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Investigating the Interaction Effects of Green Product Development and Countries Green Growth Performance: Economic Complexity Perspective

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INVESTIGATING THE INTERACTION EFFECTS OF GREEN PRODUCT DEVELOPMENT AND COUNTRIES GREEN GROWTH PERFORMANCE: ECONOMIC COMPLEXITY PERSPECTIVE

by

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ABSTRACT

For many years, natural resources have been used as the main input of production process in countries around the world, which has caused many problems to our planet such as rapid climate change, loss of biodiversity, drastic environmental events, and social problems. In recent years, pressure on countries to transition to cleaner production processes to mitigate problems arising from using natural resources has increased. As a result, green products have become a point of interest due to their low environmental impact, and green product development has become an important part of green growth policies for many countries. Green product development requires technology, capital, infrastructure, and skills which are not evenly distributed among countries, therefore, the capability to develop green products are not the same between countries. The purpose of this dissertation is to explore the evolution of green product development in 61 countries between 2003 and 2015 and explore the effect of this development on their overall green growth performance. To this end, this dissertation is designed based on the concept of product space and its main hypothesis of path-dependent economic growth. It employs an algorithm based on network science theory to identify patterns of green product development, and uses Partial Least Squares Structural Equation Modeling (PLS-SEM) as a statistical method to test the effect of green product development on Countries' Overall Green Growth Performance (COGGP) and suggest activities that can be targeted to foster countries' green product development and overall green growth performance. The results of this dissertation show countries followed the path-dependent economic growth to develop new green products, and at the same time for considerable amount of new green products, countries followed a process, non-path dependent green economic growth, to develop new green products and expand their green production baskets. In addition, the results

show empirically that investment in innovating environmental related technologies enhance countries' overall green growth performance and green product development based on path-dependent economic growth hypothesis, but it is not enough to entirely eliminate the need for technology, capital, infrastructure, and skills for green product development.

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LIST OF ABBREVIATIONS

COGGP	Countries Overall Green Growth Performance
GPS	Green Product Space
GDP	Gross Domestic Product
CGD	Country Green Diversity
HS	Harmonized System
OECD	Organization for Economic Co-operation and Development
PDGPD	Path Dependent Green Product Development
PS	Product Space
RCA	Revealed Comparative Advantage
TI	Technological Innovation
UNEP	United Nations Environment Programme

CHAPTER ONE: INTRODUCTION

The crucial role of natural resources for economic growth in many countries is unavoidable. For decades, many countries utilized natural resources as the main input in their production process to produce products to (a) meet the needs of their population, and (b) grow their economy by exporting the products they are capable of producing. On the other hand, in recent years, the extraction of natural resources increased to the extent that it was not before mainly because of the population growth, and moving toward faster economic growth (Fraccascia et al., 2018; Kurniawan and Managi, 2018).

Growth in natural resource usage and extraction has its own consequences, such as drastic increases of environmental risks, rapid climate change, and fossil fuel depletion that decrease the quality of human life for now and in the future (Hansen et al., 2013; Höök and Tang, 2013). The United Nations Environment Programme (UNEP) reported that natural resources use reached nearly 90 billion tons in 2017 and will reach nearly 180 trillion tons by 2050, which makes it impossible to achieve sustainable development goals. Therefore, it is necessary to develop efficient policies and initiatives to control natural resources usage and greenhouse emissions (UN Environment Programme, 2017).

One strategy promoted in debates on developing efficient policies and initiatives to control natural resources usage and greenhouse emissions is green product development (Chen, 2001; Albino et al., 2009; Hamwey et al., 2013; Fraccascia et al., 2018; Mealy and Teytelboym, 2020). Green product development requires a transition from traditional production processes to cleaner production processes, that is, re-structuring the production process "…to reduce the environmental impacts of [products] design, manufacture, use, and disposal" (Fraccascia et al., 2018). However, re-structuring production processes requires technologies, capital, skills, knowledge, and institutions, which are not evenly distributed among countries around the world. This makes it hard for developing countries to establish such transitions (Hidalgo et al., 2007).

Economic Complexity

According to Smith (1776), nations' wealth is related to the division of labor. As individuals enhance their specializations to do different activities in a society, economic efficiency increases (Hidalgo and Hausmann, 2009). This suggests that an economy grows when individuals within the society increase their specializations to perform different activities (Hidalgo and Hausmann, 2009).

In the modern economy, the division of labor can be seen from another point of view, where instead of humans dividing material activities, they divide their knowledge (Hausmann et al., 2014). In fact, in a modern economy, development will happen when different individuals within a society combine their knowledge in a form of group of individuals, firms, and organizations to perform different activities in order to develop different products and foster society's economic growth. This is the reason that Hausmann et al. (2014) mentioned, in economic world, a product is made with knowledge. As an example, when an economy produces a pen, it is obvious that some materials, machines, etc. were needed to make that pen. However, based on Hausmann et al.'s (2014) point of view, this pen enables us to access to the knowledge behind it, such as the knowledge that ink can be rolled by a small sphere made of steel. Therefore, a pen enables us to write what we want. The important point in this example is that different individuals with different expertise and knowledge came together and worked together as a group of individuals, firms, or organizations and shaped a complex web of interactions that enabled them to produce that pen. In fact, according to Hausmann et al. (2014), products can be considered the vehicle for knowledge, therefore, markets around the world can be considered a rich source of knowledge which societies can access.

To examine how a country can grow its economy, it is not important to know how much knowledge that society has, but it is important to know how diverse that knowledge is. This means, the knowledge that each individual has in a society matters, as they can combine a variety of information together as groups of individuals, firms, and organizations to shape an extensive and complex network of interactions. Then, within this network, individuals combine their knowledge to produce variety of products and contribute to the economic growth of the society that they live in.

Knowledge can be categorized as explicit knowledge or as tacit knowledge (Hausmann et al., 2014). Explicit knowledge is knowledge that can be learned by getting information from an object, such as reading a book, watching TV, etc., and it can easily be transferred among individuals (Hausmann et al., 2014). However, tacit knowledge is the knowledge that is hard to transfer, and could not be transferred to individuals through activities like reading a book or watching the (Hausmann et al., 2014).

Most of the knowledge that exist in a society is tacit, therefore, it is hard and costly for a society to gain all the knowledge in the world, therefore, as Hausmann et al. (2014) mentioned, individuals should specialize. If individuals within a society specialize their knowledge, e.g. one individual with expertise in physics, another in math, and so on, then together, they can accumulate their knowledge to develop a product that benefits society. This is the reason that in societies different types of firms and organizations exist, where individuals with different types of knowledge can collaborate together to develop a complex web of interactions that will enable them to produce different types of products. Therefore, productive capabilities in a society are measured by the ability of a society (country) to construct a large network of interactions between different individuals to combine their knowledge to produce variety of products (Hausmann et al., 2014).

Productive capabilities are not evenly distributed between countries; one country may have individuals with a large variety of knowledge which enables them to cooperate and shape a complex network of interactions, which in turn lets them make different types of complex products such as engines, medical devices, etc., while another country with less productive capabilities may have individuals with limited knowledge, therefore, they are not able to cooperate to produce as complex products. Economic Complexity is a measure to find how large and complex this network of interactions among individuals is, and how existing productive capabilities can be used in each country to produce different types of products (Hausmann et al., 2014).

Product Space

According to Hidalgo et al. (2007), productive capabilities are the technologies, capital, institutions, and skills that a country has to produce different products, which makes it hard to measure the amount of productive capabilities that exist in a country. However, the historical record of products traded between countries is a rich source that can be used to begin measuring countries' productive capabilities. According to Hausmann et al. (2014), by looking at what countries make, it is possible to identify and measure their existing productive capabilities. For instance, airplane engines are complex products that only a few countries can make. This shows that individuals who live in these countries have the required combined knowledge to construct a complex network of interactions which is capable of producing a complex product.

Hidalgo et al. (2007) constructed a network, Product Space (PS), to identify the productive capabilities that exist in a country based on the products that each country produces and exports. The PS network "…connects 775 products that have been traded between all countries in the world [from 1998 to 2000]" (Talebzadehhosseini et al., 2020a). The PS network is depicted in Figure 1 (Hidalgo et al., 2007, p. 8), where the nodes represent the products that were traded between countries in 2000, the links connect the products based on similar productive capabilities they require for production, the nodes size shows the trade value (in thousands of US$) of each product, and the nodes color shows different product classifications (e.g. the purple nodes show chemical products). It is important to mention that the link's color shows the proximity values between two different products, and these values stand between zero to one. In fact, the proximity values show how similar two products are in terms of the productive capabilities they need for production, that is, the higher the proximity values between a pair of products, the more similar the productive capabilities they need for production. For example, the proximity value between an apple and a peach is close to one as both of them need similar skills, institutions, and technologies for production, while the proximity value between an apple and a car engine is close to zero, as the skills, institutions, and technologies to produce a car engine are very different from those needed to produce an apple. In fact, by mapping the trade data (export value of each product that a country produce and export) of each country to the PS network, it is possible to identify the products that each country has the productive capabilities to produce and export.

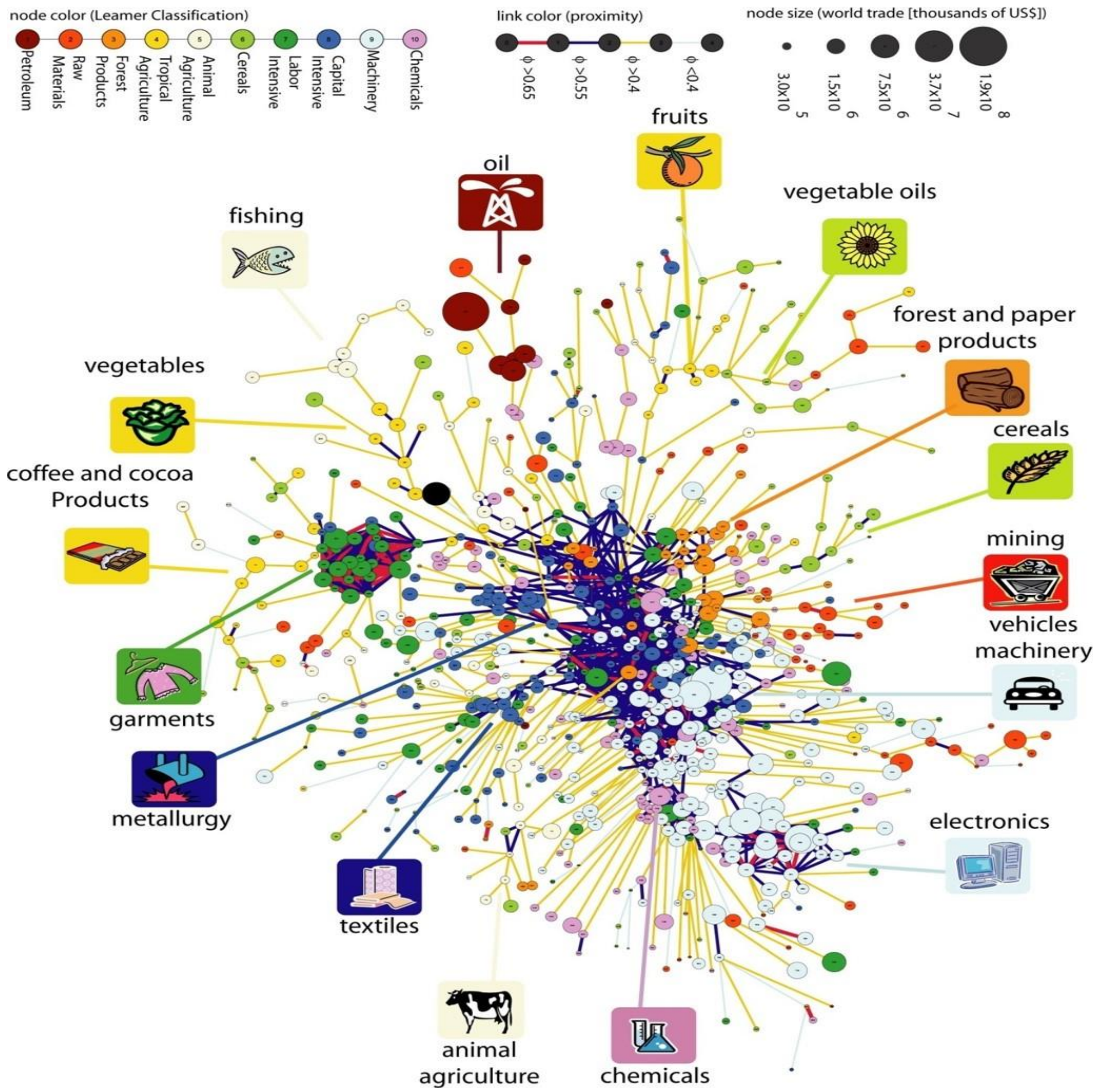

Figure 1. Product Space Network of the products that were traded between countries in 2000.

Note. From "The Product Space Conditions the Development of Nations" by Hidalgo et al., 2007, Science, 317(5837), p. 8 (*https://science.sciencemag.org/content/317/5837/482*). CC BY- American Association for the Advancement of Science.

Revealed Comparative Advantage

The Revealed Comparative Advantage (RCA) is an "...index that [is] defined as the measure of the relative ability of a country to produce a good vis-à-vis its trading partners. A country has RCA on a product if it produces and exports the product more than a share equal to the share of total world trade that the product represents" (Talebzadehhosseini et al., 2020b). For example, if an RCA value for a product, *i,* stand above one in a PS network of a country, it shows that the country's export value for product *i* is more than the total export value of product *i* that all countries export in the world, that is, a country is competitive producer of the product *i*. Being a competitive producer of a product (RCA>1) shows that the country has all the required productive capabilities needed to produce and export that product.

Path-Dependent Economic Growth

According to Hidalgo et al. (2007) a country's economy grows by upgrading the products it produces and export competitively. Therefore, based on the PS network, the path-dependent economic growth hypothesis suggest that it is better for a country to increase the type of its products by producing the new products that require similar productive capabilities, such as capital, technology, infrastructure, and labor, to the products it already produces with RCA. For example, according to this hypothesis, if a country produces and exports a product *i* with RCA>1, it is suggested that the new product, *j*, that the country plans to produce should be the one that requires similar productive capabilities (which means it has a high proximity value) to product *i*. "According to Coniglio et al. (2018), current production capabilities are the key link between what a country produces today and what it will produce tomorrow, in other words the essence, of the mechanism of path-dependent [economic growth]" (Talebzadehhosseini et al., 2020b).

Green Product Space and Path-Dependent Green Economic Growth

Following the theory of the PS network, "Mealy and Teytelboym (2020) used the concept of PS [network] and developed the Green Product Space (GPS) network for 293 green products that were traded between 1995 and 2014 [for all countries]. The main hypothesis of GPS network is that countries tend to develop their green economy according to their existing green production capabilities [(path-dependent green economic growth)]. Similar to Hidalgo et al. (2007), Mealy and Teytelboym (2020) argue that the next new green product added to a country's green production basket should be the one that has the highest proximity value with the green products that are already produced and exported in the green production baskets of that country. In addition, Mealy and Teytelboym (2020) ranked countries according to their Green Complexity Index (GCI) and showed countries with a high GCI have higher environmental patenting rates, lower CO_2 emissions, and more stringent environmental policies. They further constructed the Green Adjacent Possible (GAP) measure that represents the set of technologically proximate green products that a country could potentially become competitive in. Finally, Mealy and Teytelboym (2020) constructed a measure—Green Complexity Potential (GCP)—to predict countries' future competitiveness in green products, and show that the relation between GCP and GCI will suggest the path-dependent in the accumulation of green production capabilities" (Talebzadehhosseini et al., 2020b).

<u>Green Product Development and Green Growth Performance</u>

As mentioned earlier, one broad strategy to promote green growth is transitioning from traditional production process to cleaner production process by developing and producing green products, however, since natural resources and economic opportunities are not distributed evenly around the world, countries' ability to develop and produce a variety of green products is limited (Fraccascia et al., 2018; Hidalgo et al. 2007). This is the main reason that Hidalgo and Hausmann (2009) proposed the path-dependent economic growth hypothesis where countries should consider existing productive capabilities such as infrastructure, technologies, capital, skills, and knowledge to expand the types products they produce and export. However, only considering these capabilities produce limited positive outcomes because being dependent on existing productive capabilities can have negative consequences for overall growth (OECD, 2011a). Therefore, it is not clear how being dependent on existing productive capabilities to develop new green products affect Countries' Overall Green Growth Performance (COGGP), or in other words, we must consider if green product development based on path-dependent economic growth fosters overall green growth performance.

On the other hand, "in recent discussions of economic growth, the role of Technological Innovation (TI) has become a compelling topic for many scholars and policy makers. TI plays an important role in the overall growth, especially green growth, by separating growth from the consumption of natural resources as the only source in production process (Barbier and Burgess, 2017; OECD, 2011a; England, 2000). TI and path-dependent economic growth can be considered important factors that affect a country's overall green growth performance due to two main reasons. First, TI enable economies to produce products that have less waste and environmental impact due to efficient design and manufacturing as well as their use and disposal (Fraccascia et al., 2018). Second, in the short term, path-dependent economic growth will enhance a country's green growth performance without any need for significant structural change for new product production, as it is based on existing productive capabilities (Hidalgo et al., 2007).

Purpose of the Study

The purpose of this dissertation is to:

- Investigate the evolution of GPS networks for 61 countries from 2003 to 2015 to identify patterns of green product development in these countries.
- Discover the effect of Path-Dependent Green Product Development (PDGPD) on COGGP.

- Discover the relationships between TI, PDGPD, and COGGP to determine how TI affects PDGPD and COGGP.

Research Questions

This dissertation explores the following research questions:

RQ1: What is the pattern of green product development in 61 countries between 2003 to 2015?

RQ2: What is the effect of PDGPD on COGGP?

RQ3: What is the effect of TI on PDGPD?

RQ4: What is the effect of TI on COGGP?

Statement of Contributions

This dissertation contributes to the fields of economic complexity, green product development, and green economic growth. First, this dissertation contributes to the concepts of the GPS network and path-dependent economic growth by creating an algorithm which shows that many countries do not follow the path-dependent economic growth hypothesis to produce new green products. Second, this dissertation provides an empirical analysis based on real-world data to demonstrate how TI affects COGGP and a country’s green production development. Third, the findings of this dissertation indicate that while TI is a crucial factor that fosters COGGP and PDGPD, it is not enough to enable countries to go beyond their existing productive capabilities to produce new green products, therefore, along with productive capabilities, TI is another factor that countries should consider while developing their policy agendas for producing new green products.

In summary, this dissertation provides policy actions that can be considered by policy makers and researchers to promote green growth in countries around the world, and contributes the following conclusions to the fields of economic complexity, green product development, and green economic growth:

- Countries should not limit themselves to their existing productive capabilities when developing policy agendas for green product development.
- Investment in TI enhance COGGP.
- Investments in TI improves countries' abilities to produce more new green products based on the path-dependent economic growth hypothesis.
- Expanding countries' green production following the path-dependent economic growth hypothesis enhance COGGP.

<u>Statement of Originality</u>

Parts of this work have been included in conference presentations, a conference proceeding, a journal publication, and a journal paper under review. Other than the work discussed in the following list, the rest of this dissertation has not been published publicly at the time of writing:

- Talebzadehhosseini, S., Garibay, I. (2021). The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. Manuscript in preparation. *In review: Journal of Cleaner Production.*
- Talebzadehhosseini, S., Garibay, I. (2020, July). Analyzing Countries' Paths of Green Growth. In *6th International Conference on Computational Social Science*. Boston, MA.

- Talebzadehhosseini, S., Scheinert, S., Garibay, I. (2020). Growing Green: The Role of Path Dependency and Structural Jumps in Green Economy Expansion, *Journal on Policy and Complex Systems*, 6(1): 5-25.

- Talebzadehhosseini, S., Scheinert, S.R., Garibay, I. (2020). Global Transitioning Towards a Green Economy: Analyzing the Evolution of the Green Product Space of the Two Largest World Economies. In: Cherifi H., Gaito S., Mendes J., Moro E., Rocha L. (eds) Complex Networks and Their Applications VIII. COMPLEX NETWORKS 2019. Studies in Computational Intelligence, vol 882. Springer, Cham. https://doi.org/10.1007/978-3-030-36683-4_51

- Talebzadehhosseini, S., Rajabi, A., Garibay, I. (2019, May). An Agent Based Simulation Model for Developing and Sustaining Green Urban Growth. In *1st International Conference on Smart Tourism, Smart Cities and Enabling Technologies*, Orlando, FL.

- Talebzadehhosseini, S., Gunaratne, C., Scheinert, S., Garibay, I. (2019, April). Countries' Diversification and Transition to Green Economy. In *2nd Northeast Regional Conference on Complex Systems*, Binghamton, NY.

- Talebzadehhosseini, S., Garibay, I. (2018, September). Sustainable Business Model Innovation for Developing the Nation's Green Product Space: Toward a Better Development of Nations Green Economy. In *2018 Doctoral Consortium on Computational Sustainability*, Ithaca, NY.

- Talebzadehhosseini, S., Garibay, I. (2018, May). Multi-Agent Simulation Model for Energy and Green Buildings Sustainable Development. *In Institute of Industrial and Systems Engineers (IISE) Annual Conference and Expo*, Orlando, FL.

CHAPTER TWO: LITERATURE REVIEW

Some parts of this chapter are taken from the published papers and a paper in review of the author:

1. Talebzadehhosseini, S., Garibay, I. (2021). The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. Manuscript in preparation. *In review: Journal of Cleaner Production*.

2. Talebzadehhosseini, S., Scheinert, S. R., & Garibay, I. (2020). Growing Green: the Role of Path Dependency and Structural Jumps in Green Economy Expansion. *Journal on Policy and Complex Systems*, 6 (1): 5-26. https://doi.org/10.18278/jpcs.6.1.2

Summary

The goal of this chapter is to review literature on the concept of economic complexity to discuss how this concept is used over time as an approach to grow economies, especially green economies, and green product development. This chapter is carried out based on four main sections. The first section reviews the literature on how the concept of economic complexity was used to grow economies, the second section reviews the literature of economic complexity and green economic growth, and sections three and four provides an overview of how TI is incorporated in the concept of economic complexity in recent years.

Economic Complexity and Economic Development

Economic growth is not a sufficient indicator of the level of economic development in a country (Acemoglu et al., 2002; Moyo, 2009). Economic growth is simply the annual increase in a country's production basket along with the growth rate of its GDP (Zhang and Zeng, 2008). Economic development not only happens through changing existing production materials, but also through changes in a country's production structure. Structural changes in a country's production materials enable it to enhance its production basket and achieve its desired economic development

(Yang, 1990). This development causes countries to face several problems, such as environmental risks (Gu et al., 2018; Knight and Schor, 2014; Lederer et al., 2018) and high consumption of energy and natural resources (OECD, 2013; Talebzadehhosseini et al., 2020b).

As mentioned in the previous chapter, the goal of economic complexity is to measure the amount of productive capabilities that exist within a country. In addition, by looking at the products that countries produce, it is possible to understand the amount of knowledge that exists within the country (Hausmann et al., 2014). If the amount of knowledge that exists in a country enables it to produce variety of products, then we can say that the country has good knowledge diversity, therefore, it becomes easier for the country to produce different types of products. However, if a country makes different types of products, it means the individuals have diverse knowledge, which enables the country to produce different products (Hausmann et al., 2014).

The concept of human capital is considered a set of invisible resources such as education, experience, and healthcare that are embedded in the division of labor, which enabled the laborer to gain the required knowledge and skills to enhance productivity (Becker, 1962; Teixeira and Queiros, 2016; Goldin, 2016). Countries with more educated individuals can experience higher growth in their economy, as with more educated individuals within a country, the more knowledge available to share, therefore, individuals can be more innovative and productive, which can lead a country to produce variety of new products (Romer, 1990; Benhabib and Spiegel, 1994; Bodman and Le, 2013; Teixeira and Queiros, 2016). This shows that human capital has a direct effect on countries' economic development (Teixeira and Queiros, 2016).

In addition to the direct effect of human capital on country's economic development, humans have an indirect effect on country's economic development by interacting with a country's productive structures (Teixeira and Queiros, 2016). Human capital's indirect effect on economic development is crucial in countries that specialize in advanced technology (Silva and Teixeira, 2011). To explore the effect of changing complexity on a country's economic development, it is important to consider the demand-side factors (evolutionary economic theories), since changes in market demand will lead countries to produce different products requiring structural changes (Witt, 2001; Metcalfe et al., 2006; Dietrich, 2012; Teixeira and Queiros, 2016).

According to Teixeira and Queiros (2016), "structural changes can be instigated by both exogenous and endogenous [factors]". When the exogenous factor such as "…life cycle dynamics of a sector…" (Teixeira and Queiros, 2016) go from its birth moment to maturity moment in a country, some factors such as demand and income rate will reduce (Teixeira and Queiros, 2016). In this case, and in order for an economy to continue its growth, entrepreneurs start to invest in developing new sectors to keep the economy growing (Saviotti and Frenken, 2008; Munier, 2013). However, endogenous factors such as "…changes in consumption patterns in favor of goods…" (Teixeira and Queiros, 2016) will cause the country to implement structural changes to produce products which absorb new demands and increase the country's overall income.

When considering countries with customers that ask for high-tech and complex products, such as advanced medical devices as an example, only the US and Germany are capable of producing these devices (Hausmann et al., 2014). In fact, when new medical devices are needed, then by investing in new sectors, the US and Germany are capable of innovating new complex medical devices in order to not lose their market. In this way, the new sectors enable them to use the variety of knowledge that exist within their individuals to develop new complex products such as new medical devices. Therefore, changing the complexity of products in an economy by investing in new sectors enables the country to have its market while growing its economy. According to

(Peneder, 2003; Teixeira and Queiros, 2016), "…structural change in favor of a specialization in technologically more advanced sectors leads to economic growth".

Changes in complexity to develop an economy is different in a country with high knowledge diversity from a country with a low knowledge diversity. In a country with high knowledge diversity, human capital development has a larger effect in developing the economy when compared to a country with low knowledge diversity. In this society, individuals are more educated, and they can adapt themselves to changes in complexity more efficiently since they already have enough knowledge to accommodate this change. Therefore, in this society, structural changes to produce new products to develop the economy is more reasonable with a high chance of success. As an example, in advanced societies, most sectors are specialized in producing high-tech and complex products, therefore, structural changes in high-tech industries to change product complexity and produce new complex products can result in successful economic growth.

However, in countries with low knowledge diversity, since the individuals are less educated, the situation is different. Changing the complexity increases the risk of unsuccessful structural changes in these countries, as the individual's education level is not enough to accommodate such a change. Bringing new technologies from neighboring countries can help, since by having new technologies, individuals can gain the knowledge that exists in the imported technology, therefore, they can change complexity to experience more successful economic development.

Path-Dependent Economic Growth Hypothesis and Products Development

The concept of path-dependent economic growth hypothesis and product development was proposed by Hidalgo et al. (2007). Hausmann and Klinger (2010) and Hidalgo et al. (2007) analyze the export baskets of Ecuador and some African countries—Kenya, Mozambique, Rwanda, Tanzania, and Zambia— and show that they inhabit a peripheral position in the PS network. Coniglio et al. (2018) add that this peripheral position is persistent over time. Minondo (2011) studied export baskets of ninety-one countries to show how they are diversified in their production baskets by calculating the degree of centrality in the PS network. The results of their research showed that the degree of centrality in the PS network is a strong predictor of diversification level. Coniglio et al. (2018) mention another study that investigates path-dependency in countries' products diversification by Boschma and Capone (2016), which analyzed the process of trade diversification for EU-27 and European Neighborhood Policy (ENP) countries between 1995 and 2010. The authors find evidence of path-dependence as countries develop their revealed comparative advantage in products related to those in which they were already specialized (Talebzadehhosseini et al., 2020b).

Economic Complexity and Green Economic Growth

Mealy and Teytelboym (2020) discussed that a country's green growth and green product development also follow the path-dependent product development hypothesis. The authors showed that countries can expand their green production baskets based on their existing green production capabilities and use this finding as a fundamental basis regarding how countries can re-orient their current industrial capabilities in order to have greater green growth (Talebzadehhosseini et al., 2020b).

In many studies, economic complexity and the path-dependent economic growth hypothesis became the fundamental concepts that show how different economies can competitively diversify their production baskets to produce and export a variety of products (Mealy and Teytelboym, 2020; Talebzadehhosseini et al., 2020; Coniglio et al., 2018; Fraccascia et al., 2018; Hamwey et al., 2013). Mealy and Teytelboym (2020) consider a list of 293 green products and show that countries foster green economies following a path-dependent economic growth hypothesis, that is, the production of new green products using existing green products already being competitively produced. The authors propose the Green Adjunct Possible (GAP) index to identify the number of green products that countries can produce based on the path-dependent hypothesis. Finally, the ranking of countries based on a GAP index shows that countries with a high GAP index have a higher rate of environmental patents, lower CO_2 emissions, and more stringent environmental policies than countries lower on the list. Coniglio et al. (2018) proposed a novel approach to test if countries consider existing productive capabilities to grow their economy. The researchers point out that by creating high trade openness, utilizing high scientific and technology investments, countries can go beyond existing productive capabilities to produce products that have a higher potential for economic growth. This growth was termed non-path-dependent economic growth. However, the authors do not examine or evaluate green growth or products specifically. Fraccascia et al. (2018) construct a PS and utilize the path-dependent economic growth hypothesis to propose a method that identifies green products with the highest potential for green growth. The authors show that green products requiring similar capabilities to the products that a country already produces with a high competitive advantage should be considered as the green products that have the highest potential for green growth. By considering a limited number of green products, the authors show what green products a country can consider for production to grow its green economy. However, the analysis does not address how green products that should be considered for production affects a country's overall green growth performance. Talebzadehhosseini et al. (2020) constructed a comprehensive list of green products to explore the patterns of green growth in the United States and China, and demonstrate that the United States and China expanded their green production baskets based on the path-dependent economic growth hypothesis. Nonetheless, at the same time, there are considerable additions to their green production baskets based on the non path-dependent hypothesis, which the authors term as "High-Energy Jumps", in advancing green growth. In fact, the researchers discussed that investment in innovative environmental technologies enable the U.S and China to go beyond their existing green productive capabilities and produce a variety of competitive green products that have the highest potential for faster green growth. However, this research did not empirically show how innovation affects the United States and China's green product development and overall green growth performance. Hamwey et al. (2013) also construct a PS network and uses the path-dependent economic growth hypothesis to identify green products that Brazil can produce to diversify its green production basket. However, this limited work does not show how production of the selected green products affects overall green growth performance.

Green Economy and Green Growth

According to Knight and Schor (2014) and the United Nations Environment Programme (UNEP), a green economy can be defined as "one that results in improved human well-being and social equality, while significantly reducing environmental risks and ecological scarcities" (3723). On the other hand, green growth is defined as "growth achieved by saving and using energy and resources efficiently to reduce climate change and damage to the environment, securing new growth engines through research and development of green technology, creating new job opportunities, and achieving harmony between the economy and environment" (Kasztelan 2017, 489). Green growth and the green economy are both suggested as solutions to financial and economic crises (Kasztelan 2017). Both involve improving the global economy by investing in the environmentally friendly products, markets, and services (Kasztelan 2017). Although the terms green economy and green growth have different origins, they are often used interchangeably (Kasztelan 2017; Talebzadehhosseini et al., 2020b).

The driving force behind the development of green economy and green growth is their focus on comprehensively incorporating the environment into the economy. Mainly through technological innovations, in the concepts of the green economy and green growth, feasible approaches to improving the results of economic activity are identified while considering climatic problems and deficiency in natural resources (Kasztelan 2017). Under the green economy approach, the goal is two-fold. It aims to transform the economy in such a way that it reduces environmental and ecological deficiencies, while at the same time improving justice and social welfare. Such change will be achieved by investment, the creation of “green” jobs, the creation of markets for new products, and the reinforcement of international trade. The main goal under green growth is to maintain economic growth, while taking into account the importance of natural capital and recognizing its role in production (Kasztelan 2017; Talebzadehhosseini et al., 2020b).

Technological Innovation and Countries Overall Green Growth Performance

According to the OCED (2011b), TI is a key factor that enables countries to both grow and stay green and is one of the channels that opens new ways for advancement in green growth performance. The pressure on countries to increase green growth performance has led to more emphasis on important policy issues (Hu et al., 2019). However, the literature is not clear how increasing green TI activities affects green growth performance (Song et al., 2020). Guo et al. (2017) utilize a Structural Equation Model (SEM) to investigate the effects of Environmental Regulations (ER) and TI on Regional Green Growth Performance (RGGP) in 30 Chinese provinces. The study confirms that ER does not have any effect on RGGP, but that TI does have a positive and strong effect on RGGP. Hu et al. (2019) develop a model to assess the effects of TI and Institution Innovation (II) in 30 Chinese provinces' green growth performance using data for the years 2008 to 2017. These results confirm that TI enhances green growth performance in all 30 provinces and that there is strong and positive relation between TI and green growth performance.

Technological Innovation, Path-Dependent Green Products Development, and Countries Overall Green Growth Performance

As discussed in introduction section, RCA and proximity measures are the main concepts in the path-dependent economic growth hypothesis. When products in the PS network have an RCA above one, then the country has the required productive capabilities to produce the product and is a competitive producer of that product. Furthermore, when the product is connected to another product with high proximity value, it is better for the country to produce that product than one with a lower proximity value

By expanding on the work of Hidalgo et al. (2007), Fraccascia et al. (2018) proposed the concept of maximum proximity by constructing the PS network for 141 countries for the period of 2005 to 2013. According to Fraccascia et al. (2018), maximum proximity is the maximum value of proximity that a green product can have with products with an RCA greater than one. Following this concept, the researchers constructed the Country Green Diversity (CGD) index, which shows that the higher the CGD is for each country, the more diversified the green production basket is. Therefore, countries with higher CGD values are better positioned to advance green growth performance. Talebzadehhosseini et al. (2020b) developed the PS network for 65 countries for the years 2007 to 2017 and showed that there is strong negative relation between investment in innovating different environmental technologies and countries' path-dependent green product development. In fact, the research posits that more innovative economies have the ability to go beyond existing capabilities by producing a variety of green products competitively, which means faster green economic growth. In another work, Talebzadehhosseini et al. (2020a), constructed a GPS network for the United States and China, which showed that the world's two largest economies do not follow the path-dependent hypothesis to grow their green production baskets due to high investments in innovating environmental-related technologies. Therefore, in these cases, green products can be produced that do not require similar productive capabilities for production to the green products that were already being produced with a high comparative advantage.

Even though some researchers explore the path-dependent economic growth hypothesis to validate the green product development hypothesis, literature does not address how the path-dependent hypothesis effects countries' green growth performance. In addition, there is insufficient investigation into the role of TI in expanding a country's green production basket.

CHAPTER THREE: METHODOLOGY

This chapter is taken from the published papers and a paper in review of the author:

1. Talebzadehhosseini, S., Garibay, I. (2021). The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. Manuscript in preparation. *In review: Journal of Cleaner Production*.

2. Talebzadehhosseini, S., Scheinert, S. R., & Garibay, I. (2020). Growing Green: the Role of Path Dependency and Structural Jumps in Green Economy Expansion. *Journal on Policy and Complex Systems*, 6 (1): 5-26. https://doi.org/10.18278/jpcs.6.1.2

3. Talebzadehhosseini, S., Scheinert, S.R., Garibay, I. (2020). Global Transitioning Towards a Green Economy: Analyzing the Evolution of the Green Product Space of the Two Largest World Economies. In: Cherifi H., Gaito S., Mendes J., Moro E., Rocha L. (eds) Complex Networks and Their Applications VIII. COMPLEX NETWORKS 2019. *Studies in Computational Intelligence*, vol 882. Springer, Cham. https://doi.org/10.1007/978-3-030-36683-4_51

Summary

The concept of green product development as a strategy to foster green growth has became an important policy agenda in many countries. However, productive capabilities are not evenly distributed among countries, which make it hard for each country to identify the path with highest potential for green economic growth. Therefore, it is vital to construct a comprehensive methodology to propose the path that a country can follow through targeted policy actions to foster its green product development and identify how such a development would effect its overall green growth performance. To do so, the methodology of this dissertation is divided in four sections:

- A comprehensive list of green products and their data is obtained from the OECD database.
- The GPS network is constructed for 61 countries for the years of 2003 to 2015.
- An algorithm is proposed to investigate the evolution of GPS network in all 61 countries to identify their pattern of green products development for the years of 2003 and 2015.

- Partial Least Square Structure Equation Modeling (PLS-SEM) is employed to investigate the interaction effects of PDGPD and TI on COGGP.

To best of our knowledge, previous research constructed the GPS network for different countries and identified that patterns of green product development follow the path-dependent economic growth hypothesis. However, the algorithm used in this dissertation shows that patterns of green product development in countries not only follow the path-dependent economic growth hypothesis but also follow a different process, which we term the "Non path-dependent green economic growth hypothesis", that is, countries go beyond their existing productive capabilities to advance their green product development. This algorithm contributes to the literature by identifying that the path-dependent economic growth hypothesis that is used by many researchers as way of successful green product development is not the only hypothesis that should be considered by countries that are developing their green products development agenda.

In addition, this dissertation is one of the earliest works that show empirically how TI advancements affects countries' PDGPD and their overall green growth performance.

Data

To obtain the data for this research, first a comprehensive list of green products had to be developed. To this end, first, this dissertation uses the OECD report, *The Stringency of Environmental Regulations and Trade in Environmental Goods,* to obtain a list of green products (Sauvage 2014)[1]. The OECD report constructs a comprehensive list of green products that contains

[1] The list of green products can be found at https://www.oecd-ilibrary.org/trade/the-stringency-of-environmental-regulations-and-trade-in-environmental-goods_5jxrjn7xsnmq-en.

248 green products based on the 6- digits Harmonized System (HS). Due to data unavailability for all 248 green products, this dissertation considers 247 green products to construct a GPS network and discover the relationship between TI, PDGPD, and COGGP. Second, the green growth indicators and their related data are collected from the OCED statistics database to explore the affects of TI on PDGPD and COGGP, and PDGPD on the COGGP. In the third step, the trade data of 247 green products were obtained from the United Nation (UN) Comtrade database for the 61 countries (UN Comtrade 2019; Talebzadehhosseini et al., 2020b). Due to unavailability of green growth indicators data, out of 238 countries, this analysis only utilized data from 61 countries for the years 2003 to 2015 from the OECD database. The data includes (Talebzadehhosseini et al., 2020b):

1. Information on the year that each green product was exported
2. The countries that exported and imported green products
3. All green product codes according to HS classification
4. Each country's ISO code
5. The trade values of each green product for all countries that was traded in each year (2003–2015).

The trade value of each green product shows how much a specific green product was exported by each country. The trade value is based on US dollars, and the export values are considered for all 247 green products. Trade values are used to calculate the RCA and the proximity values for each country per year. A list of some green products and their related data is listed in Table 1 (Talebzadehhosseini et al., 2020b).

Year	Country	Country ISO code	HS6 green products code	Green product name	Export value (US$)
2013	Germany	DEU	390940	Phenolic resins, in primary forms	$251,471,129
2013	United States of America	USA	390940	Phenolic resins, in primary forms	$237,674,965
2013	China	CHN	390940	Phenolic resins, in primary forms	$156,046,507
2017	Germany	DEU	840690	Turbines; parts of steam and other vapor turbines	$500,354,255
2017	United States of America	USA	840690	Turbines; parts of steam and other vapor turbines	$309,129,267
2017	China	CHN	840690	Turbines; parts of steam and other vapor turbines	$430,767,939

Table 1. List of some green products

<u>Constructing Green Product Space</u>

Similar to Mealy and Teytelboym (2020), the GPS network for 247 green products is developed for 61 countries for the years 2003 to 2015. In order to develop a GPS network, the following steps have been taken:

- We extracted the export value of each green product for each country from the trade data for 247 green products obtained from the UN Comtrade database.
- The RCA value for each green product was calculated using equation below to identify the green products that each country produces and exports with a comparative advantage:

$$RCA_{ci} = \frac{X_{ci}}{\sum_j X_{cj}} / \frac{\sum_c X_{ci}}{\sum_{ci} X_{cj}} \tag{1}$$

where X_{ci} is the export value of product *i* for country *c*, $\sum_j X_{cj}$ is the total export value of all products, *j*, that is exported by country, *c*, $\sum_c X_{ci}$ is the total export value of product *i* that is exported by all countries *c*, and $\sum_{ci} X_{cj}$ is the total value of all products that has been traded between all countries in the world.

- After calculating the RCA for the green products, a matrix M_{cp} is developed, where *c* stands for countries and *p* stands for green products. The element of the matrix is either one or zero, that is, if the green product's RCA is above one, the element is one, otherwise, it is zero:

$$M_{ci} = \begin{Bmatrix} 1 \ if \ RCA_{ci} \geq 1; \\ 0 \ otherwise. \end{Bmatrix} \tag{2}$$

where M_{ci} is the entries in the matrix and it is 1 if country *c* exports product *i*, with an RCA larger than 1, and 0 otherwise.

- Then, the proximity between all green products is calculated using equation below:

$$\varphi_{i,j} = \min\{P(x_i \ / \ x_j), P(x_j \ / \ x_i)\} \tag{3}$$

where $\varphi_{i,j}$ is the measure of proximity between any two products *i* and *j*, x_i and x_j are the export values of products *i* and *j* that have been traded between countries, respectively, and $P(x_i \ / \ x_j), P(x_j \ / \ x_i)$ "is the conditional probability of exporting good *i* given that you export good *j*" (Hidalgo et al. 2007, 2)

- In the last step, a matrix was developed in which the elements of the matrix are the proximity values calculated in previous step. The proximity values show how two different green products are related to each other. The higher the proximity value is, the more similar the productive capabilities they required for production.

Following these steps enabled us to develop a GPS network for all 61 countries (Talebzadehhosseini et al., 2020a).

Testing the Pattern of Green Product Development Based on Green Product Space

In order to identify the pattern of green products development in the GPS network, the following steps are followed (Talebzadehhosseini et al., 2020b; Coniglio et al., 2018):

- To begin the analysis, what a new green product is must be defined. Thus, we define a new green product as a product that a country was not a competitive producer of (RCA<0.5) in 2003, but became a competitive producer of the product (RCA>1) in 2015. A RCA of <0.5 is considered the threshold for undeveloped green products, as considering other threshold values did not provide a significant difference in the final results.

- The time period of 2003 to 2015 is used to determine new green products for each country. Three separate time frames were developed, each with a span of 10 years: 2003-2013, 2004-2014, and 2005-2015. A list of new green products is developed for each country in each time interval (K_c).

- The RCA for all green products is calculated using equation (1), and for each base year, e.g. 2003, 2004, 2005, etc. the green products with RCA>1 are listed (U_{ct_0}).

- The proximity values between all pairs of green products is calculated for each base year according to equation (3).

- In the last step, a proximity matrix for all green products is constructed based on

$$D_{ic} = \begin{Bmatrix} d_{ic}(\varphi_{i,j}) = \max(\varphi_{i,j}) \; when \; j \in U_{ct_0}, i \in K_c \\ no\ value \qquad if \; j \notin U_{ct_0} \end{Bmatrix} \tag{4}$$

where $d_{ic}(\varphi_{i,j}) = \max(\varphi_{i,j})$ shows the proximity of new green products to the most related green products (RCA>1) at each base year (Coniglio et al., 2018), U_{ct_0} represents the list of green products with RCA>1 as described in step 3, and K_c is the list of new green products within a certain time interval. The maximum proximity is considered in order to determine whether new green products are developed based on products with RCA>1 at the base year. After implementing these analyses, a statistical analysis is used to show how countries expanded their green production basket. To this end, we adopted (Coniglio et al., 2018) method, and the analysis was implemented using the non-parametric statistical approach, specifically the Kernel Density Estimation (KDE). KDE uses all data points to estimate the shape of a dataset (Duranton and Overman, 2005). For the purpose of this dissertation, and in order to understand how new green products (K_c) are added to countries' green production basket, the kernel smoothed density estimation function is used for any level of proximity values. The function is as follows:

$$\overline{K}\,(d) = \frac{1}{(\sum_{i=1}^{M}\sum_{t=2003}^{2015} I_{it})h}\sum_{i=1}^{M}\sum_{t=2003}^{2015} I_{it}\, f\left(\frac{d-d_{it}}{h}\right) \tag{5}$$

where densities are calculated non-parametrically using a Gaussian Kernel function with bandwidth h set according to Silverman's optimal rule of thumb. In the above equation, $\sum_{i=1}^{M}\sum_{t=2003}^{2015} I_{it}$ equals the total number of new green products in each time interval, and d_{it} is calculated using the equation in step six (Talebzadehhosseini et al., 2020a).

Then, in order to identify the pattern of green products development in 61 countries, following steps are followed (Talebzadehhosseini et al., 2020a):

1. The equation (5) is used to estimate the shape (distribution) of the proximity values that was obtained based on equation (4). This represents the actual proximity value.

2. The Monte Carlo simulation is implemented, which takes 1,000 random draws equal to the actual number of new green products in each time interval to generate a simulated proximity value. These calculations allow us to compare the proximity values of new green products calculated in the first step with the proximity values of randomly generated new green products. The goal is to identify whether new green products are added to countries' green production basket randomly or not.

3. The distribution of proximity values (actual proximity) for the new green products is then compared with the simulated proximity values (counterfactual proximity), and will result in three possible scenarios:

    - If the distribution of the actual proximity value stands fully to the right side of the counterfactual proximity distribution, the actual proximity values are higher than the simulated proximity values, which means that new green products are developed based on the green products that a country is already capable of producing. This shows that the new green products are not randomly added to the country's green production basket; the full path-dependence hypothesis is confirmed.

    - If the distribution of actual proximity stands below the counterfactual proximity distribution the full non-path dependent hypothesis can be confirmed.

    - If the distribution of actual proximity stands below and partially to the right side of the counterfactual proximity distribution, then the path-dependent hypothesis can only be confirmed for the new green products with proximity values that are higher than the randomly generated values, that is, new green products added to country's new green production basket followed both the path-dependent and non-path dependent process (Talebzadehhosseini et al., 2020a).

Countries Green Growth Indicators

The report by OECD (2017), *Green Growth Indicators*, introduces indicators used to monitor and assess the progress of countries towards green growth development. Table 2, selected green growth indicators from OECD (2017), shows these green growth indicators. Due to space limitations, only selected green growth indicators[2] are shown. According to Table 2, the Group column shows the main objectives of the OECD (2017) green growth indicators. In fact, the goal of green growth indicators is to measure a country's efforts in creating an efficient low-carbon economy and improving living conditions while preserving natural resources and increasing economic green growth (OECD, 2017). The Sub-group column shows the main headline indicators to better communicate with policy makers, media, and citizens regarding the main elements of a country's green growth performance. The Indicator column shows the factors that measure the OECD countries' efforts in enhancing their green growth performances. For example, the production-based CO_2 emissions show the amount of CO_2 that each country caused because of their production processes. The Unit column shows each indicator's unit of measurement. Other studies (e.g. Koçak, 2020; Kim et al., 2014; Kasztelan, 2017) use different indicators to measure green growth performance. For example, Koçak (2020) selects 22 green growth indicators, such as production-based CO_2 emissions, energy intensity, development of environment-related technologies, etc., and implement gray rational analysis along with the entropy method to identify the green growth

[2] The full list of green growth indicators is accessible here: https://stats.oecd.org/Index.aspx?DataSetCode=GREEN_GROWTH

key indicators of 36 OCED countries in 2015. The results of this analysis shows that the key indicators in growing the green growth performance are CO_2 productivity, TI, and land resources. By considering the role of measuring a country's green growth performance in suggesting policy actions that promote green growth, Kim et al. (2014) selects 12 green growth indicators, such as CO_2 emissions, energy usage per unit of GDP, etc., and develop a tool to measure green growth performance in 30 countries. The findings show that a country's production and consumption processes should be more environmentally and economically sustainable. Kasztelan (2017) selects 33 indicators such as production-based CO_2 emissions, energy productivity, non-energy material productivity, environmentally related technologies, real GDP per capita, etc., and apply a multidimensional comparative analysis to measure green growth performance in 21 countries. Several researchers such as Mensah et al. (2018), Lyytimäki et al. (2018), and Mensah (2019) discuss the importance of indicators related to TI as well as CO_2 productivity in growing the overall green growth performance. Accordingly, this dissertation selects indicators related to CO_2 productivity, energy productivity, non-energy material productivity, TI, and economic context to examine the contribution of TI development on a country's green growth and green products development.

Table 2. Selected green growth indicators from OECD (2017)

Group	Sub-group	Indicator	Unit
Environmental and resource productivity	CO_2 productivity	Production-based CO_2 emissions	Tons
	Energy productivity	Energy productivity, GDP per unit of TPES	US$, 2015
	Non-energy material productivity	Non-energy material productivity, GDP per unit of DMC	US$ per kg
Natural asset base	Freshwater resources	Total renewable freshwater Per capita	Cubic meters per capita
	Land resources	Water, % total	Percentage
	Atmosphere and climate	Annual surface temperature	Number
Environmental dimension of quality of life	Exposure to environmental risks	Mean population exposure to PM2.5	Micrograms per cubic meter
Economic opportunities and policy responses	Technology and innovation: Patents	Development of environment-related technologies, % all technologies	Percentage
	Technology and innovation: R&D	Environmentally related government R&D budget, % total government R&D	Percentage
Socio-economic context	Economic context	Real GDP per capita	US$, 2015

The selected green growth indicators for each headline indicator are listed in Table 3. Descriptive statistics of variables and the data for each indicator is obtained from the OECD statistics website. It shows green growth indicator data for 61 countries from three unique time intervals: 2003-2013, 2004-2014, and 2005-2015. This time span was chosen because it takes time for countries to identify new technologies that increase or decrease the overall green growth performance. Therefore, by considering a time span of 10 years, the goal is to better understand how a country's efforts in TI affect their overall green growth performance (Coniglio et al., 2018).

Table 3. Descriptive statistics of variables

Headline Indicators (Latent Variables)	Green Growth Indicators (Measurement Variables)	Unit	N	Max.	Min.	Mean	SD
COGGP	Production-based CO_2 emissions, energy related CO_2 per capita (COGGP1)	Tons	183	20.14	0.26	6.43	4.21
	Energy intensity, TPES per capita (COGGP2)	Tons	183	18.02	0.44	3.23	2.62
	Non-energy material productivity, GDP per unit of DMC (COGGP3)	US$ per kilogram	183	8.94	0.56	2.85	1.79
	Real GDP per capita (COGGP4)	US$	183	86083.8	3175.21	30328.0	17343.7
TI	Development of environment-related technologies, % inventions worldwide (TI1)	%	183	30.7	0	1.59	5.01
	Development of environment-related technologies, % inventions per capita (TI2)	%	183	47.71	0	6.92	10.46
PDGPD	Country Green Diversity Index (PDGPD1)	Number	183	164	2	55.15	39.32
	Share of green products (PDGPD2)	%	183	0.04	0.0006	0.016	0.011

Note: Max. refers to Maximum, Min refers to Minimum, and SD refers to Standard Deviation

Path-Dependent Green Product Development

Fraccasscia et al. (2018) proposed a CGD index that demonstrates the number of green products that a country has with high RCA (greater than one) and shows how diverse a country's green production basket is. A high CGD value represents a more diversified green production basket, therefore, a country with a high CGD value is better positioned to advance its green production basket. Fraccasscia et al. (2018) define CGD as:

$$CGD_c = \sum_{p=1}^{p} A_{cp} \ where \begin{Bmatrix} A_{cp} = 1 & if & \emptyset_{cp}^{MAX} = 1 \\ A_{cp} = 0 & if & \emptyset_{cp}^{MAX} < 1 \end{Bmatrix} \quad (6)$$

where $\sum_{p=1}^{p} A_{cp}$ is the total number of green products, *p*, for each country, *c*, that have an RCA greater than one, and where $\emptyset_{cp}^{MAX}$ is the maximum proximity that a green product has with all the products that a country produces and exports with high RCA (greater than one). Maximum proximity identifies the green products that have the most similar productive capabilities with products that a country already produces and exports competitively. Therefore, a $\emptyset_{cp}^{MAX}$ of one represents new green products that a country added to its green production basket according to the path-dependent hypothesis, and a $\emptyset_{cp}^{MAX}$ below one represents green products that were not produced competitively. Fraccasscia et al. (2018) used equation (6) and found that Italy, France, the United States, and China have the highest CGD, therefore, they are in a better position to grow their green production baskets compared to other countries. However, this work only considers a limited number of green products and does not consider the effect of TI on the productive capabilities to produce new green products based on the path-dependent hypothesis and does not show how path-dependent green product development affects COGGP. Thus, this dissertation intends to fill this gap by calculating the CGD of 61 countries for the years 2003 to 2015, investigate the role of TI on a country's CGD, and analyze how it affects COGGP. To calculate the CGD (Talebzadehhosseini et al., 2019; Fraccasscia et al., 2018):

1. Three separate time frames include a span of 10 years were chosen: 2003-2013, 2004-2014, and 2005-2015.

2. Export data from the Observatory of Economic Complexity (OEC) database is used for all the products, *p*, exported by the 61 countries for each year for the analysis.

3. The analysis also utilizes the export data for 246 green products for the years 2003, 2004, 2005, 2013, 2014, and 2015 from the list of green products developed by Sauvage (2014).

4. By calculating the RCA values of all products, *p*, for each country, *c*, for each year, equation (1) derives a list in $U_{RCA_{p,t}}$, where *t* denotes year.

5. Equation (3) gives the proximity values between each pair of products, $\emptyset_{i,j}$ for the years 2003, 2004, and 2005.

6. To identify the green products that each country adds to its green production basket based on the path-dependent hypothesis, the list of green products in step 3 above was used and the green products were selected from the $U_{RCA_{p,t}}$. Then, K_c lists the green products with an RCA less than 0.5 in the years 2003, 2004, and 2005 and an RCA greater than one in 2013, 2014, and 2015 for each country. This helps identify a set of green products that a country could not produce nor export competitively in 2003, 2004, and 2005 (i.e., RCA less than 0.5) but could produce and export competitively (RCA greater than one) in 2013, 2014, and 2015.

7. By comparing the two, the difference identifies the number of green products that each country added to its green production basket based on the path-dependent hypothesis.

8. From the $U_{RCA_{p,t}}$, competitively produced and exported products (RCA greater than one) in 2003, 2004, and 2005 are identified and listed in $U_{c,t}$. Then, the proximity values between the green products in K_c and products $U_{c,t}$ is calculated using:

$$\emptyset_{cg}(t) = max\{\varphi_{gi}(t)\} \tag{7}$$

where *c* denotes the countries, g the green products, *t* the years, and $\varphi_{gi}(t)$ the proximity values of green products for products with an RCA greater than one in 2003, 2004, and 2005, $i \in U_{c,t}$, and $g \in K_c$, give the maximum proximity of green products added to green production baskets based on the highest similar productive capabilities and following the path-dependent hypothesis (Fraccascia et al., 2018).

9. Finally, by using equations (6) and (7), the CGD for each country for each time span is calculated. In addition to the CGD, the share of green products that each country produces and exports is compared to the total number of green products that all countries produce and export competitively using the following:

$$\text{Share} = \frac{CGD_c}{\sum K_c} \tag{8}$$

The CGD and share values of selected countries in each time span are shown in Table 4, and the descriptive statistics of the shares of green products and the CGD of 61 countries based on three unique time intervals are shown in Table 3 (Talebzadehhosseini et al., 2021).

Table 4. The CGD and share values of selected countries in each time span

Countries	Time Span	CGD	Share (%)
United Arab Emirates	2003 to 2013	11	0.003352
Argentina	2003 to 2013	14	0.004266
Australia	2003 to 2013	14	0.004266
Austria	2003 to 2013	127	0.038696
Bulgaria	2003 to 2013	57	0.017367
United Arab Emirates	2004 to 2014	12	0.003537736
Argentina	2004 to 2014	18	0.005306604
Australia	2004 to 2014	18	0.005306604
Austria	2004 to 2014	128	0.037735849
Bulgaria	2004 to 2014	57	0.016804245
United Arab Emirates	2005 to 2015	16	0.004679731
Argentina	2005 to 2015	22	0.00643463
Australia	2005 to 2015	16	0.004679731
Austria	2005 to 2015	132	0.03860778
Bulgaria	2005 to 2015	48	0.014039193

Partial Least Square Structural Equation Modeling

There are two types of SEMs that are available to researchers: Covariance - Based SEM (CB-SEM) and variance - based partial least squares (PLS-SEM) (Wei et al., 2019; Hair et al., 2012). CB-SEM has been widely used by many researchers, especially marketing researchers in the past, however, since PLS-SEM does not have many constraints regarding the data and specification of relationships between the variables, the focus has shifted from CB-SEM to PLS-SEM recently (Hair et al., 2012). The PLS-SEM "…is a statistical method [to study the] complex multivariate relationships [between] observed and latent variables" (Sanchez, 2013). The PLS-SEM uses the path model analysis, structural model (relation between latent variables), and measurement model (relation between each latent variable and related indicators) to analyze the complex relationship between variables (Sanchez, 2013).

In this dissertation, the PLS-SEM is used to discover the relationships among TI, PDGPD, and COGGP due to three main reasons: first, PLS-SEM uses Ordinary Least Squares (OLS) regressions to estimate the relations between variables in the model, therefore, it has limited restrictions regarding data sample size, which can achieve a high level of statistical power (Hair et al., 2012). Second, since PLS-SEM does not have many constraints regarding the size of the data, the rate of achieving "…biased test statistics, inadmissible solutions, and identification problems [are very low]" (Hair et al., 2012). Third, while CB-SEM can only handle formative variables under specific conditions, PLS-SEM can handle both formative and reflective variables without any specific conditions (Hair et al., 2012). This dissertation uses the plspm package in R software to construct the model, perform statistical analysis, and test the proposed hypotheses. Figure 2, PLS path modeling of the proposed conceptual model, depicts the PLS path model of the proposed conceptual framework and hypotheses along with the illustration of the inner and outer model. The structural model shows the relationships between different latent variables and the measurement model shows the relationships between latent variables and their blocks of indicators. As seen in Figure 2, the latent variables in the measurement model are measured indirectly through the blocks of indicators in a reflective way (Aboelmaged, 2018; Sanchez, 2013).

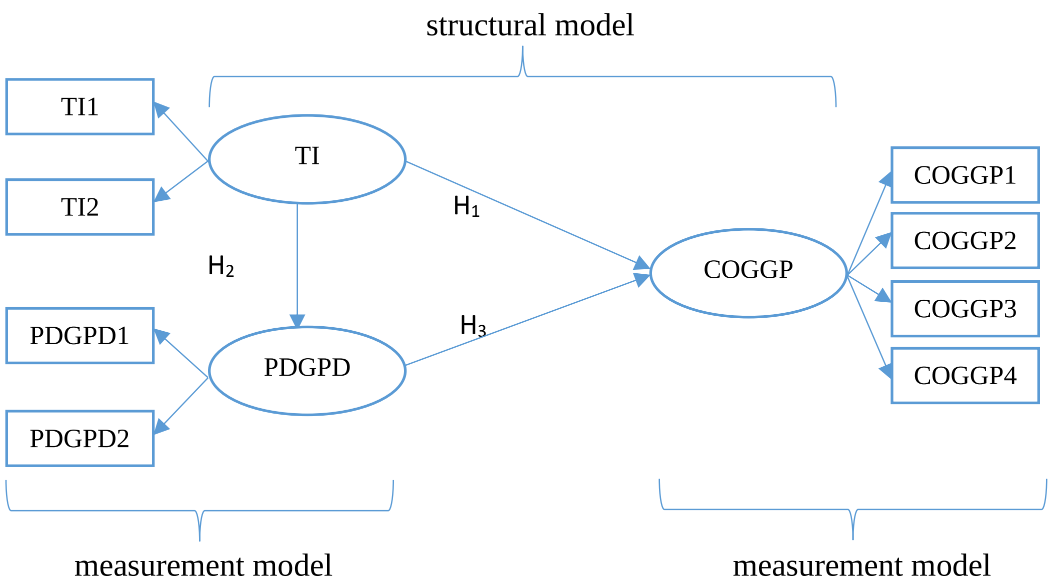

Figure 2. PLS path modeling of the proposed conceptual model.

The PLS path model analysis requires the "…assessment of the measurement models and the assessment of the structural model" (Sanchez, 2013). The assessment of the structural model is a multivariate non-parametric statistical method to test the model's statistical power when the sample size is small and the distributional assumptions are not required (Vanalle et al., 2017).

According to Sanchez (2013), to test the accountability of the constructed PLS-SEM model, first, the unidimensionality, loadings, communalities, and cross-loadings values of the measurement models are examined; and second, the linear model fitting and resampling process (i.e. bootstrapping) are examined for the structural model to test the proposed hypotheses.

CHAPTER FOUR: RESULTS

This chapter is taken from the published papers and a paper in review of the author:

1. Talebzadehhosseini, S., Garibay, I. (2021). The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. Manuscript in preparation. *In review: Journal of Cleaner Production*.

2. Talebzadehhosseini, S., Scheinert, S. R., & Garibay, I. (2020). Growing Green: the Role of Path Dependency and Structural Jumps in Green Economy Expansion. *Journal on Policy and Complex Systems*, 6 (1): 5-26. https://doi.org/10.18278/jpcs.6.1.2

3. Talebzadehhosseini, S., Scheinert, S.R., Garibay, I. (2020). Global Transitioning Towards a Green Economy: Analyzing the Evolution of the Green Product Space of the Two Largest World Economies. In: Cherifi H., Gaito S., Mendes J., Moro E., Rocha L. (eds) Complex Networks and Their Applications VIII. COMPLEX NETWORKS 2019. *Studies in Computational Intelligence*, vol 882. Springer, Cham. https://doi.org/10.1007/978-3-030-36683-4_51

Summary

The main goals of this chapter are to show how 61 countries expanded their green production basket between 2003 to 2015, that is, whether they expanded their green production basket based on the main hypothesis of path-dependent economic growth, and to explore how countries' TI activities and PDGPD affected their overall green growth performance. Therefore, this chapter is divided into three sections:

- First, the GPS network for the 246 green products that were traded between 61 countries between 2003 to 2015 will be presented to identify their pattern of green product development.

- Second, the evolution of green products development based on the constructed GPS network will be analyzed for the 61 countries to identify how they expanded their green

production basket. In addition, the evolution of green products development in the United States and China as the two largest world economies will be analyzed in this chapter as a specific case study.

- Third, the results of the constructed PLS-SEM will be discussed to explore the interaction effects of TI activities and PDGPD on COGGP.

Green Product Space Network

The GPS network of the 246 green products that were traded between 2003 to 2015 in all 61 countries is depicted in Figure 3.

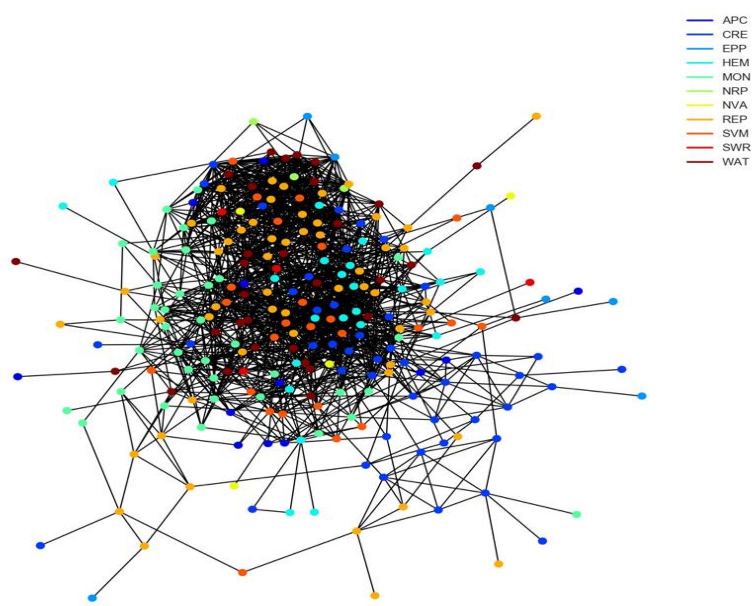

Figure 3. The Green Product Space Network of 246 green products traded between 2003 to 2015 in 61 countries; the nodes' colors represent the different categories of green products, and are connected based on their proximity values

The nodes are the 246 green products that are connected based on their proximity values (links) and the nodes colors in the network represent the different categories of green products (Sauvage, 2014): the Air Pollution Control (APC), Cleaner or more Resource Efficient technologies and products (CRE), Environmentally Preferable Products based on end use or disposal characteristics (EPP), Heat and Energy Management (HEM), Environmental monitoring, analysis and assessment equipment (MON), Natural Resources Protection (NRP), Noise and Vibration Abatement (NVA), Renewable Energy Plant (REP), Management of solid and hazardous waste and recycling systems (SWM), Clean up or remediation of soil and water (SWR), and Waste water management and potable water treatment (WAT).

According to the GPS network, green products that require a higher level productive capabilities (complex products) for production are located in the high density area of the network, while green products with less required productive capabilities are located in the periphery of the network. This means that if a country's export basket stands in the high density area of the network, a country is well positioned to advance its green production basket since it has the capabilities to produce a wide range of products. For example, the GPS networks of the United States and China are visualized in Figure 4 to represent their GPS network and identify how they diversified their green production basket.

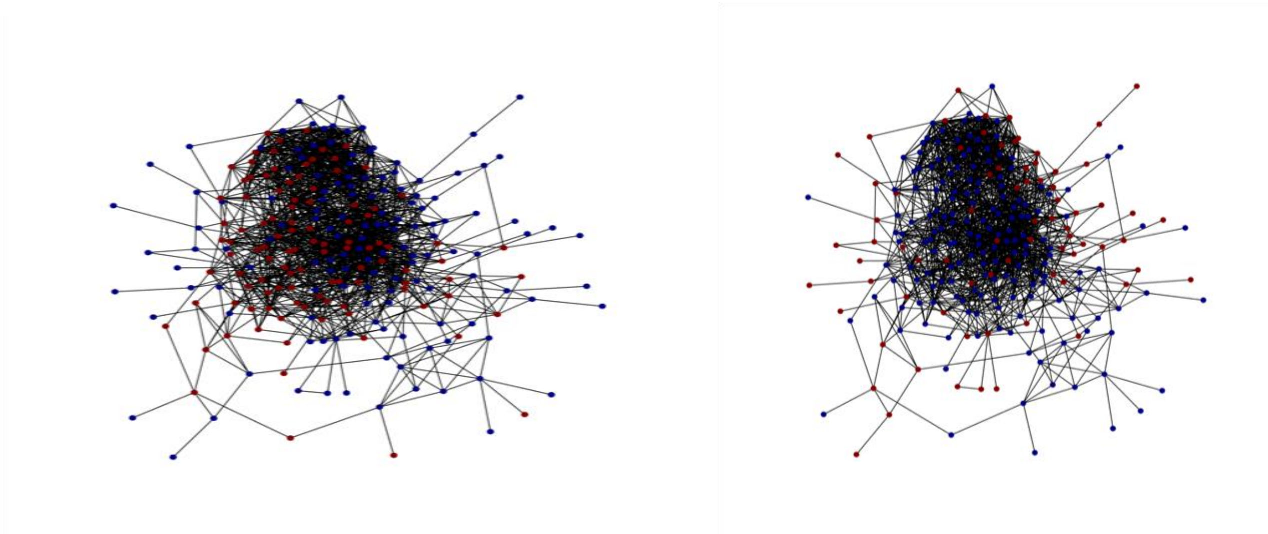

Figure 4. The number of green products (red nodes) with high RCA (RCA>1) that the United States (left) and China (right) were capable of producing in 2015; the United States' green production basket is more diversified than China

The red nodes in Figure 4 show the green products that the United States and China produce with comparative advantage (RCA>1). It can be seen that the United States has a more diversified green production basket (red nodes) in 2015 compared to China. However, we are considering how these countries developed their green production baskets, and thus how they became within the top leaders of green products development. The next section discusses this in detail.

Pattern of Green Products Development

The pattern of green products development for 61 countries obtained using the method discussed in the previous chapter. Figure 5 shows the kernel distribution of relatedness (proximities) between new green products at time t_1=2015 and the products with RCA>1 at t_0=2003 for all countries.

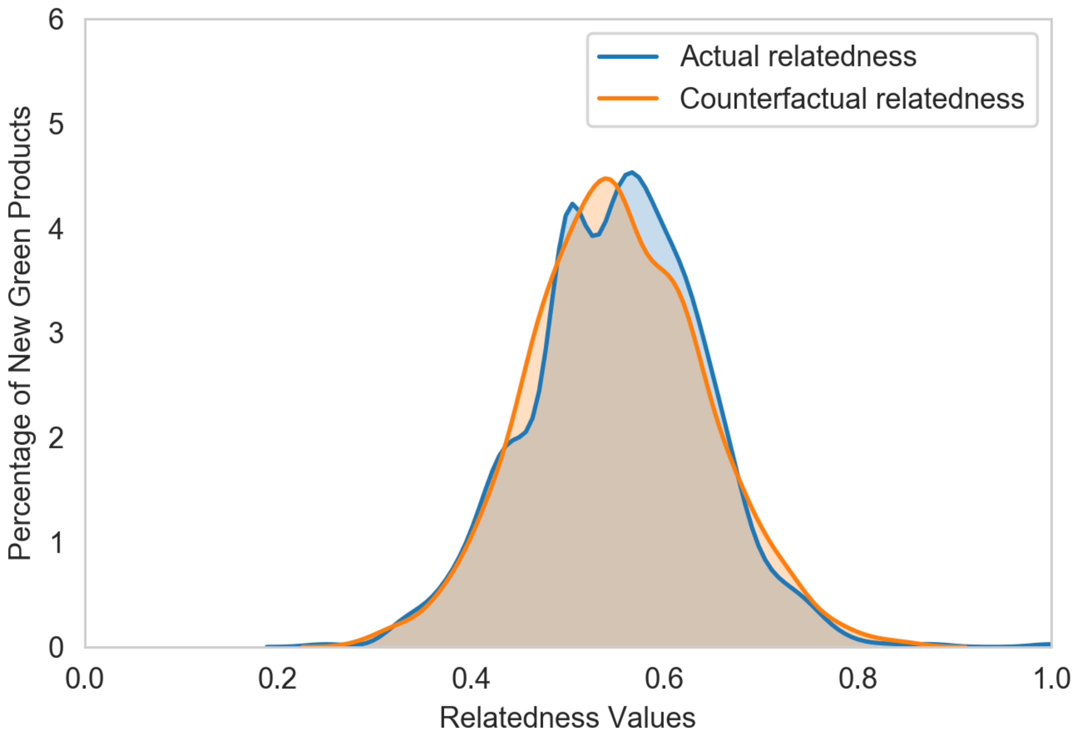

Figure 5. Kernel distribution of relatedness between new green products at time t_1=2015 and time t_0=2003: actual new green products data versus random data

The horizontal axis in Figure 5 shows the relatedness values—0 to 1—between new green products at t_1=2015 and the products with RCA>1 at t_0=2003 for all countries. The blue kernel distribution shows the relatedness between new green products at t_1=2015 and the products with RCA>1 at t_0=2003, while the orange kernel distribution shows the randomly generated relatedness values that were obtained as a result of the counterfactual analysis.

The comparison between the blue kernel distribution and orange kernel distribution shows whether the countries green growth followed a path-dependent process. The comparisons show that countries' green products development followed a path-dependent economic growth hypothesis when the relatedness values between 0.58 and 0.7. The relatedness values above 0.7 demonstrate that a non-path-dependent economic growth is followed when the products have high degree of relatedness. This shows that countries did not enhance their green production baskets based on products for which they already had an RCA>1 and they jumped in their GPS network.

The comparison also shows that countries' developed new green products based on non-path-economic growth process for a considerable number of green products (represented by the orange area above the blue area). Thus, our results show that countries jumped in their GPS network and produced green products that did not share similar capabilities with their existing green production baskets.

As mentioned in the beginning of this chapter, the patterns of green product development in the United States and China are analyzed to understand how they expanded their green production basket. Specifically, the goal is to identify if they followed the path-dependent economic growth hypothesis or the non-path-dependent economic growth hypothesis. As depicted in Figure 6, the actual relatedness distribution of new green product values (blue distribution) is similar to the counterfactual distribution of simulated green product values (orange distribution), that is, the United States' pattern of green products development does not follow Hidalgo et al. (2007)'s prediction of the path-dependent economic growth hypothesis for almost all green products, as only a few actual relatedness values are above the counterfactual relatedness values.

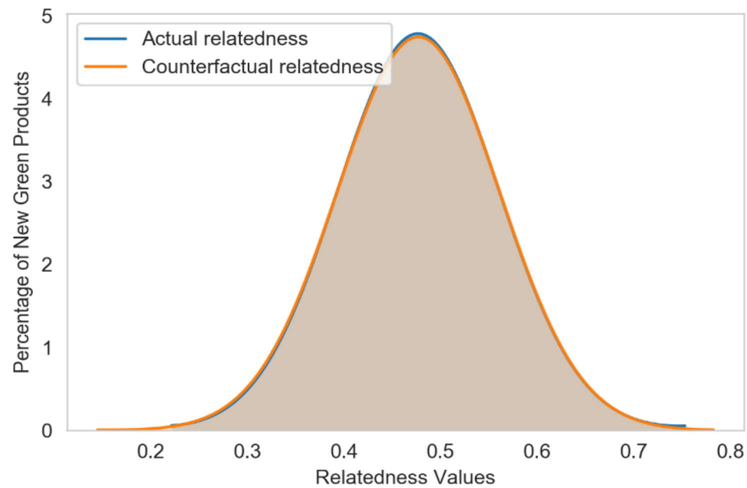

Figure 6. Comparison of the United States' actual and counterfactual kernel distribution of relatedness between 2003 and 2015

This figure confirms that the existing green production capabilities in the United States did not have an effect on most of the growth of its green production basket. Similar to Figure 6, Figure 7 depicts China's counterfactual relatedness distribution which stands slightly to the right side of the actual relatedness distribution, confirming that for most green products, the existing green production capabilities in China did not have an effect on the growth of its green production basket. Thus, China expanded its green production basket by jumping in its GPS network, and followed the non-path dependence economic growth hypothesis as a result of structural changes in its green production capabilities for many of its green products.

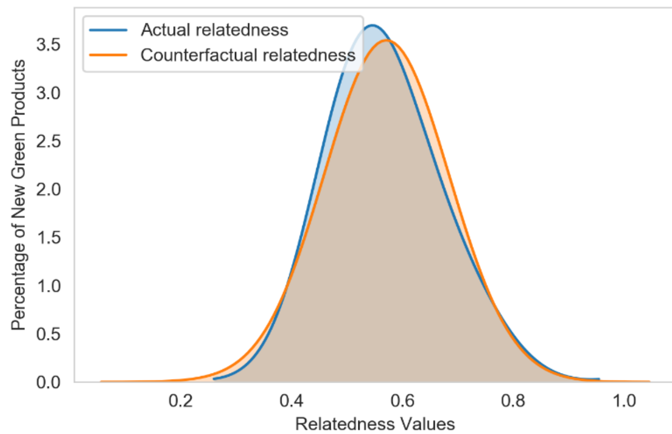

Figure 7. Comparison of China's actual and counterfactual kernel distribution of relatedness between 2003 and 2015

According to these findings, the United States focused on innovating environmental related technologies to enhance its green production basket rather than depending on its existing green production basket. China also focused on innovating new environmentally related technologies rather than expanding its previous capabilities to advance its green production basket, as most of the values in Figure 7 were within the counterfactual distribution; for the relatedness values between 0.43 to 0.62, and 0.78 to 1, the actual relatedness values stand slightly above the counterfactual values. Thus, like the United States, China expanded its green production baskets by jumping in its GPS network, and followed the non-path dependent economic growth hypothesis for many of its products. However, it should be noted that the United States followed the non-path dependent process for more of its products than China. We term this phenomena "high-energy jumping" since we conjecture that heavy investments are needed to achieve these jumps in the GPS network.

Partial Least Square Structural Equation Modeling

Measurement model assessment

The assessment of the measurement model examines how well the measurement variables reflect the corresponding latent variable. The unidimensionality implies that in each measurement model, the measurement variables reflect the aspects of one similar latent variable, therefore, it is necessary that all the measurement variables point in the same direction (Sanchez, 2013). The unidimensionality test is implemented for the three measurement models and the results are listed in Table 5, Unidimensionality metrics for each block of indicators in the measurement model. A value above 0.7 for Cronbach's alpha is acceptable and it shows the internal consistency and reliability in each measurement model, which indicate how well the measurement variables reflect the associated latent variable (Taber, 2018; Sanchez, 2013). As shown in Table 5, the Cronbach's alpha value for each measurement model is above 0.7, suggesting that each block of indicators fits the model's measurement of the associated latent variable very well. For example, the Cronbach's alpha value for COGGP is 0.871, which indicates that COGGP1, COGGP2, COGGP3, and COGGP4 are reflecting and measuring the associated latent variable (COGGP) in the constructed PLS-SEM model. Dillon-Goldstein's rho is another metric to assess the reliability of each measurement model. According to Mikolajczak et al. (2014) and Sanchez (2013), Dillon-Goldstein's rho is a better metric than Cronbach's alpha as it considers a lower bound estimate to measure the reliability of a measurement model. Acceptable values above 0.7 for Dillon-Goldstein's rho show high reliability in the block of interests (Mikolajczak et al., 2014; Balzano and Trinchera, 2011; Sanchez, 2013). According to Table 5, Unidimensionality metrics for each block of indicators in the measurement model, the Dillon-Goldstein's rho values for all three measurement models are above 0.7, confirming high reliability in each block of indicators. For example, TI1 and TI2 measure TI very well in the constructed PLS-SEM model, as the Dillon-Goldstein's rho value for this construct is 0.898, signifying high internal consistency and reliability of TI1 and TI2 in measuring their associated latent variable, TI. For each set of indicators in the measurement models, the eigenvalues of the correlation matrix are another metric that suggests the appropriateness of the measurement variables in reflecting the associated latent variable (Yim, 2019; Sanchez, 2013). As discussed by Sanchez (2013), if the first eigenvalue stands above one and the second eigenvalue stands below one in the correlation matrix, it implies that each block of indicators is unidimensional. The results of the eigenvalues analysis for the proposed PLS-SEM in Table 5, Unidimensionality metrics for each block of indicators in the measurement model, shows that the measurement variables in all three measurement models reflect these associated latent variables very well.

Table 5. Unidimensionality metrics for each block of indicators in the measurement model.

Latent variables	Measurement variables	Cronbach's alpha	Dillon-Goldstein's rho	eig.1st	eig.2nd
TI	TI1	0.772	0.898	1.629	0.370
	TI2				
PDGPD	PDGPD1	0.999	0.999	1.999	0.0004
	PDGPD2				
COGGP	COGGP1	0.871	0.915	2.946	0.7915
	COGGP2				
	COGGP3				
	COGGP4				

Along with the unidimensionality metrics, the loadings, communalities, and cross-loadings values are also examined to test the reliability of a constructed PLS-SEM model (Al-Emran et al., 2019; Sanchez, 2013). The loading value examines the correlation between the measurement variables and latent variables, while the communalities are the squared values of the correlations that examine the variability of the measurement variables captured by latent variables (Avkiran, 2018; Sanchez, 2013). According to Rumanti et al. (2020), loading values above 0.7 are acceptable. As shown in Table 6, Loadings and communalities values of each block of indicators, the loading values for all measurement variables are above 0.7, indicating that not only is there a high correlation between the measurement variables and their associated latent variable, but that all latent variables captured more than 50% of the variability in all measurement variables. For example, the loading and communality values for TI1 are 0.869 and 0.755, suggesting that there is a high correlation between TI1 and TI, and at the same time, more than 75% of the variability in TI1 is captured by TI.

Table 6. Loadings and communalities values of each block of indicators.

Latent variables	Measurement variables	Loadings	Communality
TI	TI1	0.869	0.755
	TI2	0.931	0.867
PDGPD	PDGPD1	0.999	0.999
	PDGPD2	0.999	0.999
COGGP	COGGP1	0.871	0.760
	COGGP2	0.718	0.516
	COGGP3	0.849	0.721
	COGGP4	0.947	0.898

The cross-loading values examine the shared variance between the measurement variables and all latent variables, and according to Sanchez (2013), the cross-loading value of a measurement variable with its associated latent variable should be higher than other latent variables. Accordingly, in Table 7, Cross-loadings values for each block of indicators, the cross-loading values for all measurement variables with their latent variables in each construct are higher than other latent variables.

Table 7. Cross-loadings values for each block of indicators.

Latent variables	Measurement variables	TI	PDGPD	COGGP
TI	TI1	0.869	0.488	0.344
	TI2	0.931	0.566	0.563
PDGPD	PDGPD1	0.589	0.999	0.409
	PDGPD2	0.588	0.999	0.409
COGGP	COGGP1	0.393	0.273	0.871
	COGGP2	0.491	0.415	0.718
	COGGP3	0.354	0.262	0.849
	COGGP4	0.476	0.388	0.947

To better examine the cross-loading values in the constructed PLS-SEM model, Figure 8 depicts the comparison of the cross-loadings values of each measurement variable with all latent variables. As an example, it can be seen in Figure 8, Cross-loading values of measurement variables compared to the latent variables, that in the TI measurement model, where TI1 and TI2 are associated with their latent variable TI, the cross-loading values of TI1 and TI2 are 0.896 and 0.931 respectively, which are higher than other latent variables such as PDGPD and COGGP.

The cross-loading values of each measurement variable with respect to its associated latent variable should be higher than the other latent variables. The dotted-line in each plot shows the acceptable cross-loading values for each measurement variable and shows that its associated latent variable should stand above 0.5.

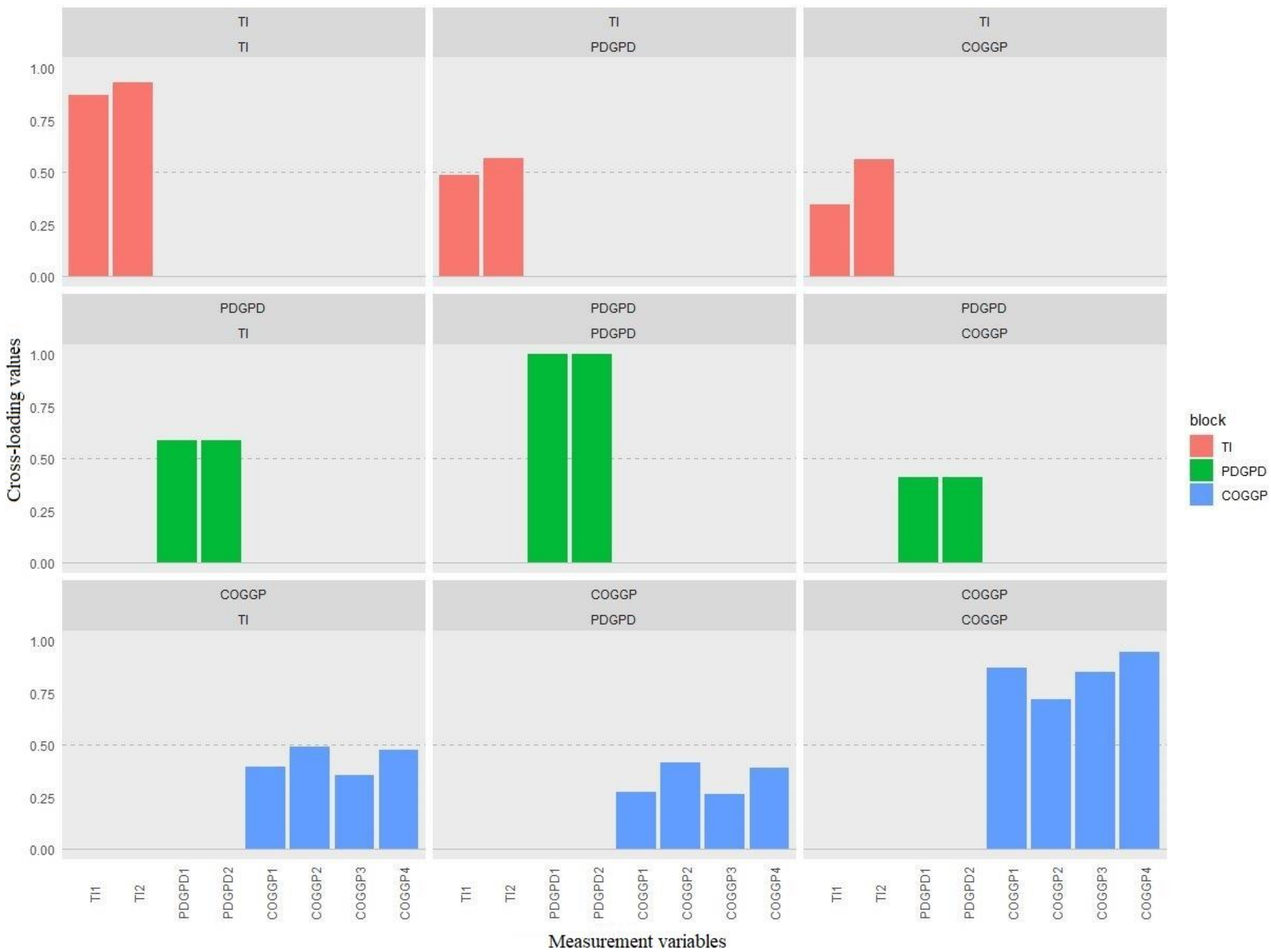

Figure 8. Cross-loading values of measurement variables compared to the latent variables

Structural model assessment and hypotheses testing

The assessment of the measurement model examines the model's reliability, that is, the measurement variables reflect their associated latent variables well and the constructed PLS-SEM model represents reliable results to test the proposed hypotheses. The reliability test of the constructed PLS-SEM model in the previous section shows that the measurement variables reflect their associated latent variables very well. Table 8 shows the model hypotheses testing results. The results of the linear regression equations for the constructed PLS-SEM indicate that TI has positive and significant effect on COGGP with a path coefficient value of 0.425, TI has a positive and significant effect on PDGPD with a path coefficient value of 0.589, and PDGPD has a positive and significant effect on COGGP with a path coefficient value of 0.158. Therefore, the model confirmed the first and third hypotheses but did not confirm the second hypothesis.

Table 8. Model hypotheses testing results

Path	Estimate	Standard Error	t-value	P	Model Hypotheses	Results
TI ⟶ COGGP	0.425	0.077	5.466	***	H_1	Supported
TI ⟶ PDGPD	0.589	0.060	9.810	***	H_2	Not Supported
PDGPD ⟶ COGGP	0.158	0.077	2.039	0.042	H_3	Supported

Notes: *** denotes significant probability values less than 0.001. Estimates show the path coefficients

Since the distribution assumption is not needed in the PLS-SEM models, to examine the accuracy of the path estimates in the resampling process, the study uses bootstrapping to verify the confidence intervals (Kock, 2018; Sanchez, 2013). For bootstrapping, first, the parameters data should be resampled n times, then the resampled data should be replaced by the original parameters dataset, and lastly, the "…bootstrap confidence interval (95%) provided by the percentiles 0.025

and 0.975 [should be examined]" (Sanchez, 2013). To verify this, the bootstrapping validation process for the constructed PLS-SEM model based on 200 resamples was run with the plspm () package in R software (Sanchez, 2013). The results of the resampling process are shown in Table 9, Bootstrap validation, where it can be seen that since the path coefficients for TI to COGGP, TI to PDGPD, and PDGPD to COGGP do not contain any zero values, the path coefficients are significant at a 5% confidence interval. For example, for TI to COGGP, the coefficient value is 0.425; with percentiles 0.025 and 0.975, the values are 0.340 and 0.527, respectively; therefore, there are no zero values between percentile 0.025 and percentile 0.975. This implies the path coefficient for TI to COGGP is significant at a 5% confidence interval.

Table 9. Bootstrap validation

Path	Estimate	Standard Error	Percentile 0.025	Percentile 0.975
TI ⟶ COGGP	0.425	0.046	0.340	0.527
TI ⟶ PDGPD	0.589	0.050	0.469	0.676
PDGPD ⟶ COGGP	0.158	0.075	0.002	0.301

CHAPTER FIVE: CONCLUSION

This chapter is taken from the published papers and a paper in review of the author:

1. Talebzadehhosseini, S., Garibay, I. (2021). The interaction effects of technological innovation and path-dependent economic growth on countries overall green growth performance. Manuscript in preparation. *In review: Journal of Cleaner Production*.

2. Talebzadehhosseini, S., Scheinert, S. R., & Garibay, I. (2020). Growing Green: the Role of Path Dependency and Structural Jumps in Green Economy Expansion. *Journal on Policy and Complex Systems*, 6 (1): 5-26. https://doi.org/10.18278/jpcs.6.1.2

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Summary

This chapter discuss the results that was obtained in the previous chapter. Then, it provides an information regarding how the results of this dissertation can be used by researchers and policy makers to enhance a country's green product development and overall green growth performance. Finally, this chapter shows the limitations of this dissertation and proposes a direction for future research.

Discussion

Economic growth and economic development forces countries to face several problems such as rapid climate change, loss of biodiversity, drastic environmental events, and social problems. Climate change is the most considerable problem that emerges when countries try to grow their economy. However, a transition to a green economy enables countries to grow their economy while reducing this environmental risk. The results of this dissertation showed that the United States and China, the countries with the largest growth in their green economy between 2003 and 2015, jumped in their green production basket to produce variety of new green products. In addition, the results of this dissertation provided a better understanding of how countries enhanced their green growth, and thus, how other countries could accomplish similar actions to create or improve their green economy development plan while reducing environmental risks, especially climate change. We characterize green growth as exhibiting dual dynamics: (1) path-dependent growth that "exploits" current infrastructure and (2) high-investment structural growth that "explores" new structural changes via strategic investments. Further, development of these frameworks will allow countries or regions to strategically promote "path-dependent growth" or "high-investment structural growth" in order to achieve their green economy goals.

This dissertation also examined how a country's efforts to advance TI activities affects its green product development based on the path-dependent economic growth hypothesis and overall green growth performance. The main findings of the empirical analysis confirm the first and third hypotheses (H_1 and H_3) but does not confirm the second hypothesis (H_2). The first hypothesis (H_1) shows that TI is positively related to COGGP. This result provides empirical evidence to the existing discussion on the role of TI as a key driver in promoting green growth performance (e.g., Hu et al., 2019; Mensah et al., 2019; Aghion et al., 2009). Furthermore, according to Aghion et al. (2009), it is hard to achieve sustainable green growth without innovation and technology development. In this dissertation, TI measures two dimensions: development of environment-related technologies and the percentage of inventions worldwide, as well as the development of environment-related technologies and inventions per capita. COGGP is measured based on four dimensions: production-based CO_2 emissions, energy intensity, non-energy material productivity, and real GDP per capita. There are two main findings based on the result of first hypothesis. First, countries with a high rate of innovation in the development of environmentally related technologies are better positioned to grow their green economy as their dependency on natural resources as the main source of their production process decreases. Second, increasing innovation and technology development makes it easier for countries to have successful transitions from traditional production processes to cleaner production processes which will decrease their pressure to address climate changes issues.

The second hypothesis (H_2) is not confirmed; TI positively affects PDGPD and this finding confirms Hidalgo et al. (2007)'s hypothesis of path-dependent economic growth. It can be explained by two main reasons. First, it was hypothesized that TI enables countries to upgrade their production basket by producing new green products that need different technologies, capital, and infrastructure that already exist for production. In fact, this result suggests that TI could be another required productive capability needed for any production based on path-dependent economic growth. When it increases, the number of green products that a country can add to its production basket increases. Second, apart from TI, advanced environmental regulations, reduced tariffs on green products, increased knowledge of green development in regional firms and small companies, and enhanced governmental support by high investment in green growth activities are needed for countries to produce and export new green products (Mealy and Teytelboym, 2020; Coniglio et al., 2018).

The third hypothesis (H_3) is confirmed, that is, PDGPD has a positive effect on COGGP. This finding confirms the discussion in literature on the importance of green product development in advancing overall green growth performance (e.g., Fraccascia et al., 2018; Hafezi and Zolfagharinia, 2018; Hamwey et al., 2013). The main finding of this is that transitioning to cleaner production has a direct effect on enhancing overall green growth performance. It is shown empirically that countries with a larger green production basket are better positioned to foster green growth performance.

Conclusions

The results of this dissertation showed that countries follow path-dependent and non-path-dependent economic growth hypothesis to develop different green products to grow their green economy. That is, if a country uses its existing productive capabilities to grow its green economy, it follows a path-dependent economic growth hypothesis, and if a country produces a product that uses divergent productive capabilities from its existing production basket, it follows a non-path-dependent economic growth hypothesis.

As pressure mounts on countries to address global climate change and high environmental risks, the necessity to transitioning to cleaner production is increasing. Evaluating green growth performance has been used widely to assess and monitor efforts toward green growth. An OECD (2017) report proposes different indicators to assess green growth performance. One of the indicators that plays a crucial role in growing a country's green growth performance is TI, however, there was not enough empirical analysis based on real-world data to show how TI affects green growth performance. In this dissertation, using the main indicators proposed by OECD (2017) and the PLS-SEM model, overall green growth performance for the years 2003 to 2015 was examined to determine the interaction effects of TI and PDGPD on 61 OECD and non-OECD countries. This dissertation empirically demonstrated how TI affects COGGP and at the same time how TI can affect a country's green production development and transition to cleaner production by reducing dependency on natural resources.

By confirming H_1 and H_3, this dissertation empirically shows that TI has a positive and significant effect on COGGP and that PDGPD has a positive and significant effect on COGGP. These findings imply that countries that focus efforts in TI and PDGPD have a corresponding increase in overall green growth performance, which means production-based CO_2 emissions, energy intensity, and non-energy material productivity decrease, while real GDP per capita increases.

In addition, by not confirming the second hypothesis (H_2), this dissertation implies that TI alone cannot enable countries to go beyond their existing productive capabilities to produce and export a variety of new green products. Along with TI, countries should modify their environmental regulations, reduce tariffs for the green products, increase knowledge of green development in regional firms and small companies, and enhance governmental support by investment in economic sectors that have the highest potential for green growth.

Implications

This dissertation proposes some implications for managers, policy makers, and researchers. From a managerial perspective, the results of this dissertation show that TI has positive effect on PDGPD and COGGP. These findings highlight the crucial role of TI to managers on promoting green growth and green products development. In fact, by focusing on TI activities, managers can smoothly shift their companies, firms, and organizations existing development and production processes to cleaner development and production processes without any need for significant structural changes in order to enhance their green products development and contribute to overall green growth performance at a national level. In addition, this dissertation shows that PDGPD has positive effect on COGGP. This finding suggests that it is important for the managers to consider their companies, firms, and organizations existing productive capabilities when diversifying their green products, which in the short term enables them to contribute to overall green growth.

From a policy perspective, the results imply that along with required productive capabilities, TI is another factor that countries should consider when developing their policy agendas for producing new green products. In fact, considering TI along with required productive capabilities enables countries to produce and export more diverse green products and fosters green growth performance. In addition, TI not only advances and diversifies green production baskets, but also advances green growth performance in a way that can reduce the pressure on countries to better control global climate change.

From a research perspective, this dissertation contributes to literature by examining the role of TI on countries' green production development and empirically shows how TI affects a country's overall green growth performance.

Limitations and future research

This dissertation has some limitations that can provide opportunities for future research. First, in the constructed PLS-SEM model, due to the lack of data availability of selected indicators for TI and COGGP variables, only the data for 61 countries is considered in this dissertation. Therefore, upon data availability for other countries, the future studies can incorporate more countries into the constructed model. Second, due to a lack of data in the OECD database, this dissertation shows the relationship between TI, PDGPD, and COGGP for the years 2003 to 2015; therefore, this dissertation does not investigate the relationship between TI, PDGPD, and COGGP for recent years, e.g. 2016 to 2021. When data is available in the OECD database, future studies can extend the constructed PLS-SEM model to discover the relationships between TI, PDGPD, and COGGP for other years. Third, this dissertation investigates the effect of PDGPD on COGGP based on two indicators, Country Green Diversity index (PDGPD1) and Share of green products (PDGPD2) for the years 2003 to 2015. Future studies can consider different indicators such as tariffs, trade openness, and product complexity to examine how PDGPD affects COGGP. Finally, TI can be measured in the constructed PLS-SEM model based on other variables that can be used to examine how TI can affect PDGPD and COGGP.

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Department of Computer Science
Complex Systems Institute
Managing Editor, Journal on Policy & Complex Systems
University of North Carolina at Charlotte
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> Managing Editor, Journal on Policy & Complex Systems
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