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The Level of Population Carrying Capacity, Natural Resources and Pollution: A Case of Iran

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ABSTRACT

A country's population carrying capacity is the maximum population a country can tolerate depending on its resources and environmental conditions. An awareness of a country's population carrying capacity can be of great help to development planners. Despite the importance of this variable, few studies have attempted to estimate it, particularly at the country level on which no study was found to have focused. The present study aimed to calculate the population carrying capacity of Iran using the expanded logistic equation, the generalized extractable energy resources equation, and the Extraction-environmental Kuznets curve (XEKC). The population growth rate of Iran, as a country with abundant primary energy and natural resources, has always been positive and its population now stands at about 83 million. The simultaneous estimation of parameters from three equations using multi-objective optimization showed that Iran's population carrying capacity was about 95 million. It is important to note that this estimate of the population carrying capacity was based on Iran's current economic growth. This means that with the growth and expansion of the economy, the population carrying capacity of Iran can be estimated higher. Also, the EKC was established with 99.5% confidence for the Iranian economy, and the value of the per capita income at the turning point of the inverted U-shaped curve was 0.435 billion Rials. Meanwhile, the amount of GDP per capita for the Iranian economy was 0.157 billion Rials at the time of this study, showing Iranian economy was on the upward sloping portion of the curve.

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1. Introduction

As a country with abundant natural resources[1], Iran was ranked 19th in the world in terms of population in 2017 and is home to 1.08% of the world's population. Figure (1) shows the population of Iran during 1957-2036[2]; as it can be seen, Iran's population follows a steadily increasing trend during this period although the rate of increase varies from year to year.

For a more detailed analysis, the population growth rate during 1957-2036 is plotted in Figure (2). Based on this figure, the population growth of Iran had been decreasing since 1957 but started to increase from 1975 onwards, with a growth spurt in 1976. This increasing trend continued until 1987 when it experienced a sharp decline, followed by a series of ups and downs. It is expected to decrease to 0.57% in 2036.

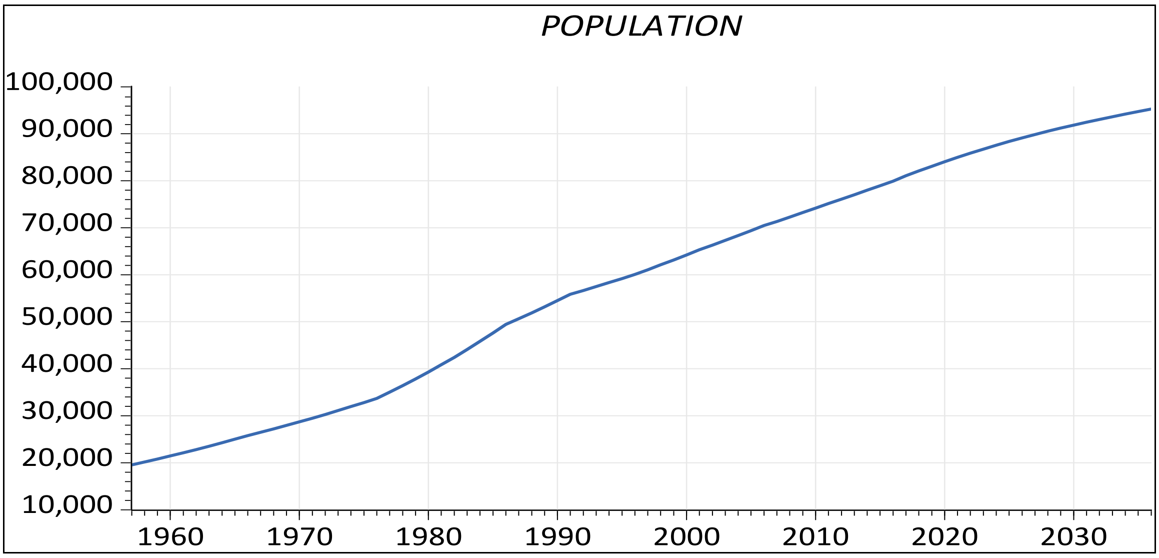

Figure 1. The Population of Iran between 1957 and 2036

Source: The Statistic Center of Iran.

In general, Iran's population experienced rapid growth during certain periods due to either concern about population aging and its ensuing costs or political and religious motives. However, in some other periods, population growth declined due to economic factors, such as poverty, a negative outlook on economic conditions, economic sanctions, political instability, or social factors, such as increasing women's employment. In addition, the country's population planning policies, in the form of pro- and anti-natalist policies, played a key role in the rate of population growth.

1. Iran in terms of natural resource revenue respect to GDP, was 25th country in the world in 2017 (Source: World Bank)
2. The Statistics Center of IRAN predicts the population of Iran for the years 2020 to 2036.

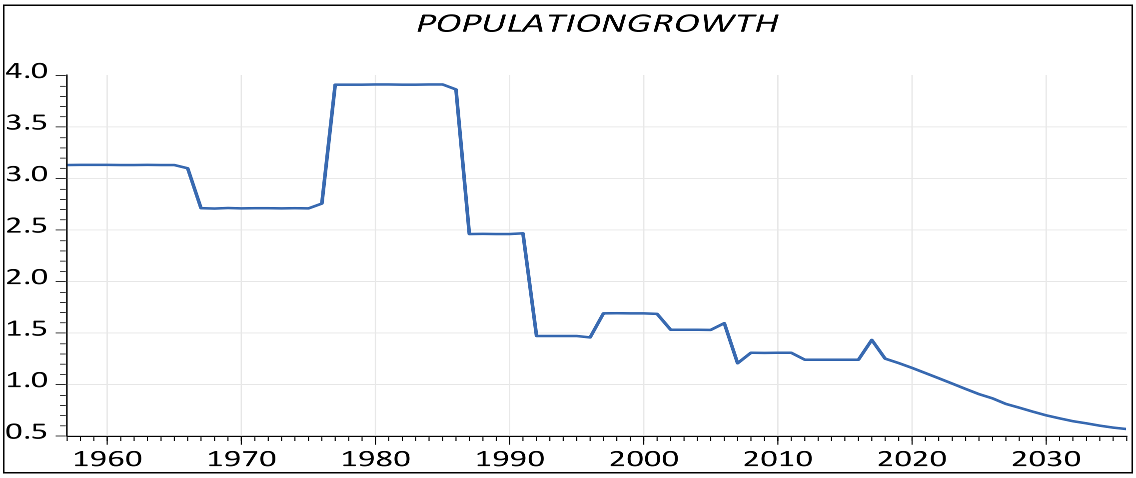

Figure 2. Population Growth Rate (Percent) of Iran between 1957 and 2036

Source: The Statistic Center of Iran.

In general, Iran's population experienced rapid growth during certain periods due to either concern about population aging and its ensuing costs or political and religious motives. However, in some other periods, population growth declined due to economic factors, such as poverty, a negative outlook on economic conditions, economic sanctions, political instability, or social factors, such as increasing women's employment. In addition, the country's population planning policies, in the form of pro- and anti-natalist policies, played a key role in the rate of population growth.

Due to the importance of population growth in the development of a country, many researchers have focused on this issue in the context of Iran. Some researchers have estimated the optimal population of a country based on limited resources. For example, by considering Iran's water resources, Daqiqi Asli et al. (2017) provided an estimate of the country's optimal population. The results of their study showed that Iran could accommodate 71 million people with its water consumption rate and the annual abstraction of freshwater resources at the time of their study.

Palivos and Yip (1993) used Bentham and Mill's social welfare function to compare population size and production growth rate. Lawson and Spears (2018) estimated the optimal population by considering the limitations of perishable resources.

It is important to note that the optimal population differs greatly from the population carrying capacity. Carrying capacity refers to the maximum population that a particular habitat can tolerate without permanent damage to the productivity of that habitat (Rees and Wackernagel, 1996). Estimating a country's population carrying capacity concerning its environmental conditions is one of the most important issues that play an important role in decisions made by policymakers. However, studies on the estimation of carrying capacity have been conducted mostly at the provincial or city level[1].

Therefore, the present study sought to estimate Iran's population carrying capacity. It should be noted that the carrying capacity of any habitat is affected by many factors, such as natural resources, environmental pollution, and technological development. While the advancement of technology can lead to the discovery and exploitation of new

1. These studies are described in the next section.

resources, it can result in more pollution and environmental degradation. At the same time, the level of economic development has a great impact on the use of environmental technologies.

The present study was an effort to estimate the population carrying capacity of Iran within the framework of an economic model, taking into account natural resources, pollution, and production. To this end, three main equations were considered. Initially, a nonlinear equation was developed to calculate the population carrying capacity of Iran. Then, an equation was used to estimate the level of primary energy resources. Finally, the environmental Kuznets curve (EKC) hypothesis was expanded and the result was introduced as Extraction- environmental Kuznets curve (XEKC). These equations were then estimated simultaneously by the multi-objective optimization method.

The present study is organized as follows. After the introduction, some published studies on the subject of carrying capacity are examined. In Section 3, the research model is expanded. The multi-objective optimization method and its application in econometrics are introduced in Section 4. After the model and the method are introduced, the parameters are estimated and the results of data analysis are presented. Finally, a summary of the research and some conclusions are offered.

2. Literature Review

The study of the population is one of the most interesting topics for researchers. For Instance, Dehghan Shabani et al., (2012), developed a simple theoretical framework to show the impact of population density on regional economic growth. Also, Lukman et al., (2019), using the ARDL model, showed that population total, gross domestic product per capita, urbanization rate, and energy use have a positive impact on carbon emissions in Nigeria. Chishti (2020) analyzed the Nexus between Demographic Changes and Economic Growth in Pakistan and showed capital stock is a mediating channel in the demographic change and economic growth relationship.

While Studies on carrying capacity have mostly focused on the following two areas: 1- Urban capacity and 2- resource and environmental carrying capacity. Researchers have used a variety of methods to calculate carrying capacity. In what follows, previous studies are categorized into six categories based on the various methods used to assess carrying capacity:

1- Supply-demand: By studying the relationship between the supply and demand of man-made physical resources, such as roads, water, sewage, and waste disposal, Onishi (1994) examined urban capacity. Similarly, Liu (2012) evaluated the urban carrying capacity of 16 Chinese cities using the concept of supply and demand balance and 12 measurable indicators, such as land, water, transportation, and environment.

2- Spatial planning: Using the spatial planning framework based on water and sewage supply infrastructure, Joardar (1998) studied the carrying capacity of Indian cities. Schroll et al. (2012) also used local spatial planning to divide the determinants of carrying capacity into the following five categories: Quantity and quality of water, food security, solid waste management, transportation, and deforestation. Santoso et al.

(2014) compared the two methods of strategic environmental assessment and spatial planning to assess the environmental carrying capacity of an Indonesian province.

3- Mean-variance analysis: Wei et al. (2016) utilized this method and 30 indicators from previous studies to evaluate the urban carrying capacity of 30 cities in central China.

4- Geographic Information System (GIS): Oh et al. (2005) employed the GIS technique and used the infrastructure and land factors, including energy, green areas, roads, metro systems, water, and wastewater treatment to determine population density.

5- Multi-factor assessment model: Li et al. (2019) used this method and various natural, economic, and social factors to evaluate the carrying capacity of resources and the environment of Xinbei District, Changzhou, China.

6- Pressure-capacity-governance (PCG) model: Bao et al. (2020) developed an analytical framework that could be utilized to assess the environmental resources and pressures, carrying capacity, and governance levels. They used this model to evaluate the urban capacity of the Yangtze River Economic Belt (YREB).

Our review of the literature showed that all the studies conducted on the carrying capacity were at the provincial or city level. It also became apparent that the studies reviewed evaluated the urban carrying capacity rather than the population carrying capacity. Given this existing research gap, the present study aimed to calculate the population carrying capacity.

In this article, the calculation of the population carrying capacity at the national level was done by considering environmental considerations, i.e. the level of resource extraction and pollution. One of the novelties of the present study is the generalization of the environmental Kuznets curve (EKC) hypothesis.

The EKC hypothesis was proposed by Grossman and Krueger in the 1990s and has been tested by many researchers since then (Jalil and Feridun, 2010; Menyah and Rufael, 2010; Almulai et al., 2015; Dadgara and Nazari, 2017; Beyene and Kotosz, 2019).

In some studies, the EKC hypothesis was expanded to the energy-environmental Kuznets curve (EEKC) hypothesis. In these studies, by adding energy consumption as one of the important factors in air pollution, the relationship between energy consumption, pollution, and production was investigated (Suri and Chapman, 1998; Luzzati and Orsini, 2009; Chen et al., 2016; Aruga, 2019).

It should be noted that although energy consumption is one of the causes of environmental pollution, in countries with abundant resources, pollution caused by the extraction of resources, especially oil, and gas, is a more important factor than energy consumption. Therefore, in the present study, the EKC for the economy of Iran, which possesses one of the world’s largest oil and gas resources, was generalized by increasing the level of resource extraction, and The Extraction-environmental Kuznets curve (XEKC) hypothesis was proposed and estimated together with the population and resource equations.

In sum, the present study is different from the previous studies on the population carrying capacity in the following ways:

1- The population carrying capacity was calculated at the country level;

2- A nonlinear model was expanded to calculate the population carrying capacity;

3- A new hypothesis, i.e. Extraction-environmental Kuznets curve (XEKC) hypothesis, was developed and estimated;

4- The multi-objective optimization method was used to simultaneously estimate the parameters of all three equations.

3. Model

In this section, the theoretical foundations of the three equations, namely, extractable energy resources, pollution, and population equation, are examined one by one and in detail. Then, these three relationships are considered simultaneously, and the multi-objective optimization method is used to simultaneously estimate the parameters from these three equations.

3.1 The Level of Resource Extraction (Resource Equation)

If S is the finite and constant stock of a finite source, S_0 is the level of finite resources in period zero. Due to the constant amount of initial stock and given that the natural growth of finite resources over time, except for different geological periods, is zero, natural resources will deplete over time. Thus, the dynamic equation of resource extraction is relational (1) (van der Ploeg, 2018).

$$S_t = S_0 - \int_{T=0}^{T=t} R_T dT \rightarrow \dot{S}_t = -R_t \tag{1}$$

Where R_t is the extraction rate in the period of t. If the above relationship is considered discrete, we will have:

$$S_{t+1} = S_t - R_t \tag{2}$$

Where S_{t+1} is the level of resources in the period t + 1. If the rate of extraction from resources in each period is considered constant and equal to m; then, $R_t = mS_t$.

On the other hand, the examination of the trend of the extractable primary energy resources over time showed that the level of these energy resources followed an increasing trend rather than a decreasing trend (Figure 3). This indicates the discovery of new resources of primary energy in different periods[1]. In this study, the amount of new exploration is a function of the level of capital available in the oil and gas sector, so the exploration function can be considered as $(\theta K_t)^{b_2}$., where θ is the percentage of the total capital available in the economy used in the primary energy exploration sector. Therefore, by replacing and expanding Equation (2), we will have the following equation:

$$S_{t+1} = S_t - mS_t + b_1(\theta K_t)^{b_2} + \varepsilon_{1t} \tag{3}$$

In Equation (3), ε_{1t}, is any factor other than capital that affects the level of resources. Thus, Equation (3) is called the equation of resources and can be used to estimate the percentage of resources that are being extracted (m) and the percentage of capital used

1. For more information on the types of exploration, refer to Kadafa (2012) and Figueirôa et al. (2019).

in the oil and gas sector (θ) that leads to discoveries. b_2 is the elasticity of the discovery of new resources relative to the capital used in the energy sector.

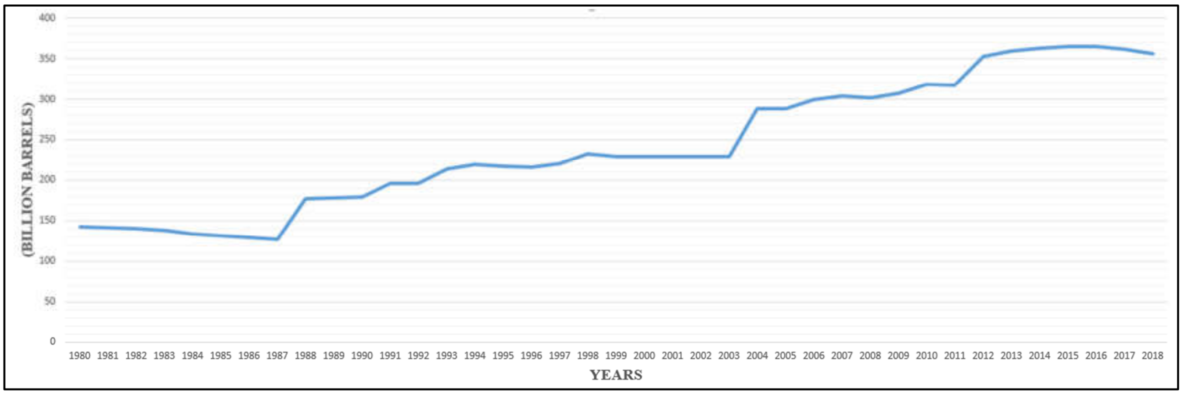

Figure 3. Proved Reserves of Natural Gas and oil for Iran (Billion Barrels), 1980-2018
Source: OPEC Annual Statistical Bulletin (Different years)

3.2 Population Equation

Population growth is a dynamic process and can be well described by differential equations. The simplest population growth model was provided by Malthus (1766-1834). His model showed the exponential growth of the population using the differential equation in Equation(4):

$$\frac{dN}{dt} = aN \tag{4}$$

where α is the growth rate (Malthus parameter). The result of this equation is an exponential function, which is shown in Equation (5):

$$N(t) = N_0 e^{at} \tag{5}$$

where N_0 is the initial population.

The Malthusian population growth model well describes the first phase of growth when the economy is far from its limits. However, the accuracy of this model is reduced in the second stage or later stages due to satiation or nonlinear effects (Dallali Isfahani and Ismailzadeh, 2006). The logistic model of the population is the developed version of the population exponential model and is shown in the form of a differential equation in Equation (6):

$$\frac{dN}{dt} = aN\left(1 - \frac{N}{M}\right) \tag{6}$$

Where M is the maximum population size. By simplifying Equation (6), the right side of this equation can be rewritten as follows:

$$\frac{dN}{dt} = aN - \frac{aN^2}{M} \tag{7}$$

The first term indicates population growth, and the second term limits this growth due to the lack of available resources and other reasons. The logistic model of population growth has an accurate answer and this answer is presented in Equation (8):

$$\frac{dN}{N\left(1-\frac{N}{M}\right)} = adt \Rightarrow \int \frac{dN}{N\left(1-\frac{N}{M}\right)} = \int adt \tag{8}$$

The right integral can be obtained through partial fraction decomposition:

Thus, the general solution to the logistic differential equation can be written as follows:

$$Ln(N) - Ln\left(1 - \frac{N}{M}\right) = at + C \Rightarrow Ln\left(\frac{N}{1-\frac{N}{M}}\right) = at + C \Rightarrow Ln\left(\frac{N}{1-\frac{N}{M}}\right) = at + C \quad (9)$$

The above algebraic equation can be used to obtain N[1]:

$$N(t) = \frac{e^{at+C}}{1+\frac{e^{at+C}}{M}} \quad (10)$$

Also, the constant C can be obtained from the initial conditions $N(t=0) = N_0$:

$$N(t=0) = N_0 \Rightarrow N_0 = \frac{e^C}{1+\frac{e^C}{M}} \Rightarrow N_0\left(1 + \frac{e^C}{M}\right) = e^C \Rightarrow N_0 + N_0\frac{e^C}{M} = e^C \Rightarrow$$

$$N_0 = e^C - N_0\frac{e^C}{M} \Rightarrow N_0 = e^C\left(1 - \frac{N_0}{M}\right) \Rightarrow \frac{N_0}{\left(1-\frac{N_0}{M}\right)} = e^C \Rightarrow C = Ln\left(\frac{N_0}{1-\frac{N_0}{M}}\right) \quad (11)$$

Inserting this value in Equation (10) yields:

$$N(t) = \frac{e^{at+C}}{1+\frac{e^{at+C}}{M}} \Rightarrow N(t) = \frac{e^{at}}{1+\frac{e^{at}}{M}\frac{N_0M}{(M-N_0)}}\left(\frac{N_0M}{(M-N_0)}\right) \Rightarrow N(t)$$

$$= \frac{N_0M}{N_0 + (M-N_0)e^{-at}}$$

$$N(t) = \frac{N_0M}{N_0+(M-N_0)e^{-at}} \quad (12)$$

Equation (12) shows the nonlinear population model and is estimated for the time series of the Iranian population in the section related to the estimation of parameters. The regression form of Equation (12) in Equation (13):

$$N_t = \frac{N_0M}{N_0+(M-N_0)e^{-at}} + \varepsilon_{2t} \quad (13)$$

where M is the population carrying capacity and a is the population growth rate parameter.

3.3 Extraction-Environmental Kuznets Curve (XEKC) Hypothesis

In his study entitled “Economic Growth and Income Inequality”, Kuznets (1955) showed that in the course of economic development, the relationship between per capita income and income inequality could be represented by an inverted U-shape. According to this hypothesis, in the early stages of economic development, as per capita income increases, the inequality of income distribution increases, and after reaching a certain level (turning point), it will gradually decrease.

Later, some environmental researchers found an inverse relationship between different environmental indicators and per capita income. Thus, the environmental Kuznets curve was developed and used in environmental studies. This inverted U-shaped relationship begins with a positive trend, flattens at the peak, and then decreases (De Groot et al., 2004).

The effect of economic growth on the environmental Kuznets curve can be expressed through three effects, which are referred to as scale, composition, and technology effects (Panayotou, 1993). The scale effect shows that to increase production in the economy, more inputs in the form of initial natural resources should be used. The production of more goods and services results in more pollution, which contributes to the destruction of the environment. Economic growth, which is synonymous with the expansion of production, has a potentially negative impact on environmental quality (Grossman and Krueger, 1995; Moutinho et al., 2017). Therefore, the scale effect indicates that environmental degradation will increase with the increase in per capita production.

The composition effect concerns the proportion of the type of productive activity to the size of the economy (Orubu and Omotor, 2011). A transition from agricultural to industrial production increases the intensity of pollution because more resources are exploited for the industry. Furthermore, the ratio of resource depletion to resource recovery will start to increase. In fact, along with economic growth, the structure of production will move towards polluting industries, and the level of pollution at this stage will be very high. However, the advancement of technology will eventually lead to the development of an eco-friendly, economy. In such a green economy, the intensity of pollution will decrease as the economy grows. This is the effect of composition. The composition effect of per capita production on the intensity of pollution is likely to be a non-monotonic function of income, similar to the inverted U-shaped curve (Swart and Brinkmann, 2020; Marsiglio et al., 2016).

In general, advances in technology reduce pollution by directly reducing the consumption of raw materials. Technological advances can also lead to better policies intended to control pollution. Moreover, the advancement of technology will enable the industry, which is inherently polluted, to produce quality products with less pollution (Sun and Lin, 2018; Orubu and Omotor, 2011).

Therefore, it can be suggested that the curve in the environmental Kuznets curve (EKC) is inverted due to the effect of scale, the effect of composition, and the effect of technology (Özokcu and Özdemir, 2017).

Early EKC models were simple second-order functions, in which pollution was expressed as the dependent variable and the income level as the independent variable. The functional form of these simple patterns is presented in Equation (14):

$$\frac{P_t}{N_t} = \alpha + \beta_1 \left(\frac{Y_t}{N_t}\right) + \beta_2 \left(\frac{Y_t}{N_t}\right)^2 + \varepsilon_{3t} \quad (14)$$

where $\frac{P_t}{N_t}$ is per capita environmental pollution, $\frac{Y_t}{N_t}$ is per capita GDP, α is the constant coefficient of per capita pollution equation, β_1 is the first degree of effect of per capita production on per capita pollution, and β_2 is the second degree of effect of per capita production on per capita pollution.

In addition to per capita production, resource extraction, especially in the case of oil and gas, appears to create a large amount of pollution in the mining area before they enter the production process. This seems to have been neglected by environmental researchers. Therefore, in the present study, the environmental Kuznets curve model was expanded for an OPEC member country, i.e. Iran, by adding the impact of per capita primary energy extraction on the environmental Kuznets curve. Equation (15) represents the expanded equation:

$$\frac{P_t}{N_t} = \alpha + \beta_1\left(\frac{Y_t}{N_t}\right) + \beta_2\left(\frac{Y_t}{N_t}\right)^2 + \beta_3\left(\frac{mS_t}{N_t}\right) + \varepsilon_{3t} \qquad (15)$$

This is called the Extraction-environmental Kuznets curve (XEKC). In Equation (15), the extraction rate in each period (mS_t) is also considered. β_3 shows the impact of per capita primary energy extraction of each period on pollution.

In the 2nd degree equation in Equation (15), first, if β_2 is negative and significant, the Kuznets' theorem is established for the economy and the environment. Also, in case β_2 is negative, the turning point of the environmental Kuznets curve will be equal to $-\frac{\beta_1}{2\beta_2}$. In other words, the turning point of the environmental Kuznets curve will be $\left(\frac{Y_t}{N_t}\right)^* = -\frac{\beta_1}{2\beta_2}$. , where $\left(\frac{Y_t}{N_t}\right)^*$ is the turning point of the U-shaped curve.

3.4 Simultaneous Equations System

In this section, to summarize the previous three sections, the equations of population, pollution, and primary resources are considered simultaneously. According to Equations (3), (13), and (15), the population equation can be considered along with the equations of primary resources and pollution. In the following sections, these equations are estimated simultaneously. The objective is to estimate the population equation (population carrying capacity) based on environmental considerations and resource constraints.

$$\begin{cases} N_t = \frac{N_0 M}{N_0 + (M - N_0)e^{-at}} + \varepsilon_{2t} \\ S_{t+1} = (1-m)S_t + b_1(\theta K_t)^{b_2} + \varepsilon_{1t} \\ \frac{P_t}{N_t} = \alpha + \beta_1\left(\frac{Y_t}{N_t}\right) + \beta_2\left(\frac{Y_t}{N_t}\right)^2 + \beta_3\left(\frac{mS_t}{N_t}\right) + \varepsilon_{3t} \end{cases} \qquad (16)$$

In most common methods used for the simultaneous estimation of equations, the equations must first be linearized. Then, the equations should be rewritten in the form of matrix equations, and one of the common methods used for solving the equations simultaneously should be applied to estimate the parameters of the expanded equation. In this study, the Pareto optimization method was expanded and then used to estimate the above equations simultaneously and nonlinearly. In what follows, first, the Pareto optimization method is examined; then, Equation (16) is estimated with this method.

4. Pareto Optimization Method (Multi-Objective Optimization (MOO))

In this section, multi-objective optimization and its application to the simultaneous estimation of population, pollution, and primary resources equations (Equation 16) are explained[1].

Multi-objective optimization, or Pareto optimization, is considered a kind of multi-criteria decision-making. In multi-objective optimization, more than one objective function (multiple objective functions) can be optimized simultaneously. To achieve optimal decisions in the system, it is necessary to strike a trade-off between two or more conflicting goals.

Even for a simple multi-objective optimization problem, it is highly unlikely to find an optimal solution that can simultaneously optimize all the objective functions defined in the problem. If the objective functions defined in the multi-objective optimization problem conflict with each other, we need to obtain optimal Pareto solutions[2] (Zheng, 2017).

Pareto optimization problems usually do not have a single solution; rather, they have a set of solutions. Without additional information, all of Pareto's optimal solutions are equally good. In this study, with an additional assumption, the best Pareto optimization solution was selected from the set of possible solutions.

Mathematically, a multi-objective optimization problem can be formulated as Equation (17), where $f(x)$ is a vector consisting of objective functions and q indicates the number of objective functions in the multi-objective optimization problem. Also, there are n variables, and q objective functions are optimized due to the variability of n. In addition, in the extended problem, m and p are inequivalent and equivalent equations, respectfully, and are considered constraints. Some definitions of this method are stated in the appendix.

$$Minimize\ f(x) = \{f_1(x), f_2(x), \dots\dots, f_q(x)\} \tag{17-1}$$

$$Subjectto: g_i(x) \leq 0 \quad i = 1, \dots, m \tag{17-2}$$

$$hj(x) = 0 \quad j = 1, \dots, p \tag{17-3}$$

$$x_k^l \leq x_k \leq x_k^u, \quad k = 1, \dots, n \tag{17-4}$$

Ideal points are obtained by minimizing each of the functions in the multi-objective optimization problem, regardless of other functions. Each time one of the objective functions in the multi-objective optimization problem is minimized, a point in the design space and a corresponding value for that objective function are obtained. Finding

1. In this section, only a brief review and the application of the multi-objective optimization method are discussed. For more information on this method, see Deb (2014).
2. Theoretically, there may be an infinite number of optimal Pareto solutions to a multi-objective optimization problem.

ideal points is very difficult and that is why ideal points are usually considered unattainable. Thus, the best option is to find the solutions (Pareto's optimal solutions) that are as close as possible to the solutions to the ideal space in the standard space. Such solutions are known as compromise solutions.

The degree of closeness between the ideal point and other points, which lead to a compromise solution, in the standard space can be defined by different methods. The point in the criterion space of a multi-objective optimization problem is usually considered the equilibrium solution; the Euclidean distance of this point from the ideal point should be minimal. The Euclidean distance of a point in the criterion space from the ideal point can be calculated through the following equation:

$$D(X) = \| f(x) - f^o \| = \sqrt{\sum_{i=1}^{q} [f_i(x) - f_i^o]^2} \tag{18}$$

where f_i^o displays a component of the ideal point in the criterion space. Compromise solutions are also known as optimal Pareto solutions.

In econometrics, to find the optimal value of the model parameters, an attempt is made to minimize the sum of the squared errors. The error refers to the difference between the estimated value of the dependent variable and its true value. Now, to estimate Equation (16) in the context of multi-objective optimization, the Euclidean space for each of these equations is presented in Equation 19. Each of these equations is, in fact, the sum of the squared errors.

$$RSS_1 = [S_{t+1} - (1-m)S_t - b_1(\theta K_t)^{b_2}]^2 \tag{19-1}$$

$$RSS_2 = \left[N_t - \frac{N_0 M}{N_0 + (M - N_0)e^{-at}}\right]^2 \tag{19-2}$$

$$RSS_3 = \left[\frac{P_t}{N_t} - \alpha - \beta_1\left(\frac{Y_t}{N_t}\right) - \beta_2\left(\frac{Y_t}{N_t}\right)^2 - \beta_3\left(\frac{mR_t}{N_t}\right)\right]^2 \tag{19-3}$$

Given the multi-objective optimization model in Equation (17) and the equations that are to be estimated simultaneously using Equation (19), Equation (20) shows a three-objective optimization model in the form of one equation. This equation can be optimized by the multi-objective optimization method and based on the $Chro = \{m, b_1, \theta, b_2, M, a, \alpha, \beta_1, \beta_2, \beta_3\}$ parameters.

$$Min\{RSS_1 = \sum_{t=1}^{T}(\varepsilon_{1t})^2, RSS_2 = \sum_{t=1}^{T}(\varepsilon_{2t})^2, RSS_3 = \sum_{t=1}^{T}(\varepsilon_{3t})^2\}$$
$$S.t \quad \begin{cases} 0 < m < 1 \\ 0 < \theta < 1 \\ M > N_0 \end{cases} \tag{20}$$

In Equation (20), some limitations are considered for the percentage of extractable resources, the percentage of capital used in the extraction of primary resources, and the population potential. Moreover, $t = \frac{\hat{\alpha}}{SE(\alpha)}$ statistic was used to test the significance of the estimated parameters. Then, the multi-objective problem-solving codes present in

Equation (20) were written in MATLAB, and the relevant parameters of the problem were estimated.

5. Estimation of Parameters and Analysis of Results

The parameters related to Equations (16) were estimated for data collected from Iran during 1980-2018 using the multi-objective optimization method (Equation 20) and MATLAB software. The data used included population time series (Statistical Centre of Iran), capital stock (Central Bank of the Islamic Republic of Iran), the level of extractable energy resources (OPEC Annual Statistical Bulletin), the level of CO_2 emissions (The World Bank), and GDP at constant prices (Central Bank of the Islamic Republic of Iran, Economic time series database).

The optimal level of Pareto was estimated based on the collected time series data and the multi-objective optimization problem represented in Equation (20). The optimal level of Pareto is plotted in Figure (4). As explained in the previous sections, there is no single optimal point in Pareto optimization; rather, there is a set of optimal points.

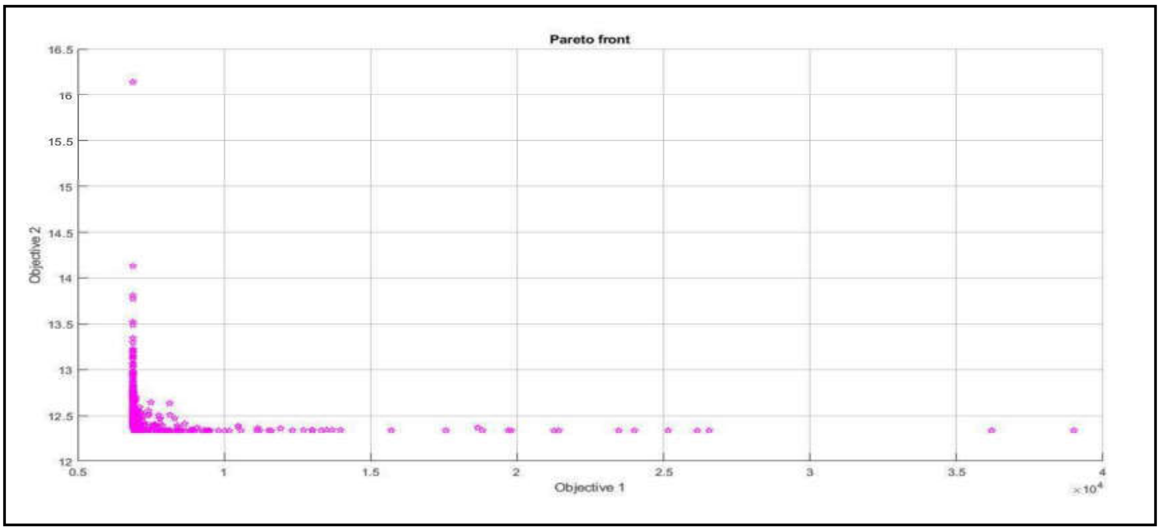

Figure 4. Parto Level in Optimal Mode (Estimated Optimal Values)
Source: Research findings.

It is important to note that all the points obtained from the multi-objective optimization have the same value and can be considered optimal points. Equation (21) can be used to find one point among the estimated optimal levels:

$$Min\ \{RSS_1 + RSS_2 + RSS_3\} \tag{21}$$

That is, from the set of parameters estimated with multi-objective optimization, the only parameter that minimizes the sum of the squared errors for all three estimated equations should be selected. The results of the estimation for each equation are presented and explained below.

Table (1) presents the estimated parameters for the equation of the level of proven extractable resources.

Table 1. Estimated Parameter of Equations of Proven Extractable Resource Levels

$S_{t+1} = S_t - mS_t + b_1(\theta K_t)^{b_2} + \varepsilon_{1t}$				
Parameter name	**The estimated value**	**Standard deviation**	**t statistic**	**p-value[1]**
m	0.0839	0.0116	7.2183	0.00
b_1	25.8194	1.0853	23.7910	0.00
θ	0.0326	0.0080	4.0682	0.00
b_2	0.5806	0.0377	15.4186	0.00
R^2 = 97.1160%				

Source: Research findings.

According to the results in Table (1), the percentage of extraction of primary energy sources was 8.3% per year. On the other hand, the percentage of capital used in the oil and gas sector was equal to 3.2% of the Iranian economy. Also, the proportion of the elasticity of resource discovery to the capital used in the oil and gas sector was 0.58%, i.e. a one percent increase in the capital used in the oil and gas sector will lead to a 0.58% increase in the level of both resource discovery and resources. Table 1 also includes the *t statistic* for all parameters. Based on the t-statistics obtained, it can be concluded that all the parameters are significant at the 99% confidence level; therefore, the results of the analyses performed on these parameters are acceptable.

Figure (5) shows the estimated and realized values for proven energy resources. According to this figure, the estimated values for the level of extractable energy sources closely matched the realized values for this parameter, indicating that the fitting effect was satisfactory. According to the estimated value of R^2 in Table (1), the fit index was 97%. The satisfactory fit shown in Figure (5) is the result of the same estimated value of R^2 (Table 1) for the level of resources in each period.

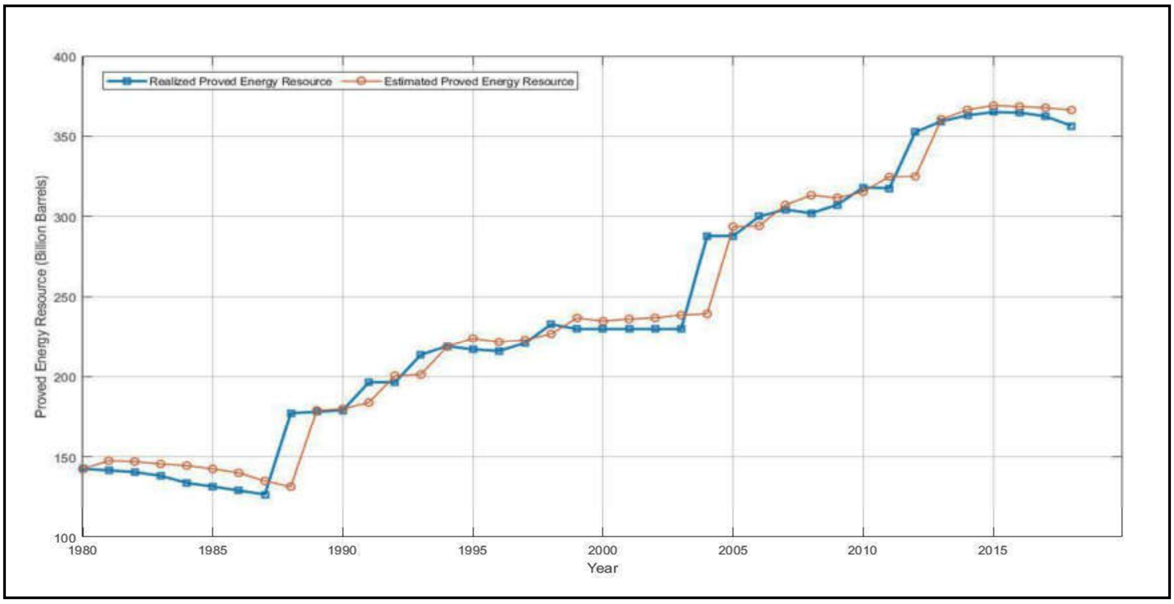

Figure 5. Realized and Estimated Values for Proven Energy Sources (Billion Barrels of Crude Oil Equivalent)

Source: Research findings.

1. Calculated based on 40 degrees of freedom and t statistical table.

In the following, the estimated parameters of the population equation are presented and analyzed. The results of estimating the population equation are reported in Table (2).

Table 2. Estimated Parameters of Population Equation

$N_t = \frac{N_0 M}{N_0 + (M - N_0)e^{-at}}$				
Parameter name	**The estimated value**	**Standard deviation**	**t statistic**	**p-value**
M	94.7079	1.3006	72.8183	0.00
a	0.4993	0.0181	27.5859	0.00
$R^2 = 98.3446\%$				

Source: Research findings.

According to the t-statistics in Table (2), all the estimated parameters are significant at the 99% confidence level. The maximum population (carrying capacity) estimated for the Iranian economy was about 95 million. It must be added that this amount of population carrying capacity was calculated according to the t economic potential of Iran at the time of this study. Thus, the population carrying capacity estimated in this study can change with the growth and expansion of the economy in the future. Figure (6) also shows the estimated and realized values for the population carrying capacity.

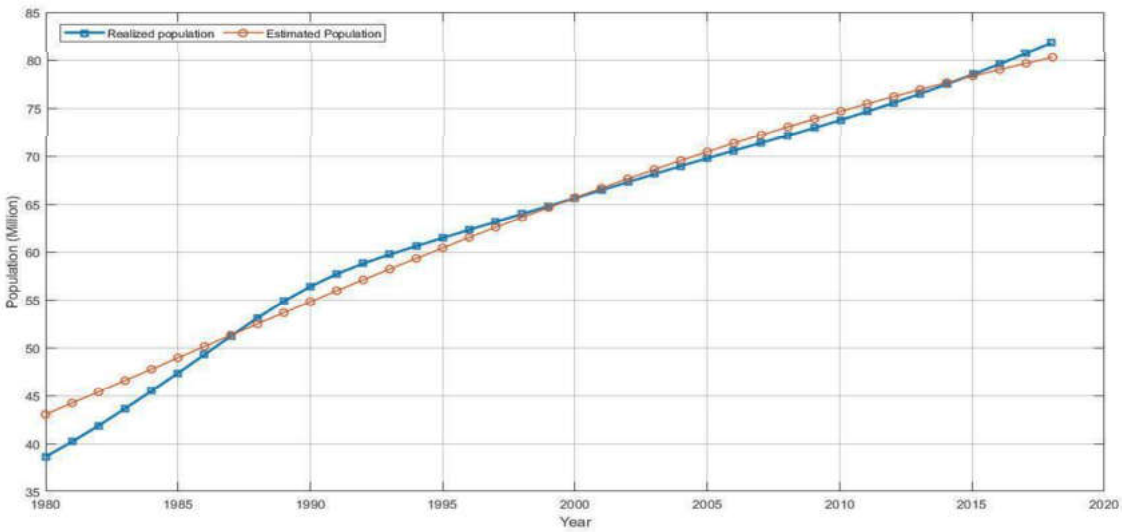

Figure 6. Realized and Estimated Value for the Population (Based on Millions of People)
Source: Research findings.

Figure (2) illustrates that the population growth rate for Iran decreased steadily during the years under study. In addition, the same figure shows that the population growth rate had been about 2% since 2005. Accordingly, using the simple equation ($n = \frac{log(N_T/N_{2019})}{log(1+r)}$), the number of years left to reach the maximum population is equal to 8 years. That is, by 2028, the Iranian economy will be in a state of population saturation and the population growth rate will reach zero unless the Iranian economy experiences a rapid growth or significant recovery. In what follows, the estimated pollution equation is discussed. Table 3 shows the estimated parameters of the pollution equation.

Table 3. Estimated Parameters of Pollution Equation

$\frac{P_t}{N_t} = \alpha + \beta_1\left(\frac{Y_t}{N_t}\right) + \beta_2\left(\frac{Y_t}{N_t}\right)^2 + \beta_3\left(\frac{mR_t}{N_t}\right) + \varepsilon_{3t}$				
Parameter name	**The estimated value**	**Standard deviation**	**t statistic**	**p-value**
α	-2.3075	0.0890	-25.9137	0.00
β_1	31.5151	4.0549	7.7720	0.00
β_2	-36.1833	12.9422	-2.7958	0.00
β_3	11.9758	1.3720	8.7214	0.00
m	0.0839	0.0116	7.2183	0.00
$R^2 = 89.2769\%$				

Source: Research findings.

According to the calculated t-statistic for each parameter, all the estimated parameters of the pollution equation are significant at the 99% confidence level. Also, based on the R^2 value obtained, the estimate provided by the pollution equation was weaker than that of the two previous equations, but the accuracy of the estimate was acceptable. The estimated and realized values for per capita pollution shown in Figure (7) are an indication of the accuracy of the estimate calculated by the per capita pollution equation.

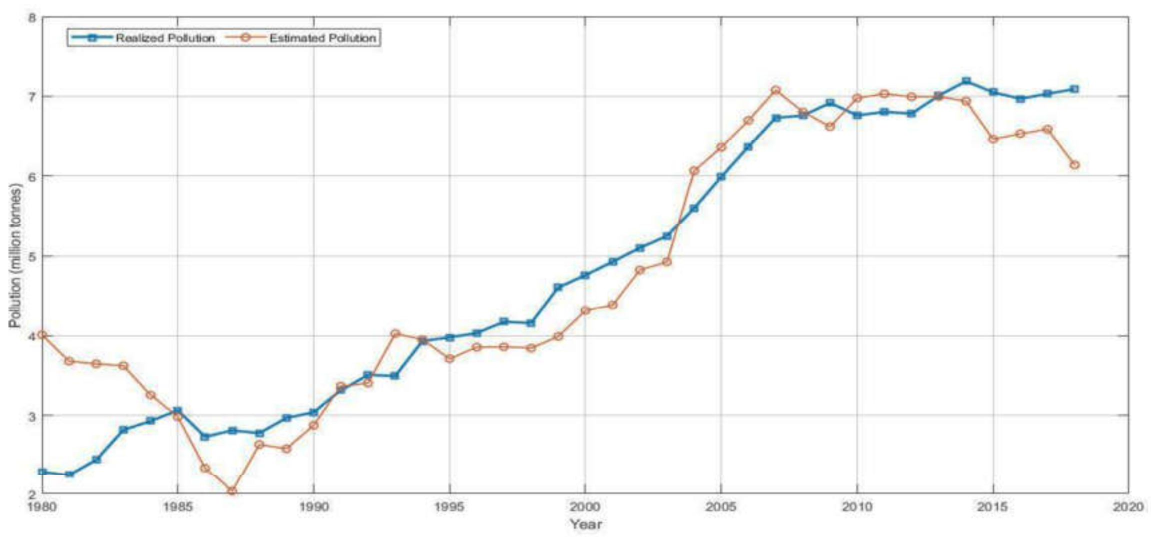

Figure 7. Realized and Estimated Value for Per Capita Pollution (Million Tons of CO2 Emitted)

Source: Research findings.

According to the data in Table (3), β_2 had a negative value and was reliable at a 99% of confidence level, verifying the environmental Kuznets curve hypothesis for the Iranian economy. As a result, and according to the theoretical foundations of this study laid out earlier, the turning point of the environmental Kuznets inverted U-shaped curve for the Iranian economy is equal to 0.435 billion Rials per person. To put this number in perspective, the current amount of GDP per capita for the Iranian economy is 0.157 billion Rials.

Therefore, given that the actual level of GDP per capita was less than the value of the turning point of the environmental Kuznets curve, it can be concluded that the Iranian economy is on the upward-sloping part of this curve, as illustrated in Figure (8). In this figure, the horizontal and vertical axes are the realized per capita production and the realized per capita pollution, respectively. It is worth mentioning that the curve illustrated in Figure (8) is not plotted over time; it is plotted as a function of GDP. The above findings revealed that the Iranian economy with 0.157 billion Rials per capita production was at a lower level than the environmental turning point. This finding shows that the Iranian economy is on the upward-sloping portion of the environmental Kuznets curve (Figure 8).

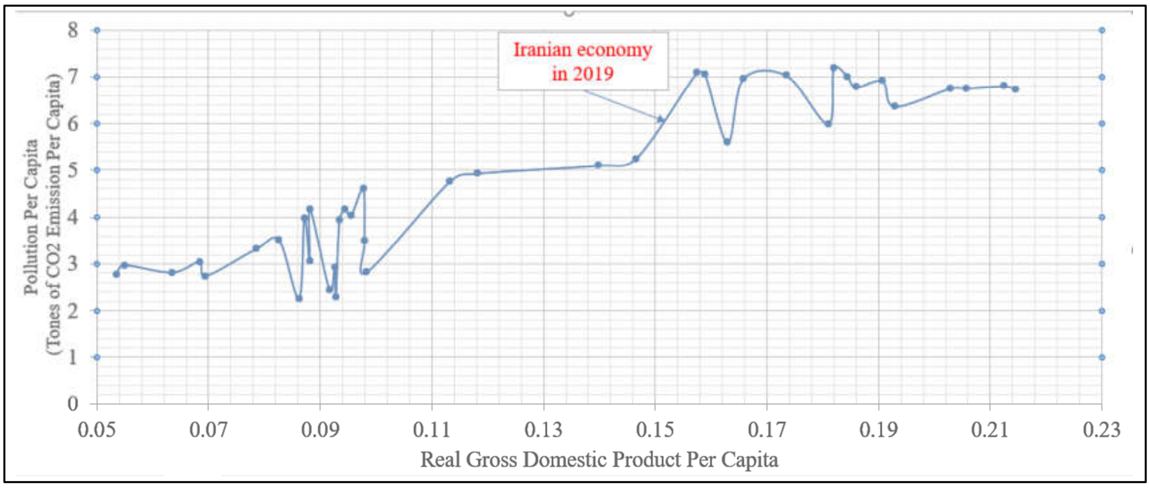

Figure 8. Per Capita Pollution Relative to GDP per Capita (XEKC Validation)
Source: Research findings.

The following is a sensitivity analysis for estimating the PCC variable. According to the national income data, 10 scenarios are assumed. The assumption is related to the economic growth rate since 2011. In the first scenario, it is assumed that from 2011 to 2019, we have experienced an annual growth rate of one percent. In this case, PCC, 95.8 million has been obtained. Similarly, in Scenario 2, it is assumed that the economy will experience a growth rate of 2%. In this case, PCC is equal to 97.7 million people. Finally, assuming a 10% growth rate, which is a very optimistic assumption for eight consecutive years, the PCC value is estimated at 149.6 million. Table 4 shows the results of the sensitivity analysis.

Table 4. Sensitivity Analysis for Estimate Population Carrying Capacity

Hypothetical value of growth rate (%)	population carrying capacity (Million people)	Simulated per capita GDP in 2019 (Billion Rials)
1%	95.8002	0.232479
2%	97.7770	0.254034
3%	101.3670	0.277348
4%	107.7635	0.302545
5%	119.4007	0.329757

Source: Research findings.

6. Conclusion

The current study endeavors to investigate the short-run and long-run impacts of uncertain exchange rates on commodity trade between Pakistan and its main trading partner Saudi Arabia. For empirical analysis, this study employs the annual data from 1981 to 2018. To compute the volatility of the exchange rate, monthly data of the exchange rate from 1981:01 to 2018:12 are employed. To estimate the volatility, this empirical study uses the average moving exchange rate’s standard deviation. In to short-run as well as the long-run, this study employs the ARDL approach model.

Considering the short-run coefficients of the exports function, we find that the uncertainty in the exchange rate affects 11 industries positively while it affects 12 industries negatively. Further, 5 industries exhibit mix (i.e., positive and negative) response to the volatility. Moreover, 11 industries remain unaffected by the effects of the volatility in the short run. Hence, most exporting industries are found to have been negatively affected by the volatility of the exchange rate. In the long run, the findings demonstrate that 10 industries have to face the loss, while the other 10 industries enjoy the benefits due to the uncertainty of the exchange rate. Ironically, 19 exporting industries do not show any response to the volatility.

Whereas the short-run coefficients of imports function are concerned, the exchange rate volatility demonstrates its deleterious repercussions on 6 industries, however, 9 other industries enjoy the benefits during the volatility. Only 2 industries show a mixed (positive as well as negative) response to the volatility. Further, 13 industries have no relationship with the EXVOL in the short run. In the long-run, the imports function exhibits that EXVOL has positive effects on the import flows of 15 industries. On the other hand, the results show that uncertainty of exchange rate affects 7 industries negatively. Further, the exchange rate volatility has no impact on the 8 importing industries. Summing up, the results divulge that most industries in the current case of bilateral trade are sensitive to the volatility of the exchange rate but the predominant influence of the volatility remains positive on the commodity-wise trade.

Unlike the previous literature, the study shows that the industries having a big share of imports and exports are sensitive to the EXVOL in the short run as well as in the long run. However, the focused industries which have importance for an economy are the exporting industries. Concerning the exporting industries, the current findings are just different from the previous studies done regarding Pakistan's economy due to employing the disaggregated data.

Focusing on the policy recommendations, the results reveal that two exporting industries coded as 61 (with a share of 6.84%) and 75 (with a share of 5.55%) get the benefits due to the volatility. As these industries are getting benefits, nothing to do with them. However, one big exporting industry coded as 658 (with a share of 14.23%) has to confront significant losses due to uncertainty in the exchange rate. Hence, the main focus should be on the portion of the exports that are negatively affected by the volatility. Here are some suggestions. First, it is in the interest of the owner of those firms who are exporting, to hedge their contracts to avoid the possible loss. Second, according to Bahmani (2013), even risk lovers can minimize their risk too through hedging. Third, Govt. should adopt a focused subsidized policy for negatively affected industries.

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Appendix

Definition 1: The vector x^* in the design space is called a Pareto-optimal problem when there is no other point such as $x \in S$, i.e.:

$$(x) \leq f_i(x^*) \ \forall \ i \tag{a1}$$

Definition 2: The point x^* in the design space is called weak Pareto optimal when there is no other point such as $x \in S$, i.e.:

$$f_i(x) < f_i(x^*) \ \forall \ i \tag{a2}$$

In other words, a point in the design space is considered weak Pareto optimal if there is no other point that can simultaneously optimize all the objective functions in the problem[1]. However, there may be some points that may increase the quality of some of the objective functions but would leave the values generated by other functions unchanged.

Definition 3: A vector consisting of the objective functions $f^* = f(x^*) \in Z$ is considered a non-dominated vector if and only if there is no other vector such as $f \in Z$, i.e.:

$$f_i \leq f_i^* \ \forall \, i \quad and \quad f_i < f_i^* \quad for\ at\ least\ one\ i \tag{a3}$$

Otherwise, the vector of f^* is a dominated vector.

Definition 4: A point, such as f_o, in the criterion space is called an ideal or utopia point if:

$$f_i^o = \min\{ f_i(x) \mid x \in S \}, i = 1, \dots, q \tag{a4}$$

where q is the number of objective functions in the multi-objective optimization problem.

1. Alternatively, simultaneously increase the quality of the solutions produced by all the objective functions.