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Optimizing the Export Diversification Strategy of Iran's Chemical Products Using Product Spaces and Economic Complexity Theories

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Abstract

Achieving sustainable development in the future requires investing in productive capabilities that lead to export diversification. Given the importance of the chemical industry as a strategic industry around the world, especially in Iran, and its effect on upstream and downstream industries, determining the optimal export diversification strategy in this sector is critical. In this regard, the theory of economic complexity will be used as a basis for identifying high-potential opportunities for export diversity and the theory of product space will be applied which is a powerful tool for identifying strategies. Using export data of chemical products (2014-2018) in 128 countries, we drew product space for Iran. Based on revealed comparative advantages of more than one, results for Iran show that out of 921 six-digit chemical products of the harmonized system, 295 product codes has potential to be activated. Subsequently, by adding two new constraints to the model, potentially activate products were reduced to 145 products. Next, by implementing five strategies: random, greedy, high degree, low degree and majority on Iran's chemical products network, an integration of greedy and majority strategies has been shown to minimize network activation time. Finally, by merging these two strategies, the optimal strategy was identified, and 145 products were prioritized in order to improve export diversity.

Highlights

- Economic complexity and product space indicators explain the dynamics of Iran's chemical exports writing.
- Optimal diversification strategies of Iran chemical products exports are combination of greedy and majority strategies.

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1. Introduction

Classical economic theories, from Ricardo (1891) to Romer (1990), emphasize the importance of countries specializing in the production of small quantities of high-quality product. However recent studies have shown that export diversification may lead to increase in economic growth (Grossman, 1991). It is acknowledged that high export diversity works as a shield against external shocks and modifies fluctuations in macroeconomic variables, including economic growth (Dunning, 2005) .

However, a look at the diversity of Iran's export goods reveals that the country's top exports are crude oil, natural gas, and raw and natural materials. This demonstrates the Iranian economy's vulnerability as a result of the price volatility of these export products. Economic sanctions, in particular, have exposed Iran's economy's fragility to a higher reliance on raw material exports in recent years. However, the question here is which products to choose in order to diversify exports.

The study of country export patterns reveals that core location and export types, such as chemical products, all contribute to a country's economic growth. Developed nations are most likely to be at the frontline of product development and to export chemical products (Li et al., 2021). This industry's value added chain holds a special place, encompassing a wide range of products from primary to intermediate to final. Chemical products are widely used in a variety of sectors, making it one of the country's most significant industries and one of the leading indicators of a country's industrial development.

The chemical industry includes 921 products at the six-digit level of HS codes, but at the two-digit level of HS codes there are 13 products, including codes 28 to 40, which are as follows[1]: Inorganic chemical, organic chemical, pharmaceutical products, fertilizers, dyes, paints, inks, essential oils, soaps, waxes, and paints, albuminoidal ; modified starches; glues; enzymes, explosives, photographic or cinematographic goods, miscellaneous chemical.

The chemical and manufacturing industries, which account for 11.7 percent of global production and 24.7 percent of factory exports, are among the world's most significant industries and the biggest and most diverse source of global supply chains (world Bank, 2019). The mentioned industry in Iran has been one of the most important industries after oil and refining industry with 19% of the total production value of factory industries and 24.7% of the total manufacture exports (Sagheb, 2020). An analysis of Iran's chemical exports from 2004 to 2011 reveals an increasing trend, from $ 1.1 billion in 2004 to $ 9.3 billion in 2011. However, due to US and UN sanctions, exports have decreased from 2012 to 2018, resulting in a $ 7.9 billion fluctuations. Figure 1 depicts the number of Iranian chemical products with a revealed comparative advantage (RCA) in exports from 2004 to 2018. Iran exported 131 products with RCA>1 out of 921

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[1] https://unstats.un.org/unsd/tradekb/Knowledgebase/50018/Harmonized-Commodity- Description-and-Coding-Systems-HS

products based on six-digit HS codes in 2004, but this number failed to 43 products in 2018.

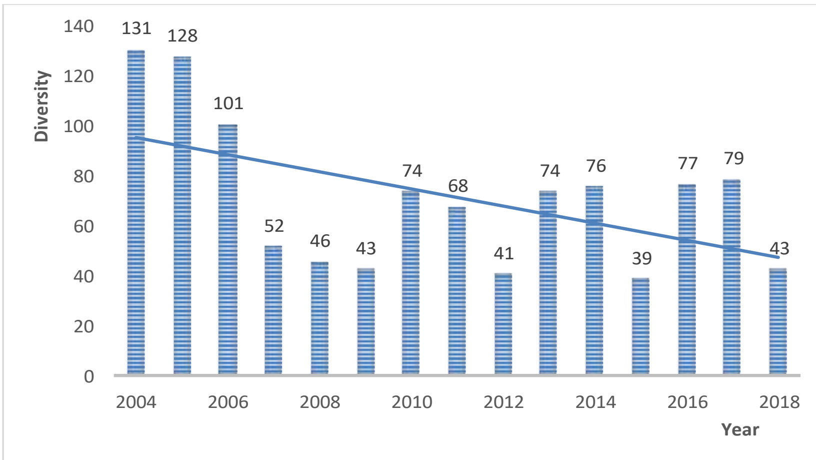

Figure 1. Export diversity of Iran's chemical products from 2004 to 2018 **(HS6)**
Source*: Research findings*

As a result, taking into account the positive effect of industry exports on economic development, the industry's share of global output and exports, the massive investment made in this industry in Iran, the strong share of industry exports in Iran's non-oil exports, and the reduction of Iran's export diversity, determining the optimal strategy for diversifying the export of chemical products is of particular importance.

In recent decades, studies show that countries are more likely to manufacture or export new products, develop new technology or industry when they have more activates in terms of relatedness (Hidalgo et al., 2007; Bahar et al., 2014; Guevara et al., 2016). Network modeling can be used to model these activities. This literature contributes to a new perception of the product's empirical path's dependencies. The path for the growth of new exports is defined by networks (Alshamsi et al., 2018). The product network should be used as a roadmap to demonstrate existing production capabilities and assess future direction in this regard. To put it another way, the combination of a country's production and export goods predicts diversity and the country's next economic growth pattern (Hartmann et al., 2017).

With various methods such as principal components, numerical taxonomy, decision support model, multi-criteria decision-making techniques, etc., chemical products can be prioritized and introduced to diversify exports by setting criteria. But by using the theory of product space and network science, it is possible to show a clear picture of the space of industry products and the possibility of extracting strategy, but by using other methods to determine the optimal strategy and strategy seems impossible.

According to the literature on export diversification, most studies have only identified products for diversification at the four-digit code level, using indicators such as product complexity, opportunity gain, density, the value of global product demand and the growth of global demand (Sagheb, 2020; Sørensen et al., 2020; Hausmann et al., 2020; Sezai, 2020). In the fields of science and products, only Alshamsi et al. (2018) presented the optimal strategy model. However, this paper aims to follow Alshamsi et al. (2018) model in terms of extracting various potential strategies, including the optimal strategy for diversifying exports in the chemical industry based on six-digit HS codes[2], using two parameters of opportunity gain and complexity.

Difficulties in producing and exporting high-tech goods that are compatible with the country's capabilities are a major issue for Iran and other nations that rely on primary product exports. However, by taking into account the constraints and structural opportunities, the theory of economic complexity, product space, and network science may help identify and select appropriate strategies. As a result, the aim of this paper is to identify the optimal approach for diversifying Iran's chemical product exports. To accomplish this aim, the product space of this industry will be detected using the six-digit code of the Harmonized System after reviewing the current status of Iran's chemical products in terms of complexity index (hs6). Products are divided into three categories in this space: active (products with RCA>1 in exports), potentially active (products with the potential to have a distinctive competitive advantage in the export industry in other words nodes with non zero activation probability) and inactive (products that have a RCA in exports equal to zero). The priority of diversifying Iran's chemical exports is determined using greedy, low-degree, majority, high-degree, and optimal strategies after passing potentially active products through various constraints.

We claim that out of 921 six-digit chemical products of the harmonized system, Iran in 295 product codes has potential products. Subsequently, by adding two new constraints to the model, potentially activate products were reduced to 145 products. Next, by implementing above mentioned strategies on Iran's chemical products network, an integration of greedy and majority strategies has been shown to minimize network activation time. Finally, by merging these two strategies, the optimal strategy was identified, and 145 products were prioritized in order to improve export diversity.

So, the questions which the study sets out to answer are as follows:

1. What is the status of Iran's chemical products in terms of economic complexity among the countries of the world?

2. What are the active, potentially active and inactive products of Iran's chemical industry in the product space network?

[2] 6-digit codes have more detailed information than 4-digit codes and are a better guide for investors in the chemical industry.

3. What is the optimal strategy for diversifying chemical products?

After the introduction, this paper review related theoretical framework and the literature. Next the methodology applied is introduced which consist the methods of calculating complexity, product space and optimal diversification model. Then we present the experimental result of econometrics model, investigation of current situation of Iran, drawing the product space and product classification. Finally, we discuss the conclusion part.

2. Theoretical Framework

One of the recent arguments in economic development theory is the degree of diversity and knowledge in countries' production and export. From Adam Smith's Absolute Advantage theory regarding division and expertise in economic growth and development to Ricardo's theory of comparative advantage and the Hecker-Ohlin-Samuelson (HOS) international business model, the neoclassical economic view was that countries need to specialize in comparative advantage of production and export.

According to structural economic development models, nations must diversify their exports from raw materials to manufactured goods in order to achieve long-term growth (Chenery, 1979; Syrquin, 1989). Recent research, on the other hand, has found a link between export diversification and economic development (Scott et al., 2017; Pitigala, 2021). The findings also show that diversity has a non-linear effect on economic development, implying that developing countries can benefit from higher export diversity (Hakala, 2020).

In general, existing views on export diversification can be examined in the form of three theories: old structuralist, neo-classics and new structuralist. The old structuralist believed in the thesis of market failure and considered a leading role for government in industrialization. Export diversification through systematic government intervention by imposing import tariffs, creating state-owned enterprises and supporting emerging industries. But the neo-classics emphasized on the role of market in resource allocation by highlighting the failure of government intervention in the economy. According to strategic business theory of neo-classics, a country can create the necessary areas for its future growth.

New structuralist is a combination of the views of old structuralist and the neo-classics. According to this approach, sustainable economic growth does not occur without structural changes, thus the optimal industrial structure of any country is determined by its comparative advantages. And comparative advantages are determined by the inventory of its factors of production. In the new structuralist, the role of government in creating and promoting industrial diversity should be restricted to provide information on new industries, coordinate related investments between firms, cultivate new industries by assisting incubators, and support foreign direct investment. Thus the role of government in the new economic structuralist is to improve hard and soft infrastructure to reduce transaction costs and facilitate the process of industrial and commercial development.

The practical framework of the new structuralist industrial development strategy was based on the two pillars of identification and facilitation. In other words, both the identification of the leading sectors and the removal of restrictions and facilitating the growth of that sector have been considered (Kruger, 1995).

In this regard, one of the theories that has examined the industrial development strategy based on structural changes is the product space theory (Hausmann & Klinger, 2006). Product space is an approach that shows how the process of structural changes. In addition it shows two products that are structurally similar to each other would be connected to each other. By using the product space, the real path of the comparative advantage model of the countries will be predictable, and in fact, the countries can identify the goods that are close to each other and provide the conditions for their export.

One of the important features of applying the product space approach is that the process of economic diversification is visually displayed and shows a beautiful picture of the field of trade using global trade data. Although other methods such as principal components, numerical taxonomy, decision support model, multi-criteria decision-making techniques can be used to determine the priority of products for export by determining indicators, but since other methods do not allow visual display and also do not determine the power of the optimal strategy, therefore, using the product space approach to achieve the objectives of this study is more appropriate.

In 2007, Harvard University and the University of Massachusetts incorporated complex economics as a new approach. This theory increases the future direction of economies towards technology and related industries by relying on the knowledge structure and economic production of countries. As a result, nations and regions often participate in similar activities (Hidalgo et al., 2007; Neffke et al., 2013; Petralia et al., 2017; Alshamsi et al., 2018; Hartmann et al., 2020).

As a result, it can be difficult and risky to expand and enter into activities that are unrelated to their existing operations and product portfolio (Zhu et al., 2017). Furthermore, complex industries or products usually necessitate a greater number of related activities in order to survive. Economic growth happens when nations accumulate productive capacities, according to the theory of economic complexity. This synergy enables them to export different range of complex products (Hausmann et al., 2013; Hidalgo & Hausman, 2009).

Over the last few decades, however, various approaches to identifying and developing economic diversification opportunities have been established (Santoalha, 2016). This research focuses on strategies for determining the feasibility and production of new products in a variety of industries (Alshamsi et al., 2018; Moiseev & Bondarenko, 2020). According to Lin and Monga (2011), developing countries need to learn how to develop from emerging economies with comparable systems but higher per capita incomes. These developing countries must then identify the tradable products that have contributed significantly to their development over the last two decades in order to build a diverse economy on that foundation. This is in line with findings by Hausmann et al. (2006) and Rodrik (2006) who focused on countries shifting toward producing goods commonly produced in higher-income countries. This move should, of course, be in line with products with a higher per capita income. As a result, nations should not encourage their diversity based on past comparative advantage trends (Klinger & Lederman, 2004; Cadot et al., 2011; Pinheiro et al., 2018).

According to network analyses, not only income, but also related knowledge and product complexity are key factors in determining growth opportunities in countries and economic diversification (Hidalgo & Hausmann, 2009). Countries must transition to a more advanced base of productive capacities in their economies. The goal of implementing this approach is to gradually increase economic complexity and expand economic diversification opportunities in the more complicated and interconnected areas of the product space map. This approach is consistent with those who believe that moving toward knowledge-based and technology-based industries is essential for sustainable growth (Lall, 2000; Lall et al., 2006).

3. Literature Review

Reviewing the related studies reveals that almost most studies have been focused on theories of economic complexity and product space and considering indicators such as opportunity gain, complexity, distance, and others to classify the ability of countries to increase development and export's diversification.

Hausmann et al. (2020) investigated Jordan's new export diversification opportunities. Their research is divided into two parts. The first section examines Jordan's economic complexity and product space, as well as an examination of the complexity of current products. The second section identifies and introduces new goods for production and export. Two variables, product complexity and distance, were used to identify new products. Also, Sørensen et al (2020) analyzed data from 131 countries based on four-digit system codes harmonized in 1221 products, they concluded that a greedy short-term strategy or low-hanging fruit was appropriate for Mozambique. Long-term plans necessitate infrastructure investment, sophisticated technology, and foreign direct investment inflow, to name a few.

Sezai in his book, Evolution of the Product Space and a New Proposal for Turkey's Export Incentive System (2020), is using the product space network, introduced 20 new high-tech products for production and export in Turkey based on the four-digit codes of ISIC. He also presented the government's incentive policies. Ranjbar et al. (2019) used the theory of economic complexity to investigate the complexities of Iran's non-oil exports from 1997 to 2015, using four-digit HS codes. The results of this study showed that the degree of complexity of the economy Iran is low and the existing export basket is not a strong stimulus for economic growth. Although there was a specialization in the production and export of a number of complex products with high power of diversity in the first half of the 2001s, in the second decade of the 2000s and the subsequent decade the export potential of these products has been declined. In a study conducted for the World Bank, Fortunto et al. (2015) operationalized the notion of product space, calculated opportunity gain and proximity indices. They identified and proposed products to diversify Ethiopia's exports based on four-digit codes.

In their paper, moving to the adjacent possible: discovering paths for export Diversification in Rwanda, Hausmann and Chauvin (2015) identified the export diversity for Rwanda. With the help of the theory of economic complexity and product space and determining three factors, they prioritized the most complexity, the least distance and the most opportunity gain of products to increase the export diversity in this country. They came to the conclusion that if Rwanda maintains a politically and socially stable society, it could serve as a model of good development performance for nations in its region and beyond. In their paper, Bogetic et al. (2013) provides an analysis of Montenegro's export potential and export diversity. Based on data from 2012, the results showed that Montenegro has a very concentrated export portfolio and the country is on the verge of a major transition to a tourism and service-oriented economy. According to findings, Montenegro has a good geographical location, sufficient human capital and suitable natural resources which have provided the country with sufficient export potential to run the engine of the economy. Shahmoradi and Samandarali Eshtehardi (2018) studied Iran's export products in comparison with the world's export goods, using the approach of economic complexity index. They identified the borders hinges products of the country's technological capabilities. They identified a total of 86 products which more technological capabilities can be accumulated if more emphasis is placed on their development, and the country can progress toward greater diversity and economic sophistication.

There are two researches in the chemical industry that can be mentioned. Sagheb (2020) used two methods to study Iran's chemical products: economic complexity and product space. The export diversification of this industry was investigated using five indicators: product complexity, opportunity gain, density, global product demand, and global demand growth. According to the findings of this study, Iran has a priority in manufacturing 60 product groups out of 194 in this industry according to the four-digit HS classification, but only 13 product groups have a comparative export advantage.

Also in another study by Sagheb et al. (2019) in order to identify suitable commodity items for diversification of downstream petrochemical industries, they focused on the five areas of downstream petrochemical activity, using the complexity and product space approaches. They mapped out diversification path of downstream petrochemical industries and the identified the suitable goods to prioritize in the rubber and plastic and the cosmetics industries.

Li et al. (2021), in contrast to the previous researchers, looked at the process of product space evolution in countries around the world. Product space theory and econometric models were used to perform this research, which was based on data from 186 countries and four-digit codes from the International Standard Industrial Classification (ISIC).

However, when it comes to completing the studies listed above, Alshamsi et al. (2018) reviewed the optimal diversity strategy in networks related to product and science domains. According to them, five types of strategies can be envisaged for free scale public networks for countries to diversify products and sciences. These five strategies were random, high- degree, low- degree, greedy, and majority. Using the product space ideology as well as network science, they introduced a new model for determining the optimal strategy in free-scale public networks.

In the present paper, as a contribution we include two indexes called product complexity and opportunity gain on chemical product to consider complexity approach mixed with network approach in finding optimized strategy for export diversification.

4. Method

This study examines the status of chemical products in terms of country complexity and industrial exports, using data from 128 countries from 2014 to 2018. The chemical products space is created using data from the Harvard University website, which was collected from the HS6 six-digit code of 921 countries. All calculations are based on the five-year average of exports. All calculations are based on the average export of this five-year period. Given Iran's sanctions, the average of five years' export data is much more credible than one year's data. Because these 128 countries account for 99 percent of global trade, 92 percent of global GDP, and 92 percent of global population, their reliability is obvious. First, the approach introduced by Hidalgo and Hausmann (2009) for calculating the economic complexity index of countries and products is explained in order to achieve the goals. Then, using the Hidalgo et al. (2007) approach, the technique of drawing the network and product space is presented, and finally, network optimization under various strategies is presented, using the model provided by Alshamsi et al. (2018).

4.1 Calculating the Complexity

The method presented by Hidalgo and Hausmann (2009) will be used to calculate the country and product complexity index (PCI). To do so, after calculating the RCA which is introduced by Balassa (1965), this criterion will be used to form the country-product matrix(Mcp). The Country-Product Matrix defines the products that each country is producing in a competitive basis. Let $\mathrm{M_{cp}} = 1$ be a matrix that indicates the exports of country c in product p, we can express the RCA that country c has in product p in equation (1):

$$M_{cp} = \begin{cases} 1 & if\ RCA_{cp} \geq 1; \\ 0 & otherwise \end{cases} \tag{1}$$

After calculating the country-product matrix (Mcp), the diversity and ubiquity of the products are calculated as follows:

Diversity is defined in equation (2):

$$k_{c0} = \sum_{P} M_{c_P} \quad (2)$$

And ubiquity in eqation (3):

$$k_{p0} = \sum_{C} M_{c_P} \quad (3)$$

A country's diversity refers to the number of goods it has a comparative advantage in producing and exporting, whereas a product's ubiquity refers to the number of countries that have a comparative advantage in produce and export it. Finally, the complexity index of countries and goods in the chemical products industry was measured using the diversity and ubiquity criteria according to the method suggested by Hidalgo and Hausmann (2009).

4.2 Product Space

Product space is a geometric representation of products based on the concept of proximity between diverse goods. Product space is based on the idea that if two goods are related, they need the same inputs, infrastructure, technology, and institutions (Fortunato et al., 2015).

If the products are exported jointly by a country or countries, they are related. Hidalgo et al. (2007) used similarities between the capabilities required to produce a pair of products to draw the network. Since the capabilities required to produce products are not observable and measurable, they took advantage of the possibility of exporting pair of goods at the same time. For a pair of goods p and p′ we define Product Proximity in equation (4):

$$Prox_{p,p'} = \frac{\sum_{c} M_{cp} M_{cp'}}{\max(k_{p0}, k_{p'0})} \quad (4)$$

Where; if country c is a competitive exporter of product *p*, Mcp will be equal to 1, otherwise it will be equal to 0.

In order to draw the product space using the proximity index, several criteria must be considered. First, all products should be related to each other and, second, density of products is not too high or too low. To do this, Hidalgo et al., used the Maximum Spanning Tree (MST) method based on the proximity index. The product density function *j* for country *k* is defined in equation (5):

$$density_j^k = \frac{\sum_k Mcp_i \emptyset_{ij}}{\sum_i \emptyset_{ij}} \quad (5)$$

Where $\emptyset_{ij}$ is the proximity matrix between two products *i* and *j*. A high density shows that country *k* has many active products nearby the product *j*. Higher density products are goods are more related to a country's export capacity, while lower density products are related to unrelated products.

In the next step, Hidalgo et al., connect the most similar products based on Maximum Spanning Tree (MST) in order to create more connection between the products. According to the method presented in this paper, all points with similarity coefficients greater than 0.55 are connected to draw the product space.

It should be explained that Microsoft Power BI software was used to draw the product space.

Products are classified into three categories based on the results of activation probability calculations: active, potentially active, and inactive. Export products for which the country currently has a RCA are considered active, and potentially active products are export products without RCA, but the probability of activating these products based on the probability calculations is greater than zero .Inactive products are those which aren't considered as goods with RCA in terms of export and whose probability of activation is considered zero.

The potentially active products were identified according to the significance of opportunity gain indicators and product complexity in this method. Then, products with a significant opportunity gain and complexity greater than the average complexity of competitive export products were chosen after identifying potentially active products. The benefit of a product's opportunity indicates the extent to which a country's economic complexity index improves if that country has a RCA in exporting that product. The opportunity gain can be written in equation (6):

$$OPG = \sum_{p'} \frac{\emptyset_{pp'}}{\sum_{p''} \emptyset_{p''p'}} \left(1 - M_{cp'}\right) PCI_{p'} - (1 - d_{cp}) PCI_p \tag{6}$$

Where $\emptyset_{pp'}$ is the proximity index defined in relation (4), $M_{cp'}$ Country-product matrix and PCI_p is product complexity index of product *p*. d_{cp} measures the distance between products that a country produces and other products that it cannot produce, and is calculated as the sum of the proximity between product *p* and other products that the country does not produce. Then, by dividing the value obtained by the sum of the proximities between product *p* and all other products, the distance criterion is normalized. In this case, if country *c* is the exporter of most products related to product *p*, then the standard value of the small numerical distance, close to zero, will be obtained. If country *c* exports a small share of products related to product *p*, then the measure of numerical distance will be close to 1. This criterion is calculated in equation (7):

$$d_{cp} = \frac{\sum_{p'} (1 - M_{cp'}) \emptyset_{pp'}}{\sum_{p'} \emptyset_{pp'}} \tag{7}$$

4.3 Optimal Diversification Model

Numerous studies have shown that diversification of production and exports are a path-dependent process. Countries develop industries that are similar to their existing technology and connected to the existing industrial structure (Sezai, 2020).

Using this approach and examining the behavior of countries, Alshamsi et al. (2018), expressed the possibility of activating the export of product *i* in equation (8):

$$P_i = B \left(\frac{\sum_{j=1} a_{ij} M_j}{k_i} \right)^{\alpha} \tag{8}$$

a_{ij} shows whether product *i* is connected to the product *j* in the product space network. $M_j$indicates whether product *j* is currently being exported by the studied country. k_i indicates the number of products associated with product *i* in the network.

B indicates the probability of activating product *i* assuming that all related products are active. In the calculations, *B* equals to 1. α represents the coefficient to determine the importance of association between products. For example, if α equals to 0, it means that the possibility of activating a product in the network will be the same as all other vertices .If α equals to 1, the possibility of activating a vertex increases linearly with increasing number of associated active vertices. Values greater than 1 will also indicate that the probability of a vertically activating vertex increases as the number of associated active vertices increases. In order to calculate α, the density function and the method proposed by Hidalgo et al. (2007) were used in such a way that the probability of activating a product is calculated according to the density of that product.

To calculate α in this study, the beginning of 2014 and the end of 2018 have been included so that which products have been deactivated in 2014 and activated at the end of the period, i.e. 2018 for each country (Figure 2). Then the density of these products was classified into eleven intervals and the probability of activation of inactive products was calculated according to these categories in each interval. In the last step, the relationship diagram between intervals was drawn based on the density values and activation probability. Then, the relationship between them is calculated based on power regression ($Y = AX^a$) according to the method proposed by Hidalgo et al, (2007). The value of α equals to 1.2143.

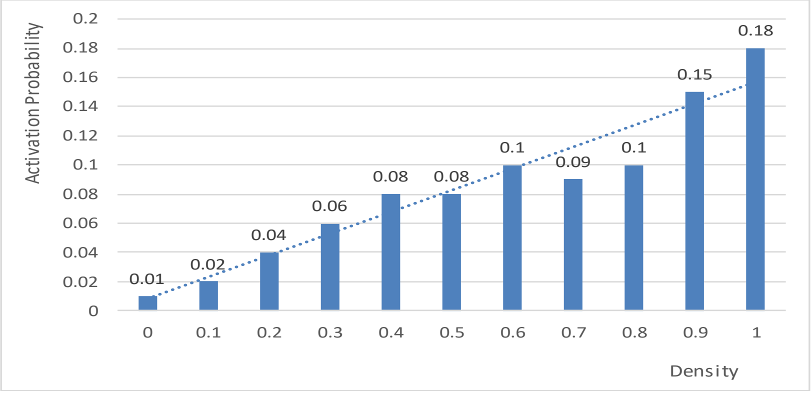

Figure 2. Relationship between density and product activation probability
***Source**: Research findings*

In the next step, to activate products with activation potential, five strategies will be used, which include random, greedy, high- degree, low- degree and majority strategies. In a random strategy, nodes are randomly selected for activation. This strategy forms a basic scenario, but in a greedy strategy, at each step, the node is selected with the highest activation probability and the lowest activation time, respectively. In the high-degree strategy, the node with the highest grade is selected for activation at each stage, and the activation of the node with the lowest grade to be activated at each stage is the low- degree strategy. Finally, in the majority strategy, the node with the maximum number of connections to active nodes is selected in each step. It is necessary to explain that the node means the products and the degree of each node is the number of products or nodes connected to each node.

Alshamsi et al. (2018) solved the model for three topologies: a Wheel network, a Generalized wheel network and Scale-free network. Figure 3, part a, shows a wheel network populated by Z nodes. A wheel network has a central hub, which is connected to all nodes, and a ring of Z−1 nodes that are connected to two neighbors and the hub. In the wheel network, the probability of activating peripheral nodes 1/3 does not change unless the hub is active. After the hub is active, the probability of activating peripheral nodes grows to 2/3. The greedy strategy in this case is to always develop the activity with the highest probability of success, and hence, to activate 1/3 of the peripheral nodes before targeting the hub. The majority strategy would target the hub after one peripheral node is infected, and would be almost identical to the high-degree strategy. The low-degree strategy would target the hub first. This can be written in equation (9):

$$T(L.a) = 3^a(L-1) + \left(\frac{Z-1}{L}\right)^a + \left(\frac{3}{2}\right)^a (Z-2-L) + 1 \qquad (9)$$

where L Measures the time or number of peripheral nodes that are activated, in which the activation time is inversely related to the probability of activation, t=1/p. 3α is the time required to activate each of the first L−1 nodes, ((Z−1)/L)α((Z−1)/L)α3^a is the time required to activate the hub, and (3/2)α is the time required to activate all remaining peripheral nodes after activating the hub, except for the last one which takes one unit of time. The optimal value (L^*) can be obtained by setting dT/dL = 0:

$$L^*(a) = (Z-1)\left(\frac{\left(\left(3/2\right)^a + 3^a\right)(Z-1)}{a}\right)^{-\frac{1}{a+1}} \qquad (10)$$

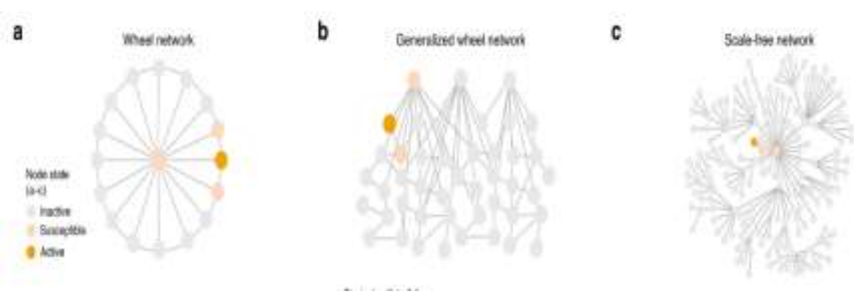

Figure 3. Comparison of wheel, Generalized wheel and Scale-free networks
***Source**: Alshamsi et al (2018)*

Figure 3, part b, shows a general wheel network with *n* nodes and *m* hubs so that z = m + n and (n> m) nodes form a random network with distribution degree D (k) and with average degree k_L The relationship between nodes and hubs is randomly formed and for simplicity it is assumed that hubs are not related and all have the same degree. This would let us to generalize the idea of the wheel network and consider in equation (11):

$$\boldsymbol{T(L\text{،}a)} = \sum_{j=2}^{L}\sum_{i=0}^{K_L-1}\binom{n-2}{k_L-1}^{-1}\binom{j-1}{i}\binom{n-j-1}{K_L-1-i}\left(\frac{mK_H+K_L}{n(1+i)}\right)^{a} +$$
$$m\sum_{I=0}^{L-1}\binom{L}{i}\binom{n-L-1}{K_H-i}\binom{n}{K_H}\left(\frac{K_H}{i+1}\right)^{a} +$$
$$\sum_{j=L+1}^{n}\sum_{i=0}^{K_L-1}\binom{n-1}{K_L}^{-1}\binom{j}{i}\binom{n-j-1}{K_L-i}\left(\frac{mK_H+nK_L}{mK_H+in}\right)^{a} \quad (11)$$

In equation (11) the first sum accounts for the activation time needed for the initial L low degree nodes, the second term accounts for the activation of the m hubs, and the third term stands for the activation time of the other n−L low degree nodes.

Figure 3, part c, is a scale-free network. As we do not have an analytical answer for the case of scale-free networks thus we investigate the problem numerically. The Scale-free network simulation results show that combination of the greedy strategy (with probability p) and the majority strategy (with probability 1−p) to minimize spreading time.

To calculate the value of p, it is necessary to apply the strategies to each year's data under different values and activation time is measured. Computational results of events related to Iran for 21 different values are measured on p and the results are presented in Figure 4. According to the results, the minimum diffusion time is obtained for p = 0.45, so in determining the optimal sequence for activation of potential products, the majority method is selected with a probability of 45% and a greedy method with a probability of 0.55.

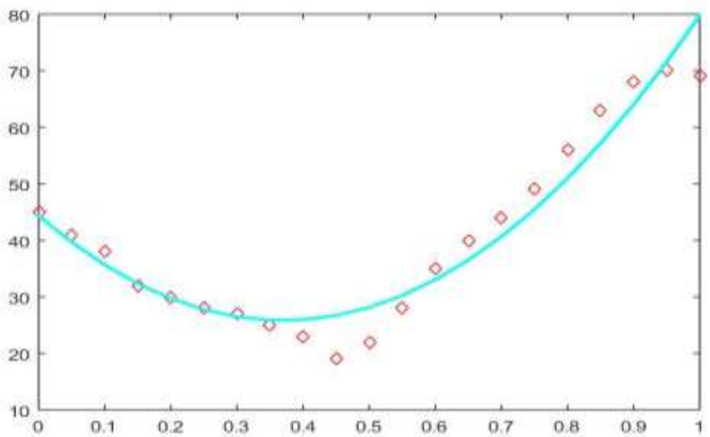

Figure 4. The optimal value of p in the optimal combination strategy
Source: *Research findings*

5. Results

This section examines the current position of Iran's chemical products in comparison to those of other countries using the economic complexity index. Then, using the proposed model to draw the product space of these industry, active, potentially active, and inactive products will be identified. Finally, after taking into account the model's limitations, chemical products with activation potential are prioritized using the optimal strategy. However, it is necessary to demonstrate that the product complexity index and density indicate the dynamics of Iran's chemical exports.

5.1 Econometrics Model

In order to demonstrate the dynamics of exports of Iranian chemical products we applied the Hausmann and Klinger(2007)model in equation (12):

$$LEX_{i,t} = \alpha + \beta LEX_{i,t-1} + \gamma PCI_{i,t} + \mu Density_{i,t} + \eta REER_{i,t} + \varepsilon_{i,t} \quad (12)$$

In which $LEX_{i,t}$ is Iranian export logarithm in chemical product i in year t, PCI is product complexity index and REER is a real exchange rate .

In order to estimate the model we used Panel Least Squares[3]. The results of model estimation based on data from 2005-2018 are shown in Tables 1 **.**It shows that the overall fit of the model based on the F_ Limer Statistic is significant and it was found that the product complexity index and density index are the determinate of export dynamics of Iran's chemical products.

Table 1. Dynamics estimation of exports of Iranian chemical products using PLS method

Variable	*Coefficient*	Std. Error	*t-Statistic*	*Prob.*
C	-0.299762	0.148546	-2.017973	0.0436
LEX(-1)	0.500672	0.010068	49.73066	0.0000
PCI	0.085974	0.022981	3.741038	0.0002
DENSITY	9.634555	0.332321	28.99172	0.0000
REER	0.011552	0.000944	12.23876	0.0001

R-Squared	0.383065	Mean Dependent Var.
Adjusted R-Squared	0.382688	S.D. Dependent Var.
S.E. of Regression	1.505323	Akaike Info Criterion
Sum Squared Resid	14833.21	Schwarz Criterion
Log Likelihood	11972.37	Hannan-Quinn Criter.
F-Statistic	1016.129	Durbin-Watson Stat
Prob.(F-statistic)	0.000000	
Total Observations: 6529		

Source*: Research findings*

[3] Least Square method will generate a line of best fit that explain the potential relationship between independent and dependent variables.

5.2 Investigating the Current Situation of Iran

The trend of Iran's economic complexity index over the last 55 years shows that Iran's ranking is deteriorating. Iran's position among 128 countries has dropped from 66 in 1964 to 101 in 2018[4].

Iran, on the other hand, has a better situation when it comes to chemical industries. According to statistics from 2014 to 2018, Singapore, Japan, and Switzerland have the highest level of complexity of the 128 countries surveyed. The economic complexity indexes of these countries are equal to 2.745, 2.660 and 2.559, respectively. On the other hand, Libya, Guinea, and Trinidad and Tobago are at the bottom. Iran's complexity index is 0.281, which places it 40th in the world. The average value of Iran's chemical exports during the study period was more than $ 7.5 billion, which takes 46% of total chemical exports of the world's countries.

The results of calculating the PCI for 921 chemical products showed that, the photo film roll, code 270291, with a PCI of 2.917, ranks first. Plastic acetate sheet, code 392073 and PCI of 2.830 and rubber sheet, rubber and plastic sheet, code 392072 and PCI of 2.435, are in the second and third ranks, respectively.

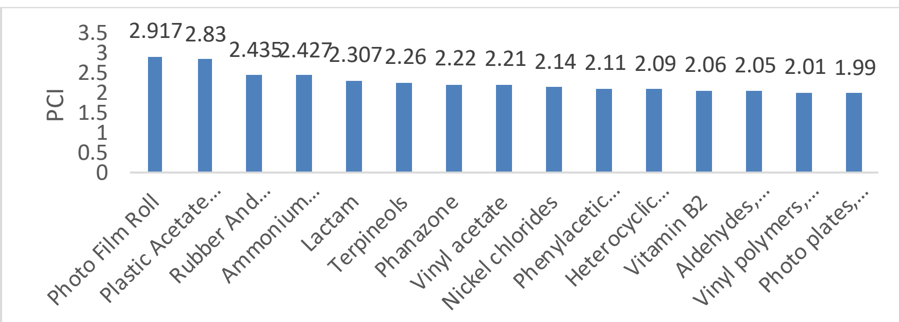

Figure 5. 15 chemical products with the highest PCI
***Source**: Research findings*

Oil products, jasmine with PCI of -2.88, lighter refill with PCI of -2.22 and natural rubber with PCI of -2.15 have the lowest PCI.

[4] https://atlas.cid.harvard.edu

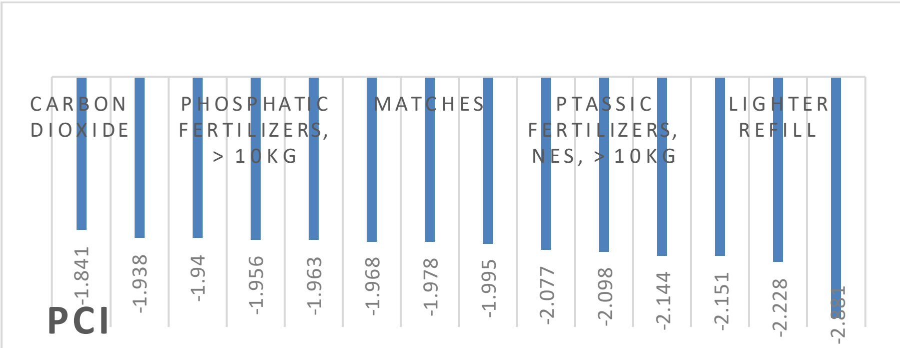

Figure 6. 15 chemical products with the lowest PCI
***Source**: Research findings*

5.3 Drawing the Product Space

The Product Space is a network that construct the idea of interconnectedness between products traded in the world economy. A network consists of nodes and links connected to some of these nodes. The proximity of products in the product space network is determined based on $\emptyset_{ij}$the square matrix, which has 921 rows and columns in this study. The space of chemical products is drawn using the Maximum Spanning Tree (MST based on the proximity index. All points with proximity coefficient of 0.55 are connected to each other. Figure 5 shows the space of Iran's chemical products, which was drawn using Microsoft Power BI software. This space can be divided into three categories. The first category is the chemical products with the RCA for Iran and this country is the exporter of them which are painted in phosphor color. The second category is the potentially active products which are divided into two categories due to the applying two constraints to the original model in terms of comparative advantage. One is potentially active, which is marked in blue, and the second is potentially active, which will be removed by constraining and marked in pantone color. The third category is products with zero probability of activation called inactive. As shown in Fig. 7, items in the third category are painted in red.

Figure 7. Product Space of chemical sector (In case of Iran: actives products are colored in phosphor, potentially active one comes in blue, potentially active removed based on filtration comes in Pantone and inactive comes in red)
***Source**: Research findings*

The space of the products of this industry has been drawn based on 6-digit codes for 921 products in order to study the trend of improvements in the space of Iran's chemical products in Figure 6 for the years 2005, 2010, 2015, and 2018. In 2005, the complexity of this industry in Iran was 0.1364, with a value of 1.6 billion dollars. In a list of 128 countries, Iran is ranked 49th. With a complexity index of 1704, Iran's chemical exports rose to $ 7.4 billion in 2010 which is ranked 44th. But in 2015, Iran ranked 14th in terms of complexity and Iran's exports in this industry decreased to $ 6.3 billion, and in 2014 Iran was the 24th country in terms of complexity in the chemical industry with a complexity index of 0.8685 and $ 5.7 billion in exports. In all the years studied, the products with the RCA of Iran are located around the space and away from the core, although in recent years the conditions have improved somewhat and products, although small, can be seen near the core of the product space.

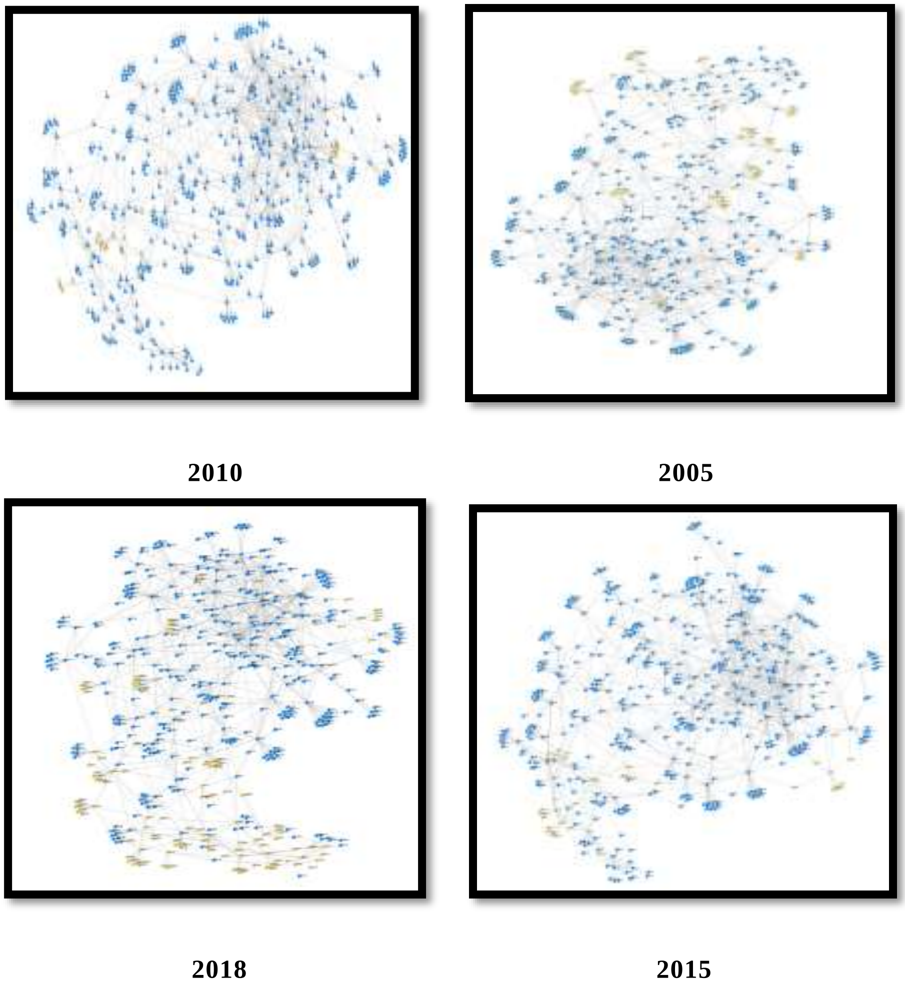

Figure 8. The pace of chemical products in 2005, 2010, 2015 and 2018 (yellow nodes indicates the Iran's export products with RCA>1).
***Source**: Research findings*

5.4 Products Classifications

In order to determine the optimal strategy for diversifying Iran's chemical exports, first the chemical products that Iran has a RCA in exporting were identified using the RCA index greater than one. Out of 921 chemical products, Iran has a RCA in exporting 78 products, so the average complexity of Iran's competitive chemical products equals to 5.83. This indicates the small number and low level of complexity of Iran's RCA export products. Table 2 shows the ten most competitive Iranian products in order of complexity. The most complex competitive chemical product of Iran is ethylene glycol mono alky ethers with a complexity index of 1.28 ranking 108 among 921 products.

Table 2. Iran's top ten competitive chemical products

Rank	Product Code	Product Name	Product Complexity Index	Rank among all chemical products
1	290944	ethylene glycol mono alky ethers	1.28	108
2	380120	Colloidal graphite	0.918	193
3	290250	Styrene	0.877	205
4	290949	Ethers – Alchols	0.828	215
5	292213	Triethanolamine, salts	0.749	235
6	290943	Mono butyl ethers	0.725	245
7	291521	acetic acid	0.591	280
8	290124	buta-1,3-diene; isoprene	0.528	291
9	290123	Butene and isomers	0.525	292
10	290290	Cyclic hydrocarbons	0.421	325

***Source**: research findings*

By eliminating 78 competitive products with RCA, it is necessary to identify the products for export diversity among the remaining 843 products, which is based on the proposed model; the probability of activation of all Iranian inactive products was calculated and determined .There are 259 products for which Iran is not currently an exporter with a RCA, but the probability of their activation is greater than zero. The probability of the remaining 584 items being activated is zero.

There are 78 active products and 259 potentially active products in Iran's export portfolio. It is not possible to activate 259 potentially active products and it is necessary to reduce this number by applying constraints. Therefore, opportunity gain and product complexity indices were used and products were selected that firstly have a positive opportunity gain and secondly, their complexity is greater than the average complexity of competitive export products (-0.583).

Products with positive opportunity gain were selected as the first constraint criterion. The number of potential active items was limited to 146 after these restrictions were implemented. The average complexity of Iran's export products was the second criterion for limiting potential products. Clearly, countries are attempting to produce products with higher technical knowledge and more complexity degree than what is actually available in their export markets. Therefore, potential products whose complexity was less than the current average complexity of Iran's export products were eliminated (-0.58). This criterion resulted in the removal of only one product. As a result, 145 items were chosen as potentially active.

What is the priority of activating 145 products? Since the production and export of products is costly, determining the appropriate strategy for activating the products is of particular importance. Countries or regions can choose a variety of strategies in this regard, which is based on the strategies of majority, greedy, high-degree, low-degree and optimal sequence of activation of potentially 145 active products to increase export diversification. Table 3 shows the first three products for activation based on different strategies. In the majority strategy, the product with the most connection to active products is selected during each stage. Based on this strategy, the first three products are phenol-salts, polycarbonate and pigments-titanium dioxide, respectively. Activation is selected in order of shorter activation time.

The first to third priorities based on this strategy are Vanadium(V) oxide, Wall - floor covering - Vinyl chloride and Titanium dioxide pigments products, respectively. In a high-degree strategy, a product with the most connection to other products in the network is selected for activation at each stage that. According to the high-degree strategy, the first three products are halogen derivatives of aromatic hydrocarbons, fluoropolymers and silicon, respectively. In the low-degree strategy, the product with the least contact with other products in the network is selected for activation during each stage. Based on this strategy, the first three products are Vanadium(V) oxide, Wall - floor covering - Vinyl chloride and m-xylene.

As explained, the product space network is a free-scale generalized wheel network. In this network, a combination of majority strategies with a probability of p and a greedy strategy with a probability of 1-p minimizes the network distribution time. To obtain p values under different values, the strategy is applied to the each year's data and the activation time is measured. Then, the minimum activation time is obtained which is p = 0.45. Therefore, in determining the optimal sequence for activating the potential active products, the majority strategy was selected with a probability of 45% and the greedy strategy with a probability of 0.55. The results of diversification sequence for 145 products were calculated based on the optimal strategy, which is a combination of greedy and majority strategies. As presented in Table 3, the first three products for activation, according to the optimal strategy, are phenol-salts, polycarbonate and titanium dioxide pigments, respectively.

Table 3. Prioritize the first three products based on different strategies and optimal strategy

the first three products		strategy	Probability of activation	Product Complexity Index	Opportunity gain
Code	Product Name				
290711	1- Phenol salts	majority	0.1702	1.0556	0.0958
390740	2- Polycarbonate		0.1081	1.4132	0.2559
320610	3- Titanium dioxide pigments		0.2857	0.3724	0.0473
282530	1- Vanadium(V) oxide	Greedy	0.3333	0.2491	0.0575
391810	2- Wall - floor covering - Vinyl chloride		0.3333	0.2369	0.1874
320610	3- Titanium dioxide pigments		0.2875	0.3724	0.0575
290369	1- Halogen derived from aromatic hydrocarbons	high degree	0.0171	1.7563	0.5823
390469	2- Flora-polymers		0.0114	1.8295	0.5027
391000	3- Silicone		0.0118	1.7033	0.4311
282530	1- Vanadium(V) oxide	low degree	0.3333	0.2491	0.0575
391810	2- Wall - floor covering - vanilla chloride		0.3333	0.2369	0.1874
290242	3- m-xylene		0.2500	0.1994	0.1273
290711	1- Phenol salts	Optimal	0.1702	1.0556	0.0958
320610	2- Titanium dioxide pigments		0.2875	0.3724	0.0575
390740	3- Polycarbonate		0.1081	1.4132	0.2559

***Source**: Research findings*

6. Concluding Remarks

The product space network contains many clues for the development of countries. Although developed countries show a declining trend after reaching the maximum of product diversity in their export portfolios, most developing countries are attempting to reach that peak. The appropriate and efficient selection of the diversification path and roadmap, on the other hand, is critical. Although Iran has chosen an export development policy in most of its development programs, available statistics and evidence suggest that it has not met its objectives.

The results, based on the theory of product space and economic complexity, suggest that there are higher-complexity products in Iran's chemical industry that are comparable to the existing export portfolio. Competitiveness in Iran's production and export can be achieved by determining the optimal strategy. Figure 5 and 6 showed the product space of Iran's chemical industry, which reveals that Iran's competitive chemical products are mainly located far from the core. Focused on the optimal strategy, this study attempted to determine a roadmap for approaching to core of the chemical industry product space.

Applying the model to the data, it was revealed that Iran has 78 active chemical products in export, 259 potentially active products potential to be activated, and 584 inactive products with a zero probability of activation. The average complexity of Iran's products with the RCA is equal to -0.58 indicating the low level of complexity of export products with competitive strength. Iran's most complex chemical products for export are Monovalent Ethers, Ethylene Glyco Ether (with complexity amount of 1.28), colloidal granite (with complexity amount of 0.918) and Styrene (with complexity amount of 0.877), respectively. However, it should be noted that Iran ranked 101st out of 128 countries in terms of economic complexity index in 2018, but ranks 24th in chemical products. This indicates that Iran's chemical product portfolio is more complex than the entire portfolio of export products.

Due to the high number of potentially active products compared to products with RCA, scientific and logical restrictions were applied to reduce this number. In this respect, the base model was subjected to two constraints: positive opportunity gain and having a higher level of complexity than the current average of competitive products. As a result, the number of products for the activation sequence was reduced to 145. A total of 145 products were listed for export diversification based on majority, greedy, high-degree, low-degree, and optimal strategies, which is a combination of majority and greedy strategies.

The findings of this study can be summarized as follows:

1. According to the average data of Iran's production export from 2004 to 2018, 78 chemical products out of 921 had RCA>1.

2. 259 other chemical products may have a RCA in Iran, but if we decide to produce and export products that are more complex than the current portfolio and have a favorable opportunity gain, the number of these products would be reduced to 145.

3. One of the study's key findings is the development of a roadmap for activating these 145 products using various strategies, one of which is the greedy strategy. This strategy has been compared to the hanging fruits because it is easier to accomplish the goals. However, in high-degree and majority strategies, products are chosen for activation in order to allow for the activation of further products in the future. These strategies target products that are difficult to activate early but will assist in the activation of other products later on, while greedy and low-degree strategies would allow for the activation of fewer products in the future.

4. Identifying the optimal strategy based on product space theory and network science to assess the best roadmap in Iran's chemical goods network is one of the study's most significant results. This optimal strategy was discovered to be a mixture of greedy and majority strategies. On the basis of this strategy, a roadmap for diversification of Iran's chemical products was created. The first rank for diversification based on optimum strategy goes to phenol salts. The global volume of this product's exports was $ 2300 million in 2004 and $ 3300 million in 2018. South Korea, the United States, and Germany were the top three exporters of this product in 2018, with exports of 549, 316, and 291 million dollars, respectively. Iran's main regional competitor is Saudi Arabia, which ranks seventh in the world and first in the region in terms of exports of this product with 163 million dollars.

The second product based on the best approach is titanium dioxide pigments. The export value of this product was $ 5400 million in 2004, and it rose to $ 8300 million in 2018. In 2018, the top three exporting countries were the United States, Germany, and the United Kingdom, with exports of 1500, 1200, and 633 million dollars, respectively. In terms of exports, Saudi Arabia is ranked 10th in the world and first in the region. Saudi Arabia's total export of this product is worth $ 205 million per year.

Polycarbonate is the third product suggested as part of the optimal strategy for diversifying exports. The volume of global exports of this product is $ 5400 million in 2004, and it rose by 99 percent to $ 10800 million in 2018. South Korea, the United States, and Germany have been the top three exporters of this product in 2018, with exports of 1750, 1,200, and 1,120 million dollars, respectively. In 2018, Saudi Arabia ranked first in the region and ninth in the world in terms of export of this product, Saudi Arabia's total export of this product is worth $564 million.

It should be acknowledged, however, that policy coordination, especially in the development of education, infrastructure, innovation, and finance, is critical to the strategy's effectiveness and to the simultaneous evolution of the product space.

Finally, in order to achieve export diversity and high growth rates in chemical products while complying to the optimal roadmap, Iran requires a policy agenda aimed at improving the product environment, including its physical, human, and institutional aspects.

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