficient of 0.696 with oil prices during the same period and a standard deviation of 15.74.

Further testing the various rankings on the full dataset without any filters that remove any countries, yielded the following results:

Table 5-26 Regression Results for All Observations in Dataset (Measured by Adjusted R^2)

	Ranking Method	Income (1962-2010)	20 Year Growth (1962-1990)	10 Year Growth (1962-2000)	5 Year Growth (1962-2005)
1	ECI without RCA	0.0317	0.0014	-0.0003	-0.0003
2	ECI	0.0161	0.0075	0.0234	0.0174
3	ECI with RPOP	0.0216	0.0017	0.0031	0.0059
4	Diversity	0.3410	0.0796	0.0445	0.0305
5	Diversity with RCA	0.2380	0.0662	0.0348	0.0193
6	Diversity with RPOP	0.4473	0.0352	0.0169	0.0088
7	PageRank	0.3314	0.0883	0.0549	0.0388
8	PageRank with RCA	0.2361	0.0736	0.0409	0.0233
9	PageRank with RPOP	0.4476	0.0386	0.0196	0.0107
	Number of observations (1,2,4,5,6)	7326	3695	5428	6348
	Number of observations (3)	7293	3669	5396	6316
	Number of observations (7)	7319	3605	5421	6341
	Number of observations (8,9)	7319	3688	5421	6341

From Table 5-26, I found that PageRank with RPOP in row 9 outperforms ECI with RCA in row 2 in predicting income and 20 year growth, its performance is lower in predicting 10 and 5 year growth. This shows the limitations of the modified index using PageRank with RPOP, and that it requires filtering for the most significant countries, which is also the case for other variations.

5.3 Testing the New Ranking

In section 2.2.2 I provided an overview of how South Korea's industrial policies allowed it to diversify its economy and change its comparative advantages, in the following figures I will examine South Korea's GDP per capita (ppp) and its rank in the modified indicator that I constructed (PageRank with RPOP):

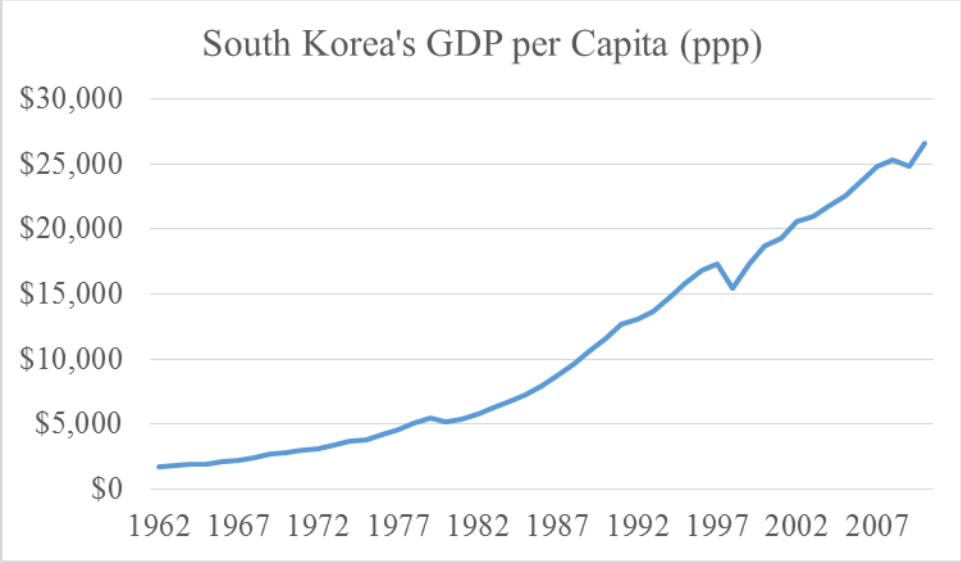

Figure 5-11 Illustrates the success of South Korea's industrial policies in economic development (Heston et al., 2012)

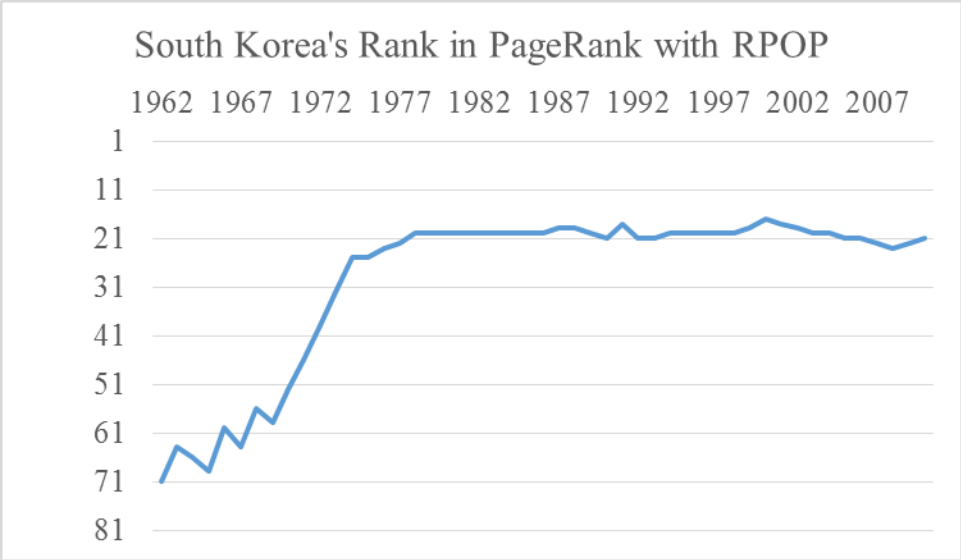

Figure 5-12 Illustrates the rise of South Korea's ranking in relation to South Korea's industrial policies.

Figure 5-11 shows the spectacular success of South Korea's economic development journey throughout the period from 1962 to 2010. Figure 5-12 illustrates South Korea's performance as measured by the PageRank with RPOP, and indicates the success of the first five year development plan from 1962 to 1966, and the outstanding success of the second five year development plan from 1967 to 1971, while shows mild success in the third five year development plan. However, for the rest of the period from 1972 till 2010, the rankings does not much improvement, however this can be due to economic convergence with advanced nations, since this a relative ranking, not the value of the index which is shown in the next figure:

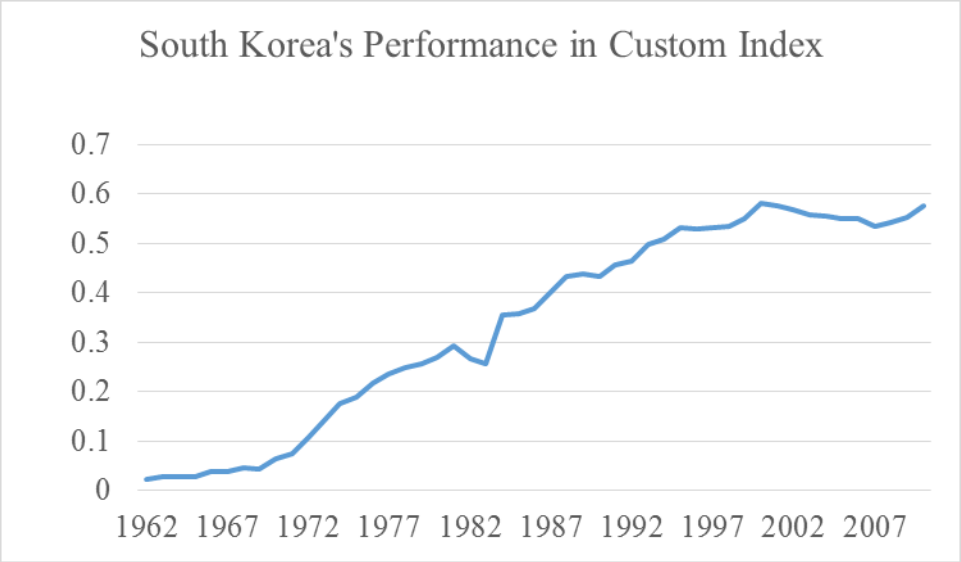

Figure 5-13 Illustrates the continued success of South Korea's industrial policies.

From Figure 5-13, it becomes clear that the plateau reached in Figure 5-12 in the late 1970s is largely due to convergence with more advanced nations, while the absolute value of South Korea's performance in economic diversification according to the modified index continued until the end of 1990s, and only plateaued in the 2000s. From the previous illustration, I conclude that the modified index can be useful for tracking the success of industrial policies.

The product ranking obtained from the PageRank calculation for the product space is illustrated in the following table:

Table 5-27 Shows the top 30 ranked products according to PageRank scores, which are a mix of products including household items and commodities in addition to machinery and tools

SITC Code	Product	PageRank Score
6992	Metal Chains	0.0014125
6417	Tissue Paper	0.0014074
7852	Bicycles	0.0014068
6424	Cut Paper	0.0014067
6418	Coated Paper	0.0014067
583	Fruit Jams	0.0014065
5832	Polypropylene	0.0014062
6415	Miscellaneous Paper	0.0014056
8994	Umbrellas and Canes	0.0014054
5543	Polishes for Floors, Footwear and Metals	0.0014043
224	Preserved Milk	0.0014040
6665	Pottery	0.0014039
7362	Metal Forming Machine Tool	0.0014038
7281	Machine Tools for Specialized Industries	0.0014038
6912	Aluminium Structures	0.0014033
7212	Harvesting Machines	0.0014031
5232	Metallic Salts	0.0014029
6612	Cement	0.0014021
6651	Glass Bottles	0.0014020
6782	Seamless Iron Tubes	0.0014020
7413	Industrial Furnaces and Ovens	0.0014017
6921	Reservoir Tanks	0.0014015
6521	Unbleached Cotton Woven Fabrics	0.0014015
5221	Chemical Elements	0.0014013
7247	Miscellaneous Textile Machinery	0.0014010
6733	Iron Shapes	0.0014009
730	Chocolate	0.001400815
8951	Metal Office Products	0.001400635
620	Confectionary Sugar	0.001400476
6931	Metal Cables	0.001400299

In the following figures, I provide some comparisons of the rankings of countries using ECI as published by Harvard CID, and the modified index that I propose, followed by some observations:

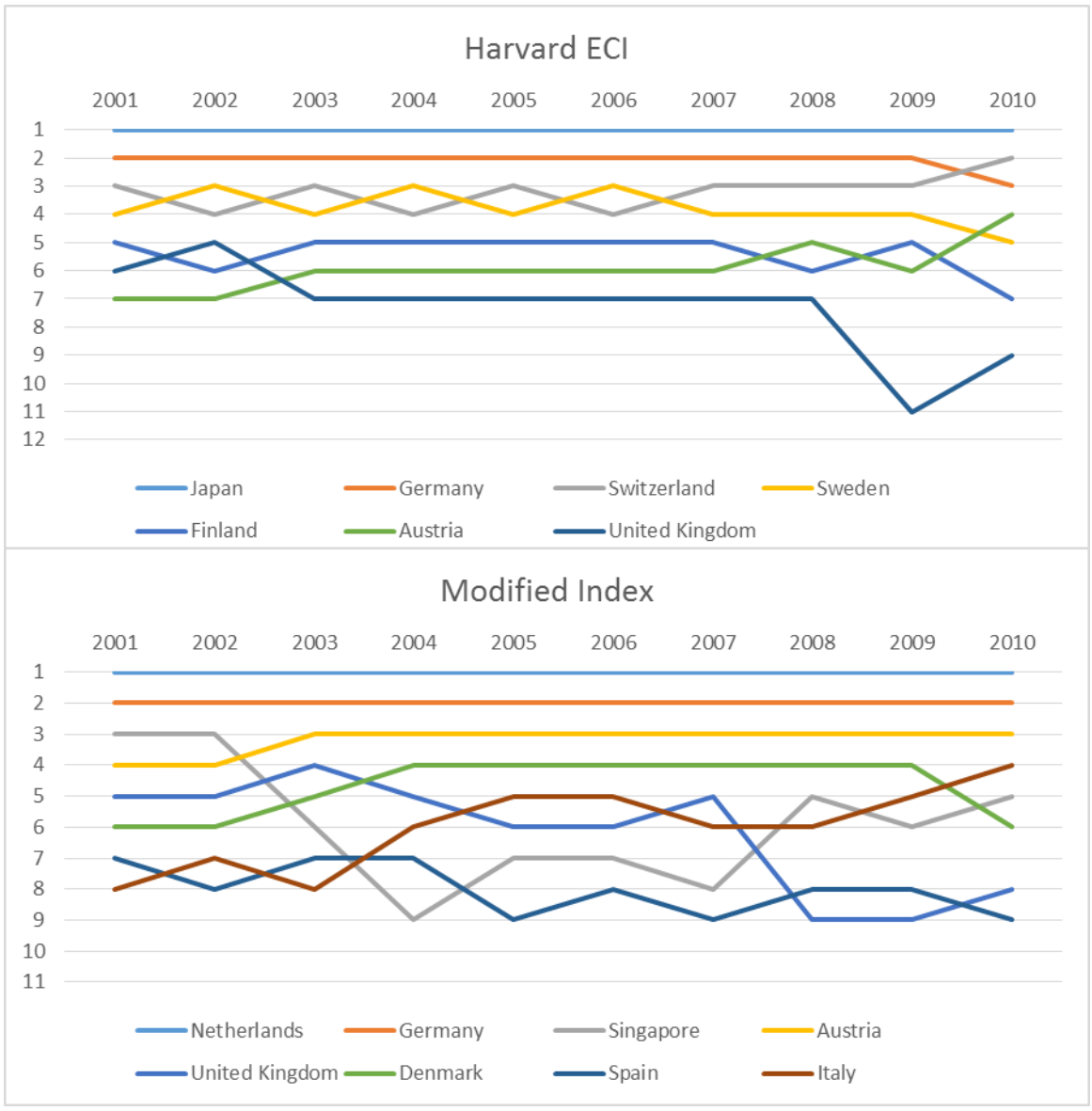

Figure 5-14 Compares the top 5 ranked countries in the ECI and the modified index over the period 2001 to 2010 (Center for International Development, n.d.-a)

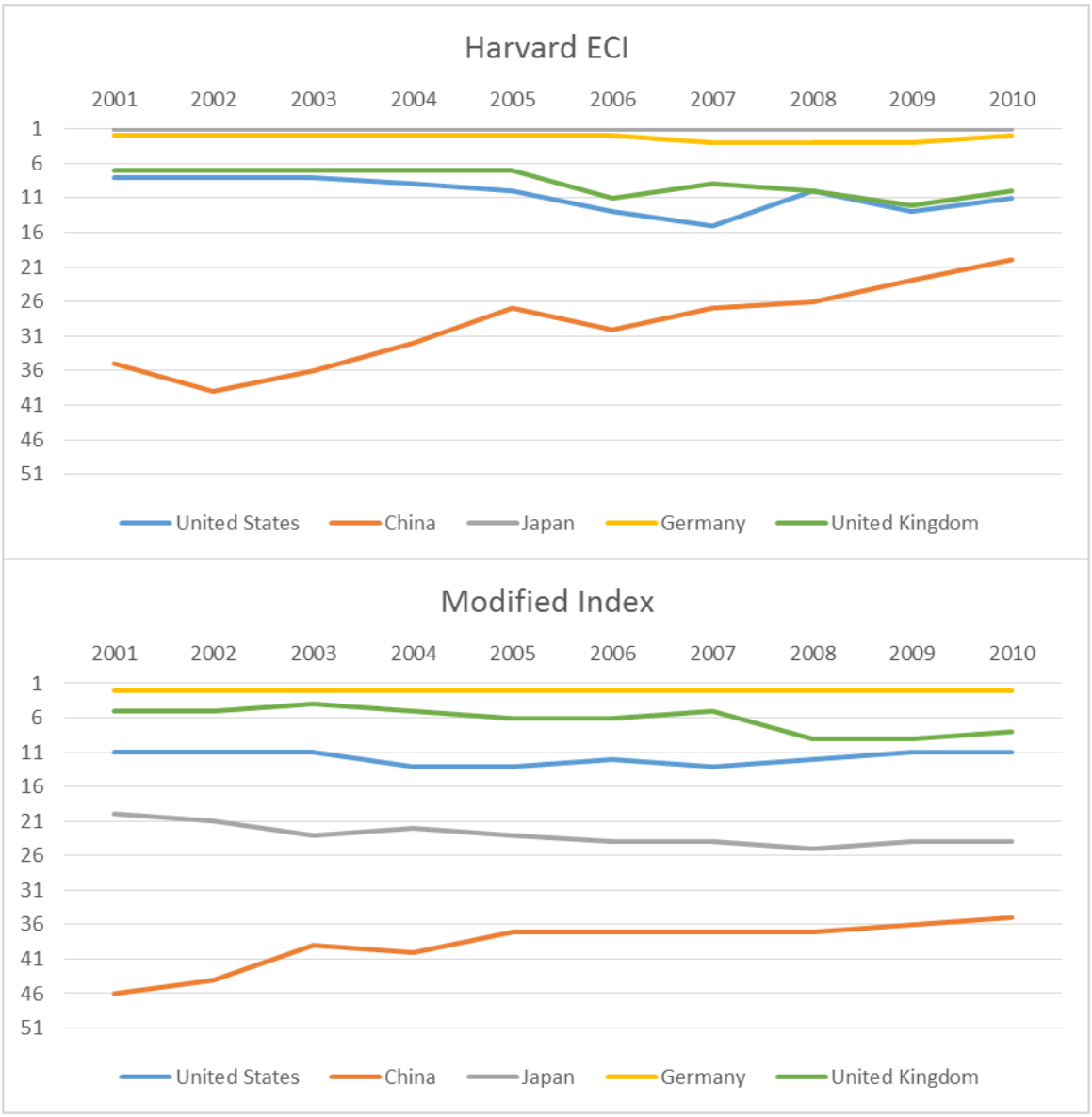

Figure 5-15 Compares the largest five economies rankings in the ECI and the modified index over the period 2001 to 2010 (Center for International Development, n.d.-a)

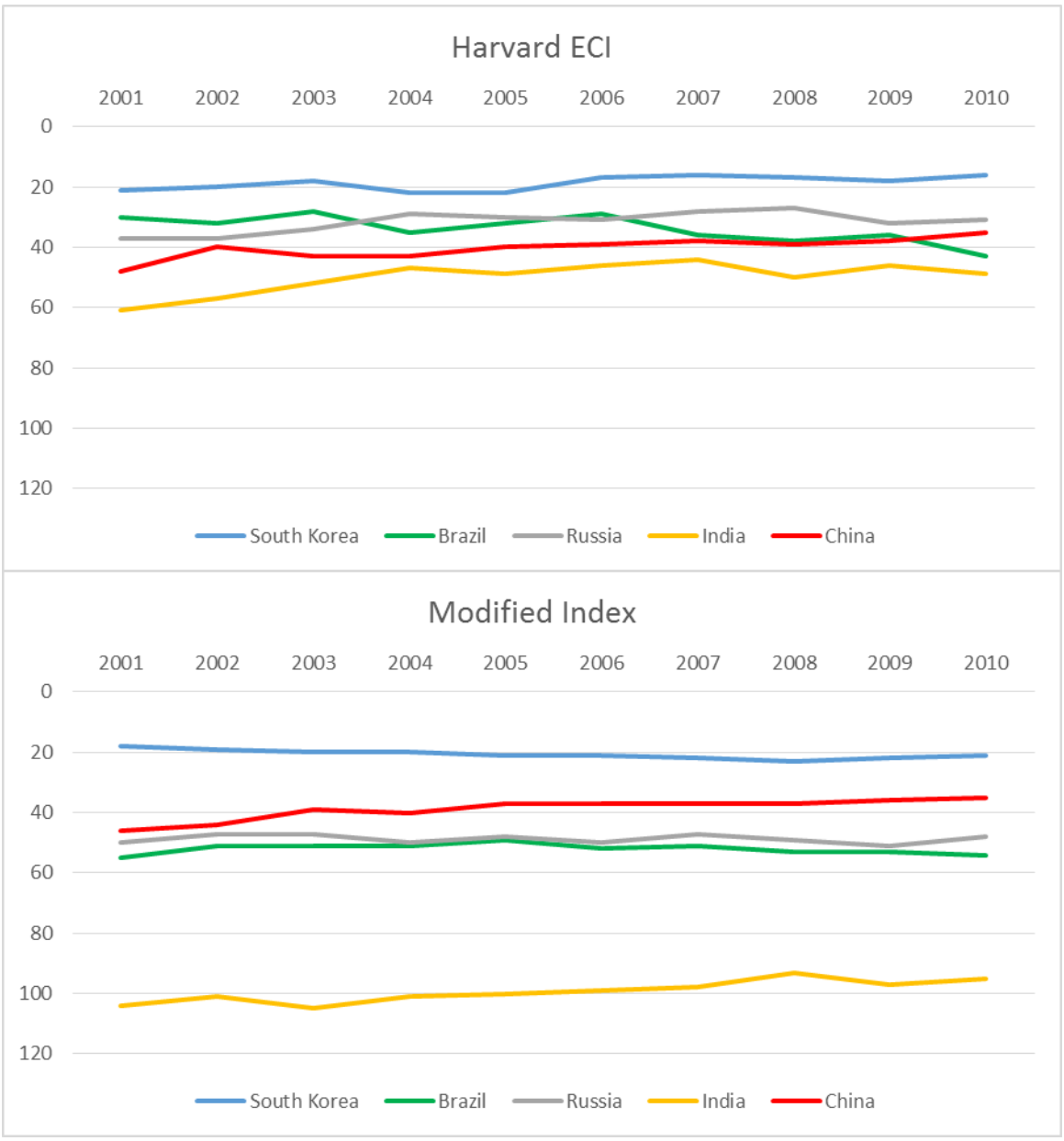

Figure 5-16 Compares the BRICs and South Korea's rankings in the ECI and the modified index over the period 2001 to 2010 (Center for International Development, n.d.-a)

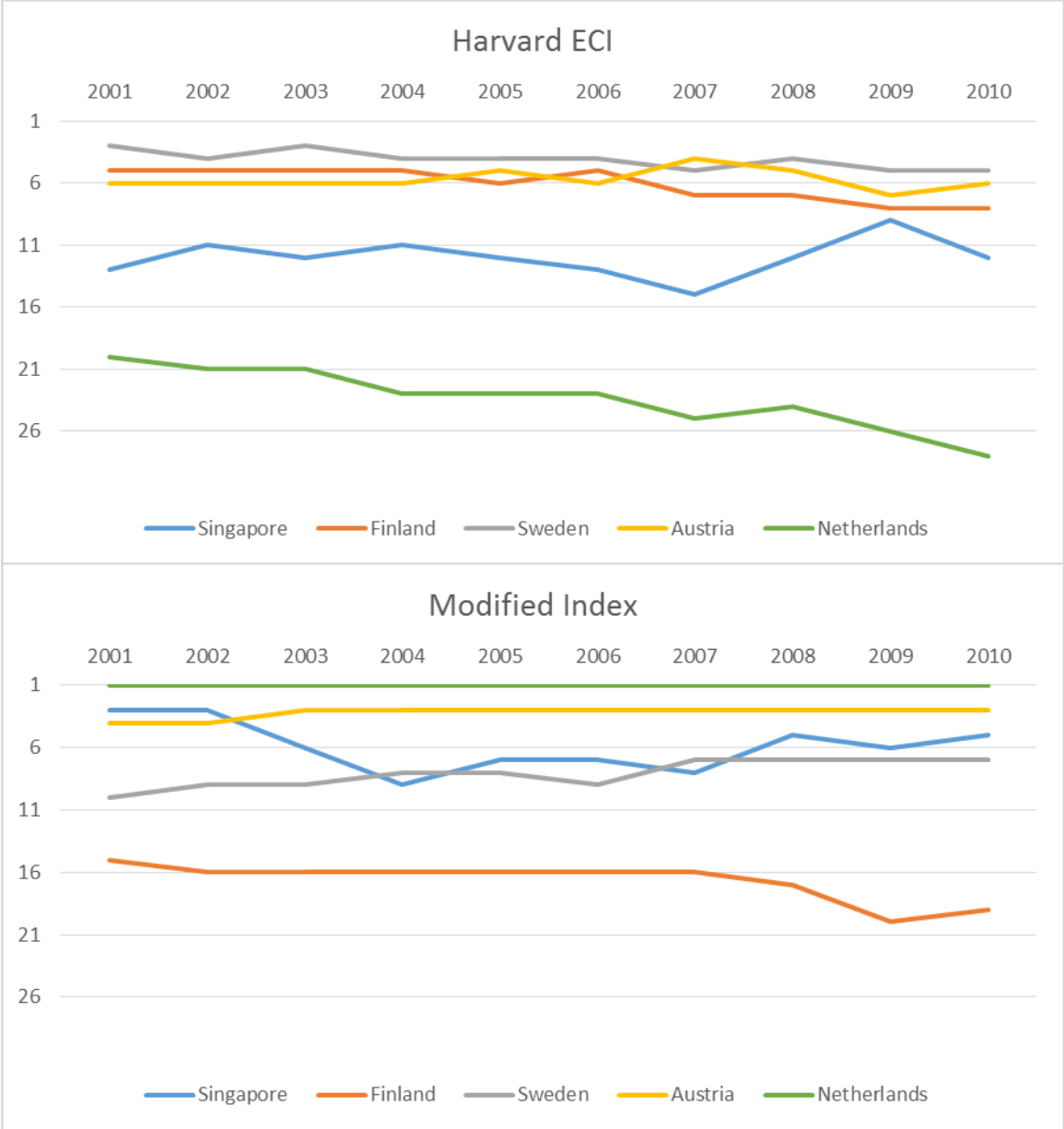

Figure 5-17 Compares select small advanced countries rankings in the ECI and the modified index over the period 2001 to 2010 (Center for International Development, n.d.-a)

From Figure 5-14, I found that the top ranked countries differ significantly between the two rankings, while Germany ranks near the top of both. Figure 5-15 shows with the exception of Japan, the rest of the countries have comparable rankings in both indices,

which might be due to Japan's large population and specialization in highly complex industrial sectors. I also found from Figure 5-16 find South Korea is ranked similarly in both rankings with minor variation in the overall trend, and similar trends for the BRIC countries with slightly lower overall rankings, with the exception of India which ranks significantly lower due to its large population while also trending upwards. Figure 5-17 shows that the while the modified ranking appears to favor the advanced economies with smaller populations as clearly illustrated by the Netherlands topping the modified ranking, however it ranked Finland significantly lower than ECI which might be due to its specialization in advanced industries and limited comparative diversification.

5.4 Using the New Ranking for Tracking Industrial Policy

This modified index appears to be a good leading indicator for economic diversification efforts, as it only accounts for products where a country has a revealed comparative advantage, relative to its population size. This in turn can limit potential attempts to game the rankings, which can take place through producing and exporting insignificant amounts of products only to improve the rankings. If the ECI is used as a policy guide, then Saudi Arabia can significantly improve its ranking by just reducing its oil exports, while that would not have any impact on its ranking in the modified index and therefore the new index avoids such negative side effects. On the other hand, the modified index uses the RPOP as the method of calculating the revealed comparative advantage which has some disadvantages as well, as it ignores the economies of scale in the larger economies, although this effect appears to be limited as observed from the actual rankings.

Undiversified countries can utilize these rankings to guide their vertical industrial policies, through targeting sectors maximize learning spillovers, as implied by the

PageRank rankings of products in different sectors, combined with information about their proximity to existing products which implies the likelihood of success in producing them with the existing knowhow and capabilities in the country. In the case of Saudi Arabia the industrial policy targeting, or government interventions, must be coordinated by the Council of Economic and Development Affairs (CEDA), which is the closest equivalent to the Economic Planning Board in South Korea that led successful industrial policies as highlighted in sub-section 2.2.2, and has been mandated by the Saudi Council of Ministers to establish the mechanisms and develop the programs for achieving the Saudi Vision 2030 (Kingdom of Saudi Arabia, 2016; Vision 2030, 2016). From the literature review summarized in sub-section 2.2.4, I also found that successful industrial policies require focusing on a small number of sectors and industries, and coordination by a board that combines the long-term and short-term considerations, which should select the targeted sectors and limit them. The Saudi industrial policy should guide but not be limited to the initiatives under the new "National Industrial Development Program" mentioned in section 1.3, but it also needs to guide and coordinate the operational activities of the various existing relevant government organizations. The government interventions should focus on maximizing experimentation and learning by doing spillovers and positive externalities, following an adaptive approach and what Henry Mintzberg terms as "Emergent Strategy" rather than a completely deliberate one (Mintzberg, 1978). Accordingly, it can include the following activities by the various government agencies:

- Saudi Public Investment Fund: direct domestic and international investments towards the development of the targeted sectors, to exploit nearby products that require major capital infusion and have the potential of major learning spillovers, and facilitate

partnerships for technology transfer in sectors where product proximity is a bit further away. This can include the creation of new SOEs, international partnerships through joint-ventures, or mergers and acquisitions of international firms.

- Saudi Arabian General Investment Authority: focus efforts to promote and attract FDI in targeted sectors.
- Saudi Exports Development Authority: focus promotional support and services on products in targeted sectors.
- Saudi Industrial Development Fund: offer preferential support for pioneer projects that introduce production of new products in Saudi Arabia, especially in targeted sectors.
- Saudi Industrial Clusters Program: support the creation and nurturing of industrial clusters for the targeted sectors.
- General Authority for Small and Medium Enterprises: provide preferential support for projects in the target sectors, and projects that develop new products in Saudi Arabia.
- Universities and Research Centers: provide funding and incentives to research focused on the development of the target sectors, and development of products with high PageRank scores that are not currently produced in Saudi Arabia.

6 Conclusions & Recommendations

This study developed a new index for economic complexity that can be utilized as the main leading indicator to measure the success of industrial policies for diversification efforts of countries, and guide their vertical industrial policies and targeting efforts, to maximize their ranking and thereby the positive learning by doing spillovers and positive externalities. Additionally, the study investigated the case for an industrial policy in Saudi Arabia, to guide its efforts toward diversifying its economy and increasing its non-oil exports, and drew relevant lessons from the East Asian Miracle and South Korea more specifically. The study accordingly recommends the new index to be used as metric to measure the success of the "National Industrial Development Program" as one of the Saudi Vision 2030 realization programs, as it overcomes the limitations inherit in the ECI for countries whose economies are dominated by a few products sectors, such as Saudi Arabia.

6.1 Hypotheses Resolution

As illustrated in Table 5-25 Table 5-24 and Table 5-25, the PageRank with RPOP ranking outperforms ECI with RCA ranking in its correlation with income per capita as measured by the adjusted R squared, allowing me to reject the null hypothesis for Hypothesis I, and accept the alternative hypothesis. Similar results are shown for the GDP growth predictions, controlled for the initial level of income per capita, for the periods of 5, 10 and 20 years. Thus, I also reject the null hypothesis for Hypothesis II and accept the alternative hypothesis. Therefore, the PageRank with RPOP serves as a viable alternative measure of Economic Complexity that works better for undiversified economies, which is tested through examining the case of Saudi Arabia with its dominating oil sector. While the results obtained were based on the specific datasets and filtering mechanism, they

appear to be more robust to changes than the other ranking methods, additionally the modified index was tested on a larger dataset than the dataset originally used for the ECI. This in turn can lead to the conclusion that the modified index is potentially a more robust measure for Economic Complexity overall, however that conclusion requires further research to ensure its validity. Overall, the modified index is therefore shown to be correlated with the initial income per capital, holds predictive power for future GDP growth, and robust to oil price fluctuations.

6.2 Contribution

This study highlighted some of the limitations of the ECI for Saudi Arabia, specifically due to the use of RCA to normalize, and the adverse impact that the oil price fluctuations has on Saudi Arabia's export RCAs; this limitation can also affect other countries whose economies are dominated by a few products or sectors. The study also offered an modified Economic Complexity index and ranking methodology that both captures the information in the product space network, and is comparable in its predictive power and more suitable for use in undiversified countries, as a complementary measure of the ECI.

6.3 Boundaries of Study

This study utilized limited datasets, with GDP per capita data only available until 2010, and the number of countries included in the study was limited to the 128 countries used by Hausmann and Hidalgo (2009) in their paper to eliminate distortions due to data quality issues. The study did not attempt to find all shortcomings of the ECI or the method of reflections, rather it attempted to complement the Economic Complexity framework, and address its limitations for the case of Saudi Arabia. Additionally, the study does not

propose the modified index as a complete replacement for the ECI, rather as a complementary index to be used. The study does not detail all the differences in rankings between the two indices, nor attempt to explain them in details. Detailing an industrial policy for Saudi Arabia is also beyond the scope of this study, as it only highlights the need for having one, and provides broad guiding principles that such a policy should follow. The study also only focused on product exports, and does not address service exports.

6.4 Recommendations for Future Research

Future research and applications can focus on investigating which products Saudi Arabia should target for development and experimentation to find new comparative advantages, this can be achieved by leveraging the PageRank scores of the different exports in the product space and based on their proximity to current Saudi exports.

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