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The Optimal Allocation of Iran's Natural Gas

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Abstract

The optimal allocation of natural gas resources to various uses such as final and intermediate consumption, injection into oil fields, and exports can help policymakers to use this kind of resources efficiently. Empirical evidence support using hyperbolic discount rates instead of fixed discount rates in the economic literature. The purpose of this study is to maximize the social welfare function and analyze the optimal paths of different uses of natural gas over the next three decades based on a nonlinear dynamic programming model using a hyperbolic discount rate. The results show that in the current situation, gas exports do not maximize social welfare, but by expanding Iran's natural gas production, exports will lead to maximizing social welfare.

Keywords: Natural Gas, Optimal Allocation, Hyperbolic Discounting, Iran.
JEL Classifications: Q34, Q48, C61.

1. Introduction

Today, the key role of energy in economic growth is undeniable. Energy is an essential element of the productive sectors, such as industry, agriculture, and services (Stern, 2010). At the same time, its final demand by residential and commercial sectors has a significant role in providing social welfare (Sorensen, 2016). In addition, in countries that have energy resources, its supply, management, and distribution between inside and outside uses have always been the major issue, especially how to use and allocate it efficiently and

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optimally. The more countries can use their energy resources efficiently, the more welfare can bring for their societies (Soltanifar, 2010).

Natural gas due to its nature and characteristics (compared to the other energy sources such as oil), such as low emissions, cheapness and affordable price in origin, plenty of discovered resources (proven sources of natural gas over the past two decades has increased more than 50% (BP, 2016), as well as its widespread use, has great importance. Therefore, in recent decades, the role of natural gas in the international arena is promoted which the formation of GECF[1] is an example (Soltanifar, 2010).

Iran, among countries with natural resources, especially natural gas has a unique situation. Indeed, it with more than 33.5 trillion cubic meters of proven reserves in 2015 is the first among all the countries with gas reserves. These resources equal more than 18% of all proven gas reserves in the world. It is worth noting that over the past two decades, Iran's proven gas ratio to the world's total gas resources has increased as much as 2%. This huge volume of natural gas privileges Iran's situation as the biggest country with the world's gas reserves (BP, 2016).

Natural gas due to the technological and political considerations is allocated to the different uses. Exports of natural gas can be considered as one of the tools of political power in the current world. Injection into oil reservoirs can lead to an increase in the productivity of these reservoirs. Another use of natural gas is as feed and fuel of petrochemicals and energy industries to create value-added on them. Ultimately the final domestic consumptions (industrial, transportation, commercial and residential sectors) are among the most important uses of it (Islamic Parliament Research Center, 2008).

In fact, introducing a model that can optimally allocate natural gas to its various uses over time is one of the most important economic discussions. The main purpose of this study is to build a model for the optimal allocation of natural gas to its various uses in Iran.

Since natural gas allocation should be made in such a way to maximize the social welfare over time, this criterion must be

1. Gas Exporting Countries Forum

considered that the opportunity cost of gas allocated to different uses should be the same. Therefore, the opportunity cost of allocation between the periods of natural gas exploitation and different sectors' uses should be minimized. In other words, a function of the benefits and costs of gas allocation to its various usages overtime should be calculated (Rowse, 2008).

In this study, based on John Rowse (1985, 1986, 1991, and 2008), and Renani et al. (2009), a social welfare function for Iran is defined as the total surplus of producer and consumer. Then it will be maximized according to constraints in the form of a nonlinear dynamic programming framework.

Here, using a hyperbolic discount rate, instead of exponential discount rates, allocates gas optimally in a long-term model for Iran, as one of the developing countries with the vast resources and various uses. This study can help to a better understanding of the discussion of hyperbolic discount rates and its applications in addition to being a guide for the policies adopted by Iran's decision-makers.

The forecast period is 2016 to 2045 based on Iran’s energy data. The results obtained at this period, in addition to covering the second half of the document of development prospect can help policymakers in the future plans of development. It will be also helpful for the planning of the next document of development prospect (2025-2045).

In fact, the allocation of Iran’s natural gas, using a mathematical model in the form of a dynamic nonlinear problem with hyperbolic discounting, is optimized during the period 2015 - 2045. In this regard, first, using the concept of economic welfare, an objective function which includes the benefits and costs of natural gas uses is defined. Then, this function with constraints such as the maximum production level, final and intermediate consumption, technical limitations for injection into oil fields and exports, is maximized.

In this study, the research model is introduced after reviewing the literature. Then the variables and research data are introduced. Finally, the results are presented and discussed.

2. Review of Research Literature

John Rowse is one of the economists who studied the allocation of gas resources. In his article (1986), based on his previous work (1985) and other researchers such as Copithorne (1979), Nordhaus (1973), Richard & Walker (1984), estimates a model for the allocation of Canadian gas to domestic uses and exports. He uses nonlinear optimization for the allocation of Canadian gas resources using a mathematical model and calculates a social welfare function to find the optimal route of the amount of export and domestic consumption. In this case, he considers different constraints such as equalization of production with exports and domestic consumption, technical constraints such as decreasing production with extraction over time and limiting the supply from new sources.

Rowse (1990a, 1990b, 1991) in the next step considers the importance of the discount rate and shows that if it is not accurately estimated, in the allocations for various consumptions of non-renewable resources, although social welfare lost will be negligible, but the optimal amount of calculated variables will be different.

Over the past two decades, the debate on discount rates and how to use them has continued. Henderson and Batman (1995), by stating that "this is shown to be strong indirect evidence that the true social discount rate may be a hyperbolic function, and there is also empirical evidence for this hypothesis, as well as the nature of hyperbolic nature of discounting is also standard findings in the behavioral science" considered a new discussion about the hyperbolic discount rate. Following that, Cropper and Laibsen (1999) explicitly state that "there is strong empirical evidence that people in a hyperbolic way reduce future values and use higher discount rates at closer times to further times " caused the discussion to be seriously raised among economists. Frederick et al. (2002), Weitzman (1998 and 2001), as well as Newell and Pizer (2003) discuss the crucial and controversial nature of the time discount rate.

In addition, some other economists, such as Azfar (1999) discuss the more rational aspect of hyperbolic functions. He explicitly states that when economic factors are faced with uncertainty about their discount rates, the use of hyperbolic discount rather than exponential is more rational and consistent with the empirical behavior of people.

Rowse (2008) once again estimates his model for allocating Canadian gas resources using the hyperbolic discount rate. In his paper, he does not estimate the discount rate directly and uses the discount rates estimated by Henderson and Batman (1995), Nordhaus and Boyer (2000), Weitzman (2001), and Settle and Shogren (2004). Indeed, Rowse introduces Canadian gas resource allocation to its uses as an application of the hyperbolic discount rates in energy models and again estimates the previous model (1986) with different hyperbolic discount rates.

In one of the most recent studies, Graves and Ringuest (2012), by comparing hyperbolic and exponential discount rates, showed that hyperbolic discounting should be used in the long-term evaluations, while the exponential discount is appropriate for the short-term evaluations.

In 2002, the long-term energy policies of Iran in the gas sector were announced. Based on it, the greater use of natural gas through the expansion of the domestic gas supply network and promoting the position of Iran in exporting gas was mentioned (Report of Ministry of Energy, 2011). However, the correctness of these policies, considering the long-term interests of the country, has been challenged by economists and consequently other decision-makers in the domestic studied. Conference on the use of gas resources in the perspective of twenty years held by the institute for strategic research of the Expediency Council in 2005, report of estimation of natural gas production and consumption and its allocation till 1403 prepared by the management and planning organization in 2006 and the report of the research center of the parliament about optimum use from Iranian gas resources in 2008 are some examples of these studies.

In addition, there are studies that have been carried out by Iranian economists. Derakhshan (2010), by examining the status of oil reservoirs, points out the necessity of developing a comprehensive gas supply model for Iran with a special role for the injection of gas into oil resources. The injection will not only increase the recycling rate of these resources, but it can be transported several tons of cubic meters of gas from the vast South Pars field (which shares with Qatar) to the independent oil fields of the country and stored for the future generations.

Jafari Samimi and Dehghani (2007), using the new Markowitz optimization method and preferential analysis theory, investigate the optimal allocation of natural gas to various uses such as exports, petrochemical and injection facilities to oilfields. The results indicate that the order of priority of gas projects is gas exports, gas injection and petrochemical projects respectively.

Renani et al. (2009) studied priorities for the use of gas reserves in Iran to domestic uses including petrochemicals, injection, exports, and store and transfer during the time. The estimation results based on different constant discount rates, at low discount rates, gas injection is preferred to gas exports at low discount rates. Nevertheless, at the higher rates, this priority does not exist and the optimum gas quantity is determined simultaneously.

Mohaghar et al. (2010) used the fuzzy approach based on decision-making methods to optimize the allocation of natural gas. The results show that the injection into the oil fields is the first priority. The transportation sector with gas industries jointly, power plants, domestic, commercial and public consumptions, exports of liquefied natural gas (LNG) by tankers, exports of natural gas by the pipelines and petrochemical industries are the second to the seventh priority of natural gas use.

3. Research Model

For the proper exploitation of Iran's gas resources, a social welfare function is defined for the various uses of gas, given the existing constraints. Then it is solved according to the definition of various assumptions and scenarios due to the uncertainties in this section. The initial idea, as mentioned above, derived from Rowse's studies for the allocation of gas resources to Canadian exports and domestic consumption and adjusted for the conditions of Iran.

This model is, in fact, a nonlinear dynamic mathematical programming problem in which social welfare is maximized due to the allocation of gas to its various uses and the optimal paths of the various uses of gas are obtained. The dynamic programming is extensively used in economic modeling because it is sufficiently rich to model any problem involving sequential decision making over time and under uncertainty.[1]

1. see Stokey and Lucas (1987) for examples of DP models in economic theory.

The objective function (total surplus welfare) due to the various gas uses can be defined mathematically as follows:

$$wf = \sum_{t=1}^{T} \delta_t * \Lambda_t(Qm_t) + \sum_{t=1}^{T} \delta_t * \mathrm{K}_t(\mathrm{Qr}_t) + \sum_{t=1}^{T} \delta_t * pex(t) * \mathrm{export}(t) + \sum_{t=1}^{T} \delta_t * s(t) * sal(t) + \sum_{t=1}^{T} \delta_t * vinj(t) * inj(t) - \sum_{t=1}^{T} \delta_t * cdom(t) * U\,(t) \quad (1)$$

Here wf is social welfare due to the various usages of gas, δ_t is the discount rate, Qm_t is the final consumption of gas (residential, commercial and transportation), Qr_t is intermediate consumption of gas (power plants and petrochemical industries), $pex(t)$ is export prices of gas, $\mathrm{export}(t)$ is exported gas, $s(t)$ is the value of stored gas, $sal(t)$ is the amount of extractable gas stored in the resources, $vinj(t)$ is the value of injected gas into the oil fields, $inj(t)$ is the amount of injected gas into the oil fields, $cdom(t)$ is the final cost of production and $U\,(t)$ is the total amount of produced gas.

In fact, the first part of the objective function that shows the value of gas in its various uses is divided into the following sections:

A) The value of final gas consumption:

Using the reverse function of the final gas consumption demand, the value of consumer surplus is calculated each year and discounted to the base year.

$$\Lambda_t(Qm_t) = \int_{qm0}^{qmt} P_{mt}\,(Qm_t\,)\, dQm_t \quad (2)$$

Here, domestic consumption will consist of two parts, an exogenous consumption, which is supposed to grow at a constant rate (y_{t1}), and another part which is a function of the price (P_{mt}). The demand function of final gas consumption according to Rowse's research (1990 and 2008) is defined as follows:

$$Qm_t = y_{t1}\, q_0 + \alpha_1\, P_{mt}^{-\beta_1} \quad (3)$$

B) The value of intermediate gas consumption:

The value of consumer surplus resulting from the consumption of intermediate gas in the country, using the integral below, is calculated each year and discounted to the base year.

$$\mathrm{K_t}(\mathrm{Qr_t}) = \int_{qr0}^{qrt} P_{Rt}(\mathrm{Qr_t})\, d\mathrm{Qr_t} \qquad (4)$$

The intermediate consumption consists of two parts: a part of consumption which is exogenous and has an incremental fixed-rate (y_{t2}), and the other part is a function of the intermediate gas price (P_{Rt}). The demand for intermediate consumption of gas is defined as follows:

$$\mathrm{Qr_t} = y_{t2}\, q_0 + \alpha_2\, P_{Rt}^{-\beta_2} \qquad (5)$$

Its estimated parameters will be used in solving the model.

C) The value of exported gas:

The value of exported gas is equal to the total revenue from the export of gas which is discounted to the present time. Given Iran's exports, it is assumed that Iran does not have significant market power and takes prices from the global markets.

$$\sum_{t=1}^{T} \delta_t * pex(t) * export(t) \qquad (6)$$

D) The value of stored extractable gas:

The value of stored extractable gas is calculated according to Hotelling's theory and measures the cost of time interval opportunity. The variable sal (t) represents the amount of gas that can be extracted technically, but for the reasons of optimization and intergenerational benefits, we prefer to keep it in the fields. In fact, the existence of this variable allows the transmission of gas between time periods according to the model constraints.

$$\sum_{t=1}^{T} \delta_t * s(t) * sal(t) \qquad (7)$$

E) The value of increasing oil recovery through injection into the oil fields:

The value is calculated as follows:

$$\sum_{t=1}^{T} \delta_t * vinj(t) * \ inj(t) \tag{8}$$

The value of injected gas into the oil fields (vinj (t)) was calculated according to the following equation i.e. the amount of oil recovered by injection (oil (t)) after the injection time t = m, and the oil prices at that time $poil(t)$ and discounted to the present time. Here it is worth noting that injection into oil fields in the upcoming periods will increase the oil taking, and it is assumed that this increase will be extracted on average and evenly in the remaining periods.

$$vinj\ (t) = \ \sum_{t=m}^{M} \delta_t * poil(t) * oil\ (t) \tag{9}$$

The second part of the objective function also covers the costs associated with gas production and included the average costs of production and distribution of gas within the country. It should be noted that given the fact that the costs of production and distribution, whether intermediate, final consumption or exports is not different. Here the total consumption in the country is considered as an aggregation[1], and the average costs of the gas industry are used in exploration, extraction, and distribution.

Based on the Henderson and Batman studies (2016), as well as Stell and Shorgen (2004) δ_t is used as hyperbolic discount rates as follows:

$$\delta_t = \frac{1}{(1+r_h\ t)} \tag{10}$$

For this objective function, the technical and economic constraints should be considered as follows:

- Supply and demand balance of gas in each period

The total amount of produced gas in each year (U (t)) while the amount of operational waste (waste (t)) is subtracted, must be equal to the consumption in different sectors:

1. It should be noted that the main reason for cost aggregation in the objective function is the lack of access to detailed cost data.

$$[U(t) - waste(t)] = Qm_t + Qr_t + export(t) + inj(t) \quad (11)$$

- The supply-side Constraints

This constrains which are a combination of technical and economic constraints show that the maximum gas production per technical period (UPP_T) should be equal to the amount of production (U_t) and the stored gas (sal_t). The important point is that the total volume of stored gas in year t will not be withdrawn in the coming years due to the technical limitations in the gas industry. In fact, the annual withdrawal capability and the use of stored gas are reduced by a decreasing rate. This constraint is in line with the intergenerational justice that was mentioned in the objective function:

$$U_1 + sal_1 = UPP_1$$
$$U_2 + sal_2 = UPP_2 + \varepsilon_1 sal_1$$
$$U_3 + sal_3 = UPP_3 + \varepsilon_2 sal_1 + \varepsilon_1 sal_2$$
...
$$U_T + sal_T = UPP_T + \varepsilon_{t-1} sal_1 + \varepsilon_{t-2} sal_2 \ldots. + \varepsilon_1 sal_{T-1} \quad (12)$$

-The constraints of injected gas:

According to the announced scenarios from Iran’s Ministry of Petroleum and Experts, the need to inject the country's gas is estimated for the pressure increase of oil reservoirs and a specified injection rate which was announced. Therefore, two specified constraints for the gas injection per period and the total equality of the injected gas required in each scenario (inject) with the total injection up to that period are considered as follows:

$$Inject_t = C_t$$
$$Inject = \sum_{t=1}^{T} inj(t) \quad (13)$$

-The constraint of gas export contracts:

According to the long-term gas export contracts, it is assumed that gas exports will be at least 90% of the previous year.

$$Export(t) \geq 0.9\, export(t-1) \quad (14)$$

-The constraint of exogenous growth of final gas consumption:

Here, for convenience, it is assumed that gas consumption grows at a constant rate over time.

-The constraint associated with the growth of gas intermediate consumption:

The gas consumption in this sector is also defined exogenously and it is assumed that this growth will also be constant over time.

4. Variables and Data

In order to avoid complications in the demand function, as shown in equation 5, the demand for final gas consumption divided into two parts. The first part is defined independently of price and is supposed to increase with a constant coefficient at the expansion rate in Iran's gas distribution network in the past years. It is also assumed that in the coming years, the gas distribution network will increase with the same rate of the previous years (the last 5 years and after the implementation of the subsidies reform plan), and the increase of gas final consumption in the function is considered to be 6.2%.

The second part of the consumption function is a function of the price. Considering that a part of the increase in consumption in the previous years is due to an increase in the gas distribution network and the increase of subscribers in the various residential, commercial and other sectors, in order to be more precise, the ratio of final gas consumption to the subscribers is considered as the consumption of gas in the final sectors. Also, given different prices of gas in different sectors, the average weight of real price, which is actually the prices adjusted by the consumer price index, is considered as the price of gas for the final consumption in different sectors. Then the demand for final gas consumption was estimated and its results are summarized in Table 1.

The results show that the long-run price elasticity of final gas consumption is -0.27 and was used in equation (2).

Table 1: The Estimation Results of Final Gas Consumption in Iran During 1989-2015

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.843305	0.022638	-213.9435	**0.0000**
LOG (RFPRICE)	-0.276628	0.056447	-4.900656	**0.0000**
R-squared	0.489967		F-statistic	**24.01643**
S.E. of regression	0.108571		Prob (F-statistic)	**0.000048**

The intermediate gas demand which also includes two parts is estimated below. The first part is independent of the price and is increasing due to the programs of gas industries. In order to avoid complexity, the same development process which was existed in the past years is supposed to continue in the future. Given the data of past years, and in particular the past 5 years (after implementing the subsidies reform plan), it is assumed that this rate is exogenous and equal to 5%.

The second part of intermediate gas demand inside the country is a function of price. Given the data in the intermediary sectors, this demand function can also be estimated. The remarkable point about the prices is that given the fact that most of the intermediate consumption in the country over the past decades is related to the power plants, and the cost of delivery to power plants and the other intermediate energy consumptions is similar, the actual delivery price to the power plants (adjusted by the consumer price index) is considered as the gas price for the intermediate consumption.

Also, due to omitting the subsidies reform plan effects, the dummy variable is defined. The results are presented in Table 2. The long-run price elasticity of gas consumption in intermediary sectors is 1.42 and was used in equation (4) as β_2 .

The third part is the export prices. Given Iran's lack of significant market power in the gas export market, it is assumed to be a price taker. In this research, the forecast of the U.S. Energy Information Administration (EIA) for the price of gas in the next three decades based on Henry hub Market as the basis for gas price in the model was used.[1]

1. In the introduced instruction of gas price determining for petrochemical feed in 2015 by Iran’s Ministry of petroleum, Henry Hub Market gas prices is one of the most influential markets in world gas prices, which is being used in Iran's gas pricing.

Table 2: The Estimation Results of Intermediate Gas Consumption in Iran During 1989-2015

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	9.888380	0.141520	69.87253	**0.0000**
LOG(RNPRICE)	-1.429758	0.638558	-2.239042	**0.0347**
DUM1	3.351281	1.181211	2.837156	**0.0091**
R-squared	0.333496		F-statistic	**6.004400**
S.E. of regression	0.553551		Prob (F-statistic)	**0.007685**

The price of gas has a fixed trend. The main reason for this is the massive expansion of shale gas and the expansion of its resources in the last decade in different parts of the world (Sorensen, 2016; Soltanifar, 2010).

Table 3: Forecasting Oil and Gas Prices in 2016-2045

Year	Forecast gas price dollars per million Btu	Forecast oil price b/S	Year	Forecast gas price dollars per million Btu	Forecast oil price b/S
2016	2.65714	53.0627	2031	5.004542	94.5245
2017	2.500707	43.427	2032	5.105417	96.81451
2018	2.995931	49.91499	2033	5.106509	99.52779
2019	3.403222	63.04242	2034	5.02927	99.64922
2020	3.964807	70.37261	2035	5.004105	101.4547
2021	4.505039	74.81668	2036	5.090952	102.1503
2022	4.391413	78.14704	2037	5.071395	104.9944
2023	4.255652	80.71196	2038	5.071714	105.5177
2024	4.280964	82.27976	2039	5.054315	106.6719
2025	4.413484	83.71717	2040	5.081584	108.3859
2026	4.505631	86.23224	2041	5.066741	109.3652
2027	4.641376	88.55359	2042	5.086185	110.0413
2028	4.752409	89.9971	2043	5.179222	110.2392
2029	4.863319	90.67681	2044	5.309446	110.8374
2030	4.962029	92.07156	2045	5.3599	111.3793

Source: US Energy Information Administration

The value of extracted gas stored, as noted above, is according to Hotelling's theory and to measure the time interval opportunity cost. In order to avoid complexities of the valuation of non-renewable resources, in the base scenario, its value is assumed to be equal to the difference between the value of export prices and production costs (Rowse, 2008; 1986). The forecast of export prices in Table 3 was based on it.

The next variable is the price of oil. Indeed, given the fact that the value of injected gas into oil fields is reflected through the price of oil in target function, the valuation and forecasting of oil prices during the research period are also very important. In order to avoid the complexities of the pricing of renewable resources, we used the forecast of the US Energy Information Administration for oil prices, which is summarized in Table 3.[1]

In order to determine the amount of oil extracted by injection, we used the report of the parliament Research Center in February 2016. In this report, the average volume of gas required to produce 1 barrel (primary + secondary) in projects of gas injection of south oil districts is about 76 square meters (Report of Deputy of Infrastructure Research and Manufacturing Affairs of Parliament Research Center, February 2016).

In this regard, it is also assumed here that the injection of 76 cubic meters of gas will lead to extracting one more oil barrel. The point that must be noted is that if the gas injection occurs in year t, the whole extractable in the years after (n-t) will be gradually extracted at a similar level each year.

The next data is the average costs of the gas industry, which includes exploration, extraction, and distribution. Due to the confidentiality of industry costs, access to the detailed data of these costs was not possible and in some cases is out of the access of researchers. Therefore, according to the restrictions, all costs were considered integrated and in accordance with the reports and interviews of the officials of Iran’s Ministry of Petroleum, the average cost is equal to 23 cents per cubic meter of natural gas.[2]

1. Data is related to the forecast of Brent oil price.
2. Interview of Seyyed Mohammad Sadeghzadeh, Managing Director of Iran's New Energy Company, with Ana News, Oct. 2015.

The next variables are maximum withdrawal production capacity as well as the withdrawal of stored gas in the coming years. Given that Iran has always faced with severe supply constraints over the past years[1], then the amount produced in recent years can be considered as the maximum capacity of Iran's production.

In addition, the sixth development plan of Iran was specified the forecast of production level of Iran's next five years. In this regard, the maximum production capacity in the next six years (2015-2020) is utilized. Also, the average of the last ten years, i.e. the growth rate (2010-2020), which is an average of 7.2%, was used as the basis for the growth rate of Iran's productive capacity in the next years.

The capability of withdrawal of stored gas is a function of different technical factors and the structure of this extraction is determined by the use of the related studies. Rowse (2008) by considering the technical limitations in the gas field, assumes that 10% of the capability of withdrawal of stored gas decreases annually. In fact, every year, only a part of stored gas can be extracted, and this will decrease over time. Mathematically in Equation 6, we have:

$$\varepsilon_j = 0.1\,(0.9)^{j-1}$$

$$\sum_{k=1}^{j} \varepsilon_k = 1 - (0.9)^j \qquad \text{For} \quad j > 1 \tag{15}$$

The next constraint is the volume of gas injected into the oil fields. According to official reports such as the National Company of Oil and Gas Centers of South in 2015 and the sixth Iran’s development plan, as well as the reports of Iran’s Parliament Research Center, the amount of gas required to produce oil from the fields in the next 10 years is a maximum of 200 million cubic meters per day. In this study, the same amount is considered as the highest injection.

The last variable is the discount rate. As discussed before, the discount factor is defined as hyperbolic (eq.10). Determining r_h is important in this equation. Here, according to Rowse (2008), using the Henderson and Batman (1995) and Cropper (1992) studies, the rate r_h is equal to 0.21.

1. During the last few years, due to supply-side constraints, only 50% of the gas needed is injected into the oil fields (Islamic parliament research center of the Islamic Republic of Iran).

5. Results and Discussion

The dynamic nonlinear programming problem as noted before has 180 variables in the objective function and 150 constrains. The problem variables during the period 2016-2045 are: the final consumption value of natural gas (in residential, commercial and transportation sectors) i.e. $Qm_1, Qm_2, \dots, Qm_{30}$, the intermediate consumption value of natural gas (in power plants and petrochemical industries) i.e. $Qr_1, Qr_2, \dots, Qr_{30}$, the be exports of gas, i.e. $export_1$, $export_2$, $\dots, export_{30}$, the amount of stored gas, i.e. $sal_1, sal_2, \dots, sal_{30}$, the amount of gas injections into the oil fields, i.e. $inj_1, inj_2, \dots, inj_{30}$ and the total amount of produced gas, i.e. $U_1,\ U_2, \dots,\ U_{30}$. The constraints are shown by Equations 11 to 14. For solving the model, MATLAB software is used.

The first result is the path obtained from maximizing the social welfare function for the amount of gas demand in the final sectors over the next three decades, as shown in Table 4 and Figure 1. As can be seen, the final consumption of gas is increasing sharply, and a large amount of this increase is due to the constraint assumed that the final consumption of gas is independent of price over the coming years.

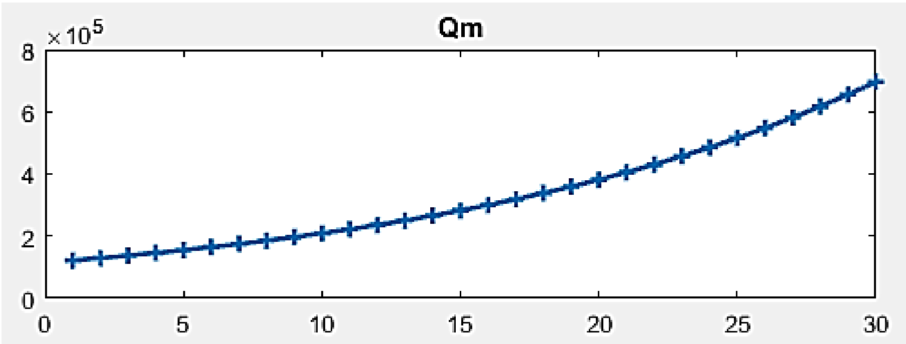

Figure 1: The Optimal Values of Iran's Final Gas Consumption During 2016-2045
Source: Research results

The second result is related to the values of intermediate gas consumption to maximize the social welfare function. The values obtained show that, in order to increase welfare, these values should be significantly increased in the next three decades. Of course, in obtaining these results, the assumptions and limitations of the model are also significant. One of the most important assumptions is the exogenous increase in the intermediate demand for gas, which was derived from officially announced policies to increase gas distribution to large and intermediate industries (Iran's Oil and Gas Industry Prospectus Document 1404, Ministry of Oil, 2010).

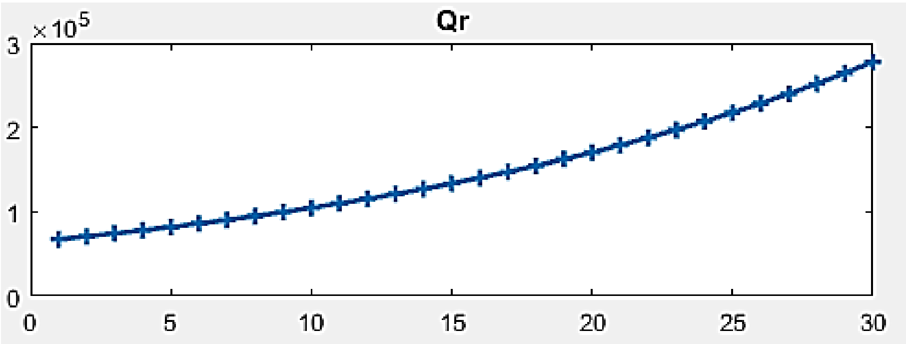

Figure 2: The Optimal Values of Iran's Gas Intermediate Consumption During 2016-2045

Source: Research results

Table 4: The Optimal Amount of Gas Allocation to Various Uses in Iran From 2016 to 2045 (Million Cubic Meters per Year)

Year	Final consumption of gas	Intermediate consumptions of gas	Exports	Injection to oil fields
2016	121638.99	67449.854	8802	57956.64783
2017	129180.6074	73520.34086	26790.4847	73000
2018	137189.805	80137.17154	62050.79449	73000
2019	145695.5729	87349.51698	83438.90197	73000
2020	154728.6985	95210.9735	100401.72	73000
2021	164321.8778	103779.9611	124573.6056	73000
2022	174509.8342	113120.1576	393390.0845	73000
2023	185329.4439	123300.9718	429519.8511	73000
2024	196819.8694	134398.0593	468371.034	73000
2025	209022.7013	146493.8846	510144.8782	73000
2026	221982.1088	159678.3342	555057.3228	73000
2027	235744.9996	174049.3843	603340.0647	73000
2028	250361.1896	189713.8289	655241.6983	73000
2029	265883.5833	206788.0735	711028.9373	73000
2030	282368.3655	225399.0001	770987.9236	73000

Year	Final consumption of gas	Intermediate consumptions of gas	Exports	Injection to oil fields
2031	299875.2041	245684.9101	835425.6314	73000
2032	318467.4668	267796.552	904671.3709	73000
2033	338212.4497	291898.2417	979078.4007	73000
2034	359181.6216	318169.0834	1059025.656	73000
2035	381450.8822	346804.301	1144919.599	73000
2036	405100.8368	378016.688	1237196.205	73000
2037	430217.0887	412038.19	1336323.089	73000
2038	456890.5482	449121.6271	1442801.783	73000
2039	485217.7622	489542.5735	1557170.183	73000
2040	515301.2635	533601.4051	1680005.159	73000
2041	547249.9418	581625.5316	1811925.369	73000
2042	581179.4382	633971.8294	1953594.256	73000
2043	617212.5634	691029.2941	2105723.275	73000
2044	655479.7423	753221.9305	2269075.342	73000
2045	696119.4863	821011.9043	2444468.529	73000

Source: Research results

The optimal amount of exports is summarized in Table 4 and Figure 3. As the results show, gas exports should begin to increase based on the sixth development plan for production after a decline in the first year that is due to a lack of resources. The priority of allocation is to provide domestic and intermediate consumptions, and then injection to the oil fields. In the first year, only the minimum amount of exports undertaken is provided (equivalent to 90% of the previous year, according to international obligations, exports should be done). Indeed, after providing final and intermediate consumptions, gas injection to the oil field increases the welfare.

Also, as shown by the other studies in Iran’s Ministry of Oil, the results confirm foreign plans and diplomacy for gas exports, such as GECF. Changing Iran into a major exporter of gas will have economic rationality and will lead to higher social welfare if investments in the manufacturing sector are done according to the designed plan. Here the export prices of gas have great importance. In fact, due to the events that have occurred in the energy market in recent years and led to reducing export prices, all the gas price forecasts have also been faced with significant reductions.

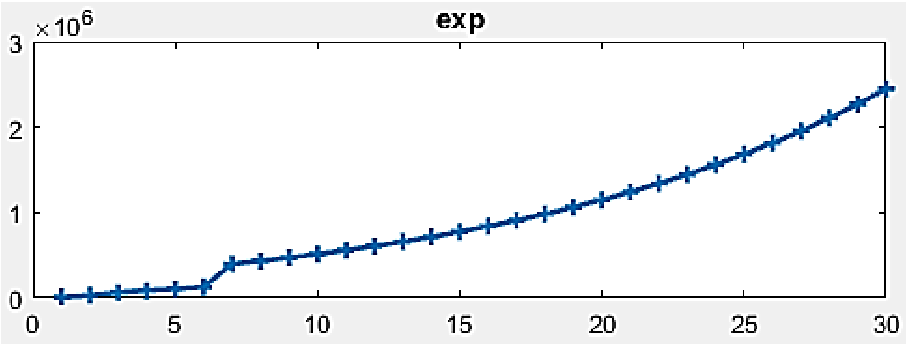

Figure 3: The optimal values of Iran's gas exports during 2016-2045
Source: Research results

Finally, a variable whose analysis is important and has a significant role in policymaking is the amount of gas injected into the oil fields. The result of the amounts of injected gas for maximum social welfare in the next thirty years is shown in Table 4 and Figure 4. As can be seen, only in the first year, the constraints and lack of resources prevent the allocation of all required injection levels for the oil fields. In fact, if the maximum amount of gas production is achieved based on the model, the injected gas level should be fixed and to be allocated equally to the maximum considered to maximize the social welfare.

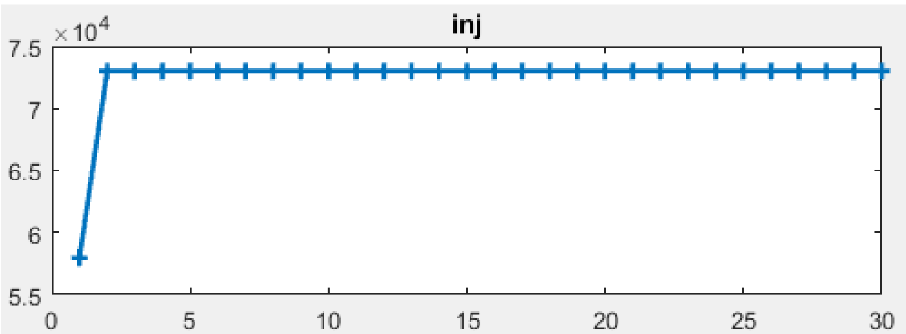

Figure 4: The Values of Gas Injected into Oil Fields for Maximizing the Social Welfare Function
Source: Research results

As the results show if all the needed gas injected into the oil fields will have a great importance in increasing the welfare due to the allocation of gas to various uses. In this regard, the energy sector decision-makers in the country should focus on allocating all the needs related to injection into the oil fields. The results are confirmed by the other researches that in prioritizing the various usages of gas, the injection into the oil fields is important and it needs particular attention.

The results obtained here are consistent with the other studies on the allocation of gas resources in Iran. For example, our results about the importance of gas injection into the oil fields are similar to the results of Derakhshan (2010) and Mohaghar et al. (2010). In addition, the importance of gas exports in this study is also emphasized by the Oil Ministry (2006; 2010) and Ja'fari Samimi and Dehghani (2007).

6. Conclusion

This study seeks to find the optimal paths of various uses of gas for 2016-2045 in Iran using hyperbolic discount rates when the social welfare maximizes. So, an optimal allocation model was designed and discussed as a nonlinear dynamic programming problem. In some cases, such as final and intermediate demand function, the model parameters were estimated using econometric models. In other cases, the inputs of the problem were determined using the studies and forecasts of international organizations as well as the policies announced in the country.

The results show that if Iran's gas production plans are successful and the level of gas production achieves the levels announced in the development plans, it needs to target a great level of gas exports to maximize social welfare. In other words, the gas exports should not be one of the priorities of Iran's policy when the production level is faced with constraint (which is confirmed by other studies over the past decade), and domestic consumptions and in particular, injection into oil fields has higher social welfare. But if policies of increasing production are successful and the level of Iran's production is increased with a level that is predicted in the sixth development plan, the mass exportation of gas will lead to increase social welfare. This shows the need for extensive planning invests in this area.

One of the most important policy implications is the increasing transmission capacities of Iran. It is also worth mentioning that one of the reasons for the high level of energy consumption in the final sectors is the lack of attention to correct the pattern of consumption. Of course, in this regard, the large subsidies received by the energy sector, especially the gas sector is an important reason for it. Also, for the natural gas demand model, official prices of natural gas have been used, which also includes subsidies, and should be considered in the analysis of the results. Therefore, although the increased volume of natural gas needs special attention in the next three decades and the necessary infrastructures for the extraction of gas resources in the area of final gas consumption must be developed in order to increase social welfare, but at the same time, crucial strategies should be used that lead to improving consumptions patterns.

According to the results, when the gas market does not have meaningful changes to reduce prices, and without significant problems in foreign policy, Iran will have some large export capacities; and special programming, such as pipeline transmission and LNG capacity building is needed.

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