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R&D and Innovation Activities in Leading Export-Based Industries in Türkiye: An Analysis for Future Insights

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ABSTRACT

Purpose: Research and Development (R&D) and innovation activities critically impact an organization's development and competitive advantage. Although all industries have R&D and innovation activities, sectoral applications vary depending on readiness, investment opportunities, and organizational strategies. This study focuses on the automotive, textile, and main metal industries, with the highest export rates in Türkiye. This study aims to analyze R&D and innovation activities for the selected industries and provide practitioners with future insights.

Methodology: Six different R&D and innovation indicators, i.e., current expenditure, personnel expenditures, trade investments, number of patent applications and number of R&D personnel, are considered for this study, and the GM (1,1) forecasting model is used to predict 2022-2030.

Findings: As a result, although an increase in R&D and innovation activities in the automotive industry is expected, especially for each indicator, these values are limited for textile and main metal. It is realized that especially these two industries need more support.

Originality: Within the scope of this study, future insights and suggestions are given under digitalization and technology adoption, encouraging postgraduate studies of employees and higher education - industry collaborations, adopting R&D and innovation as a part of corporate culture, extending R&D and innovation incentives, supporting SMEs in R&D and innovation activities according to sectoral comparisons.

Keywords: Research and Development, Innovation Management, Forecasting.

JEL Codes: M11, O32, C53.

Türkiye'nin İhracata Dayalı Öncü Endüstrilerinde Ar-Ge ve İnovasyon Faaliyetleri: Gelecek Görüşleri İçin Bir Analiz

ÖZET

Amaç: Araştırma ve Geliştirme (Ar-Ge) ve inovasyon faaliyetleri, organizasyonun gelişimi ve rekabet avantajı üzerinde kritik etkilere sahiptir. Tüm sektörlerin Ar-Ge ve inovasyon faaliyetleri olmasına rağmen, sektörel uygulamalar; hazırlık düzeyi, yatırım fırsatları ve organizasyonel stratejilere göre farklılık göstermektedir. Bu çalışma, Türkiye'nin en yüksek ihracat oranlarına sahip otomotiv, tekstil ve ana metal sektörlerine odaklanmaktadır. Bu çalışma, seçilen endüstriler için Ar-Ge ve yenilik faaliyetlerini analiz etmeyi ve uygulayıcılara geleceğe yönelik öngörüler sağlamayı amaçlamaktadır.

Yöntem: Bu çalışma için cari harcamalar, personel harcamaları, ticari yatırımlar, patent başvuru sayısı ve Ar-Ge personeli sayısı olmak üzere altı farklı Ar-Ge ve yenilik göstergesi dikkate alınmış ve 2022-2030 tahmininde GM (1, 1) tahmin modeli kullanılmıştır.

Bulgular: Sonuç olarak, özellikle her gösterge için otomotiv sanayinde Ar-Ge ve inovasyon faaliyetlerinde artış beklenmesine rağmen, tekstil ve ana metal için bu değerler sınırlıdır. Özellikle bu iki sektörün daha fazla desteğe ihtiyacı olduğu anlaşılmaktadır.

Özgünlük: Bu çalışma kapsamında, sektörel farklılıklar göz önüne alınarak dijitalleşme ve teknolojinin benimsenmesi, çalışanların lisansüstü eğitimlerinin ve yükseköğretim-sanayi işbirliklerinin teşvik edilmesi, Ar-Ge ve inovasyonun kurum kültürünün bir parçası olarak benimsenmesi, Ar-Ge ve inovasyon teşviklerinin yaygınlaştırılması, Ar-Ge ve yenilik faaliyetlerinde KOBİ'lerin desteklenmesi gibi başlıkları altında geleceğe yönelik öngörü ve öneriler verilerek sektörel açıdan katkı sağlamak amaçlanmaktadır.

Anahtar Kelimeler: Araştırma ve Geliştirme, İnovasyon Yönetimi, Tahminleme.

JEL Kodları: M11, O32, C53.

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1. INTRODUCTION

Research and Development (R&D) and innovation activities are vital in discovering new ideas, ensuring technological progress and productivity and gaining a competitive advantage globally (Ahmad and Zheng, 2023). Successful innovation practices increase profit and market share and reduce costs (Yanmaz Arpacı and Gülel, 2023). Businesses, universities, research institutions and governments invest heavily in R&D and innovation activities (Zhou and Wang, 2023). Many countries follow strategic plans to lead R&D and innovation activities and compete globally. These plans aim to encourage innovative ideas, support R&D activities, encourage scientific studies and commercialize new technologies (Yontar and Ersoy Duran, 2023). Innovation and R&D studies have an impact on many different industries (Cipek et al., 2023). For example, significant progress has been made in areas such as developing new products in the technology industry and discovering renewable energy sources in the energy industry. In addition, in recent years, there has been a significant focus on innovation and R&D studies in areas such as artificial intelligence, big data analytics, and the Internet of Things (Murrieta-Oquendo ve De la Vega, 2023). These technologies have transformed many industries and created new business opportunities.

The development of R&D and innovation activities in a country provides excellent benefits to that country (Temel et al., 2023). Similarly, R&D and innovation activities in Türkiye are essential for economic growth, competitiveness and sustainable development (Yontar and Ersoy Duran, 2023). To be competitive in the global economy, offering innovative products and services is necessary. R&D and innovation activities enable companies to develop products and services based on new technologies by increasing their competitiveness (Dhar et al., 2023). In addition, innovative products and technologies increase export potential (Dong et al., 2022). Thanks to R&D and innovation activities, Türkiye can become more competitive in exports by producing high-value-added products (Çalık, 2021). Besides R&D and innovation activities, it encourages technological development and increases the country's knowledge, which enables Türkiye to become a country with advanced technologies (Ahmad and Zheng, 2023).

In addition to being a country with a high export rate, when the last three reports of the Türkiye Exporters Assembly published until 2023 are examined, based on export rates, the leading industries are automotive, textile, main metal, chemicals, electricity and electronics. However, considering the increase in exports between years, the three industries with the highest rates are the automotive, textile and main metal (Türkiye Exporters Assembly, 2022, Türkiye Exporters Assembly, 2023). In these industries, carrying out R&D and innovation activities and planning the proper expenditures have become crucial. Being environmentally friendly, sustainable and circular in globalizing conditions in these leading industries has become a critical competitive advantage and productivity issue. Hence, it is necessary to make predictions situation of Türkiye in terms of R&D and innovation activities to make future-oriented approaches in these industries. Therefore, the following research question needs to be answered;

- What are future insights for R&D and innovation activities in leading export-based industries in Türkiye?

To answer the research question, firstly, based on Turkish Statistical Institute (TurkStat) data, industrial R&D and innovation indicators in Türkiye are chosen as the most affordable and most suitable inclusiveness. Then, the data set belonging to these indicators between 2018-2021 is determined and predicted until 2030 by the GM (1,1) forecasting model. Forecasting R&D and innovation activities in Türkiye’s leading export-oriented industries is vital in strengthening the country's economic success. First, these activities enable companies to gain a competitive advantage in the international market. Innovative products and processes offer the ability to compete with other countries and quickly adapt to global demands.

Moreover, anticipating technological developments enables sectors to maintain their leading positions and adapt to changes in the world economy, which is a critical factor for long-term sustainable growth. Additionally, when environmental factors are becoming increasingly important, R&D and innovation support sustainability by focusing on developing environmentally friendly products and processes. This provides a strategic advantage in terms of adapting to the demands of consumers and the global market and fulfilling environmental responsibilities. As a result, forecasting R&D and innovation activities in Türkiye's leading export-oriented industries plays an important key role in economic growth, competitiveness, environmental sustainability and long-term success. Accurate forecasts made in this context contribute to the country's ability to effectively respond to future challenges and achieve a strong position in the international area. Therefore, this study aims to forecast industrial R&D and innovation indicators in Türkiye until 2030. By doing this, future insights for R&D and innovation activities in leading export-based industries in Türkiye are presented in this study.

The structure of this study as follows; firstly, R&D and innovation activities in Türkiye will be explained and industrial R&D and innovation indicators in Türkiye will be determined. Ten, materials and methods will be explained and results will be presented. In the following section, a theoretical background of R&D and innovation activities in Türkiye is explained in detail.

2. LITERATURE REVIEW

2.1. R&D and Innovation Activites in Türkiye

As an emerging economy, Türkiye's economy is based on exports, which are essential for the country's growth and development. Türkiye exports various products to many countries around the world. In recent years, Türkiye's export performance has been gradually increasing. Export is vital in the country's economy and constitutes a large part of the national income.

Among Türkiye's most important export items are automotive and sub-industry products, textile and ready-made clothing, chemicals, steel, electronics and agricultural products. The biggest markets for Türkiye's exports are generally the European Union countries, the Middle East, North America and Asian countries. Türkiye's most significant export partner countries include Germany, England, Italy, France and the United States. According to Turkish Statistical Institute data, in the January-December period of 2022, exports increased by 12.9% compared to the same period of the previous year. They reached 254 billion 172 million dollars, while imports increased by 34.0% and reached 363 billion 711 million dollars. In addition, since the increase in exports and R&D activities support each other, an increase is observed in the investments made in R&D in Türkiye to gain a competitive advantage and increase productivity.

Moreover, as R&D and innovation activities increase the demand for a highly qualified workforce, they support employment opportunities and human resources development in Türkiye (Belgin and Balkan, 2019). In addition, R&D and innovation activities contribute to developing environmentally friendly and sustainable solutions, which supports Türkiye's achievement of environmental sustainability and green economy goals (Costantiello and Leogrande, 2023). Considering these benefits, the contribution of R&D and innovation activities in Türkiye to the country's development is revealed again. R&D and innovation activities and a country's export status can be associated with each other (Jiyamuratov, 2023). The relationship between the export rate in Türkiye and R&D and innovation activities enables Türkiye to increase its export revenues by increasing its competitive power. Therefore, the Turkish government encourages R&D and innovation activities with policies such as R&D incentives and support programs and contributes to increased exports and productivity in operations. Consequently, it is essential to detail the leading industries for the country in terms of exports to examine the R&D and innovation activities in Türkiye.

As mentioned before, it has been determined that the most critical three industries are the automotive, textile and main metal industries based on their increase in export rates between years, respectively (Türkiye Exporters Assembly, 2023). The automotive industry is generally defined as an industry branch that manufactures road vehicles (passenger cars, buses, minibusses, tow trucks, trucks, tractors, etc.) and the parts used to produce these vehicles (Barazza, 2023). The automotive industry is considered the locomotive of the economy in all industrialized countries (Cipek et al., 2023). This is because it is very closely related to other branches of industry and other industries of the economy. Changes in this industry have a significant impact on the economy. The automotive industry's share in the total production of the manufacturing industry in Türkiye is above the average of the manufacturing industries (Yontar and Ersoy Duran, 2023). Although the export rate of the automotive industry has fluctuated between years, it has increased every year and reached 251 billion dollars in 2021 (Ministry of Industry and Technology, 2021a). In addition, the employment increase in the industry in 2021 is 73% (Ministry of Industry and Technology, 2021a).

Although the automotive industry has the highest export rate in Türkiye, it has become the export base of foreign automotive companies due to the world's leading automotive companies establishing facilities with Turkish partners (Ministry of Industry and Technology, 2021a). Since there has been great competition in the Turkish automotive industry in recent years due to the increase in R&D and the high investment requirement for the use of new technology, there has been an increase in power alliances through mergers between companies (Akçomak and Bürken, 2021). R&D and innovation activities in the industry have become even more critical in Türkiye than in the rest of the world, with the ability to meet the financial burden of excess capacity in the automotive industry, the competitive environment in the industry, the limited growth in the market, and the more selective customers (Alpkan and Gemici, 2023).

The textile industry has a wide range of production, also under the supply chain of the ready-to-wear industry in Türkiye. The textile industry ranks first in Türkiye regarding product quality and high technology (Kantur and Türkekul, 2023). In 2021, the textile industry's export was approximately 17 billion dollars and employs around 1 million people (Ministry of Industry and Technology, 2021b). In this industry, where the competition level is increasing daily, R&D and innovation activities also increase. In the textile industry, which is applicable in R&D and innovation activities, improvements and innovations made at each stage of production significantly contribute to the value chain of products and product groups (Kose and Atasever, 2023). Especially with digital and green transformation, developments and innovations in sustainable, ecological and technical textile products bring serious value to businesses (Xu et al., 2023).

Moreover, the main metal industry in Türkiye includes many sub-branches, especially iron-steel and aluminum industries (Ministry of Industry and Technology, 2021c). It provides primary inputs and raw materials to the main metal industry, machinery, automotive, electronics, chemistry, defense, aviation, mining and transportation industries throughout the country. In 2021, the industry that increased its exports the most in terms of value was the iron and steel industry, which is considered within the main metal industry with 52% (TurkStat, 2022). When the developments in recent years are examined, effects are seen in terms of R&D and innovation activities in this industry.

When the three industries with the highest export rates in Türkiye are examined, it is seen that there is a general increase in export rates, although there have been fluctuations over the years. In addition, the importance given to R&D care and innovation activities is increasing in all three industries with the competition conditions around the world, the increase in environmental awareness and the variability in customer demands. However, this increase has not yet reached a sufficient level throughout the country (Ministry of Industry and Technology, 2021a).

As mentioned before, for Türkiye, R&D and innovation activities have become more important. Therefore, it has become highly critical for the country to identify industrial R&D and innovation indicators in Türkiye and find solutions to improve them. Hence, in the following section, industrial R&D and innovation indicators in Türkiye are explained in detail.

2.2. Industrial R&D and Innovation Indicators in Türkiye

Industrial R&D and innovation indicators in Türkiye are the data used to evaluate the country's technological capacity and innovation performance. These indicators are of great importance in terms of economic growth, competitiveness and sustainable development of the country.

Previous studies mostly approached the subject by only considering R&D and innovation investments while making country-wised assessments, and most of these studies investigated the relationship between these investments and the economic growth of Türkiye (i.e., Demir and Geyik, 2014; Bozkurt, 2015; Sungur et al., 2016; Börü and Çelik, 2019).

For instance, Demir and Geyik (2014) considered R&D and innovation investments as patent applications and the number of patents and made a comparison between East Asian countries with Türkiye. In addition, Bozkurt (2015) investigated the long-term relationship between R&D and innovation expenditures and economic growth and concluded that there is a unidirectional causal relationship between them. Moreover, Sungur et al. (2016) analyzed the number of R&D researchers, R&D expenditures, patents and innovation activities on export and economic growth for Türkiye between 1990 to 2013, and they provide outcomes related to the relationship between these indicators. On the other hand, Börü and Çelik (2019) investigated the impacts of R&D and innovation investments on economic growth with a focus on the innovative investment movement in Türkiye.

Furthermore, in a recent study, Çubuk (2023) proposed an R&D and innovation map for Türkiye by using a hybrid methodology. In this study, 81 cities in Türkiye were evaluated according to their R&D and innovation performance by considering twelve different criteria. On the other hand, it is revealed that the current literature related to Türkiye lacks in providing sectoral analysis in terms of R&D and Innovation activities. From this point of view, this study specifically focuses on the automotive, textile, and main metal industries, which are leading industries based on export rates.

Different indicators are detected when examining the "R&D Investments" data set in the Turkish Statistical Institute's database. Among them, six indicators with high data availability and coverage are selected for analysis in this study. These indicators can be summarized as follows;

- *Current Expenditure:* Current expenditures refer to the direct costs of resources used for R&D and innovation projects, such as personnel salaries, materials, equipment, laboratory costs, consultancy services, travel expenses, and software licenses (Pelikánová, 2019).
- *Personnel Expenditure:* Personnel expenditures in R&D and innovation investments represent the costs for employees to carry out research and development activities of companies such as salaries, fringe benefits, insurance premiums, training and development expenses of researchers, engineers, scientists, technicians and other personnel working in the R&D and innovation department (Afriana and Khoirunurrofik, 2023).

- *Trade Investment:* Trade investments aim to use financial resources related to R&D and innovation projects, and these projects produce results that increase the company's revenues or reduce its costs (Belgin and Balkan, 2019). Transforming R&D and innovation investments into commercial investments provides introducing new products to the market, obtaining patents, commercial evaluation of technological innovations or gaining competitive advantage (Madaleno and Nogueira, 2023).
- *Foreign Investment:* Foreign investment refers to investments made by a foreign company or investor in a country's R&D activities (Cao et al., 2023).
- *Number of Patent Applications:* The number of patent applications in investments refers to the number of applications filed by companies to claim patent protection for new inventions or technological innovations (Aydin et al., 2023).
- *Number of R&D Personnel:* It refers to the number of R&D employees companies employ to conduct research and development activities (Çelik, 2020). R&D personnel include researchers, engineers, scientists, technicians and other experts.

Being aware of the indicators for the country and making sectoral analyses provide essential information for policymakers and decision-makers while simultaneously revealing the technological capacity of Türkiye, innovation capabilities and sectoral competitiveness. Evaluation of competitiveness is vital to identify the country's strengths and improve its weaknesses. In addition, these indicators enable the identification of potential business opportunities and investment areas.

Moreover, analyzing the indicators and predicting the future makes it easier to obtain information about Türkiye and its current situation in the world, as it will enable international comparisons. Therefore, it is critical to predict these indicators until 2030 so that future investments can be planned, the workforce can be designed, and priority areas can be identified in leading export-based industries in Türkiye. By comparing the previous studies, GM (1,1) methods are used for forecasting about environmental issues such as energy consumption (Khan et al., 2023), greenhouse gas emissions (Kazancoglu et al., 2021), solid waste generation (Pudcha et al., 2023), and also production and consumption topics (Wang et al., 2023), hydropower generation capacities (Zeng et al., 2023) etc. Therefore, this method is practical and appropriate to forecast R&D and innovation activities in Türkiye.

3. MATERIALS and METHOD

In this study, a 4-stage methodology is followed. According to the flowchart presented in Figure 1, firstly, R&D and innovation activities in Türkiye and industrial R&D and innovation indicators in Türkiye are examined to know the current situation of Türkiye. Then, based on defined indicators, the time series data between 2018-2021 are determined separately for the automotive, textile and main metal industries. These data are gathered from TIS and Turkish Patent and Trademark Office databases. According to these data sets, a total of 18 calculations are made using the GM (1,1) model to forecast these data until 2030 for each industry and each indicator separately. Lastly, it is aimed to present future insights for R&D and innovation activities in leading export-based industries in Türkiye.

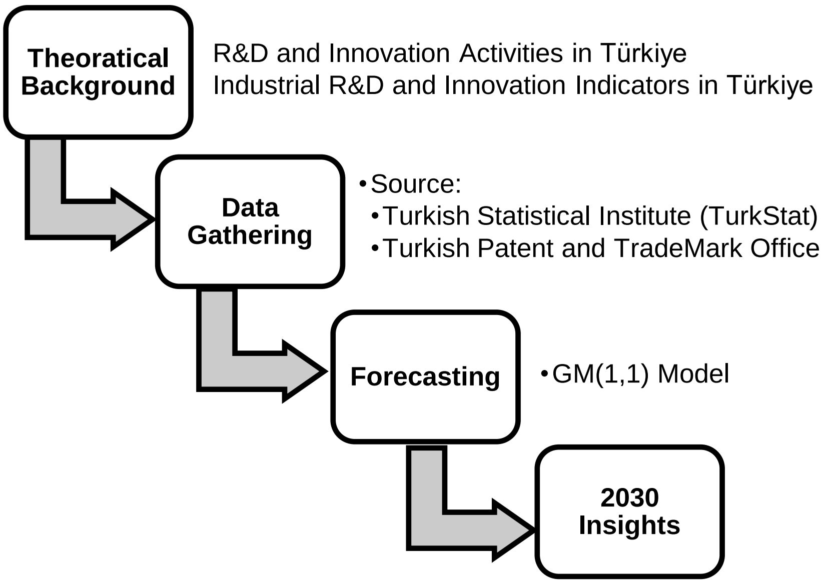


Figure 1. Flow chart of the research

In the following sections, each stage of the methodology is explained respectively. From this view, the next section presents the data set.

3.1. Data Set

As mentioned in the previous section, data related to R&D and innovation indicators were derived from the Turkish Statistical Institute (TurkStat) and the Turkish Patent and Trademark Office. Due to the nature of the methodology, data from the previous four years are required. Except for the number of patent applications, the recent data belongs to 2021; therefore, forecasting is made from 2022 to 2030.

The data set, presented in Table 1, includes data related to current expenditures (₺), personnel expenditures (₺), trade investments ($), number of patent applications and number of R&D personnel for textile, main metal and automotive industries. The last four years' data clearly shows that the automotive industry comes to the fore in the R&D and innovation activities.

Table 1. Data set

	Period			
Indicators/Industries	*2018*	*2019*	*2020*	*2021*
Current Expenditures (₺)				
Textile Industry	250,554,864	355,831,879	389,106,887	442,606,840
Main Metal Industry	153,621,198	186,489,935	265,859,690	374,558,864
Automotive Industry	2,215,673,056	2,823,580,559	3,552,349,701	5,464,924,027
Personnel Expenditures (₺)				
Textile Industry	148,289,387	203,182,656	237,410,401	259,386,926
Main Metal Industry	88,345,115	110,107,895	143,450,313	177,025,681
Automotive Industry	907,931,895	1,074,556,307	1,205,051,721	1,845,851,592
Trade Investments (₺)				
Textile Industry	268,343,068	348,948,876	396,342,855	449,211,019
Main Metal Industry	209,557,367	267,032,832	277,125,548	415,423,995
Automotive Industry	2,261,507,064	2,768,658,210	3,021,010,444	5,265,387,350
Foreign Investments ($)				
Textile Industry	839,999	149,089	2,121,224	1,168,239
Main Metal Industry	444,181	1,009,971	2,777,913	5,511,576
Automotive Industry	131,385,059	275,796,542	342,223,793	516,493,500
Number of Patent Applications				
Textile Industry	144	159	114	111
Main Metal Industry	342	363	357	337
Automotive Industry	950	1,048	882	1,009
Number of R&D Personnel				
Textile Industry	2,561	2,719	2,708	2,639
Main Metal Industry	1,200	1,407	1,440	1,398
Automotive Industry	8,328	8,641	9,034	10,085

The methodology used for forecasting R&D and innovation activities in textile, main metal and automotive industries is explained in detail in the following section.

3.2. GM (1,1) Model

The GM (1,1) model is a prediction model known as the Grey System Theory. This model analyses time series with limited data and predicts future trends. The GM (1,1) model reveals the hidden dynamics within the system and makes predictions. The basic principle of the GM (1,1) model is to use first-order differential equations and arithmetic mean data. This model works to separate the systematic and random components of the data series.

The GM (1,1) forecasting method, based on grey system theory, is notable for its simplicity and ability to deal with limited or irregular data sets. Especially effective when historical information is limited or uncertain, GM (1,1) requires less data and does not assume linearity compared to traditional techniques such as ARIMA or exponential smoothing (Khan and Osinska, 2023). Additionally, compared to more complex predictive tools such as machine learning models and neural networks, GM (1,1) is less complicated but valuable in situations where a basic model is sufficient (Wei et al., 2023). Machine learning models are effective at capturing complex relationships. Still, they may require larger data sets and complex parameter tuning and neural networks, on the other hand, are known for their capacity to recognize intricate patterns but require larger data and computational resources (Su and Huang, 2023). Fundamentally, the choice between GM (1,1) and other forecasting techniques focuses on the characteristics of the data and the complexity requirements of the prediction task encountered (Li et al., 2023). In the study, GM (1,1) model implementation was preferred as the method because the data was limited and required a more practical implementation.

The steps of the GM (1,1) model are as follows:

GM (1, 1) model includes actual data of series (x_1^0 , x_2^0..) and aims to predict future data as $x_3^0, \ldots, x_{n}^1$,. In this study, a total of 18 GM (1, 1) models are applied. According to the actual data set (x0), the Accumulating Generation Operation (AGO) is calculated. The formula is as shown in Equation 1.

$$x_k^1 = \sum_{i=1}^{k} x^0 i \quad (1)$$

After finding the AGO formula, x_1 series are expressed as Equation 2.

$$x_k^1 = x_1^1, x_2^1, \ldots., x_n^1 \quad (2)$$

Then, z_k^1 is calculated after finding x_k^1 series. The generated mean sequence z_k^1 of x_k^1 is expressed as in Equation 3.

$$z_k^1 = 0.5x_k^1 + 0.5\, x_{(k-1)}^1 \quad (3)$$

k = 1, 2,….., n

By using the formula, z_k^1 is obtained as in Equation 4.

$$z_k^1 = (z_1^1, z_2^1, \ldots.. z_n^1) \quad (4)$$

Moreover, a and b parameters are found by using Equation 5 and 6. These parameters are used for the prediction of data.

3.3. Least Square Method

To use Equation 5, all values are substituted as in the Equation 6.

$$b = x_{(k)}^0 + a z_k^1 \quad (5)$$

$$x_{(2)}^0 = a z_2^1 + b$$

$$x_{(3)}^0 = a z_3^1 + b$$

……………………

$$x_{(n)}^0 = a z_n^1 + b \quad (6)$$

Equation 7 is used to find a and b values, which are x and z series, shown as "B" and "Y" in the matrix representation.

$$Y = \begin{matrix} x_2^0 \\ x_3^0 \\ x_n^0 \end{matrix} \qquad B = \begin{matrix} -z_2^1 & 1 \\ -z_3^1 & 1 \\ -z_n^1 & 1 \end{matrix} \quad (7)$$

Then, the matrix method is applied by using Equation 8.

$$\alpha = [a, b]^T = (B^T B)^{-1}(B^T.Y) \quad (8)$$

Furthermore, the Grey differential equation should be calculated to get the estimated value of the initial data at a time (k + 1) in Equation 9.

$$x_{(k+1)}^1 = \left[x_1^0 - \frac{b}{a}\right] e^{-ak} + \frac{b}{a} \quad (9)$$

After that, the Inverse Accumulating Generation Operation is calculated by using Equation 10.

$$x_{(k+1)}^0 = x_{(k+1)}^1 - x_k^1 \quad (10)$$

$k = 1,2,3, \ldots, n$

At the end of the implementation, the error rate is calculated by using Equation 11.

Prediction can be made when k <n. to find the error average of the model; equation 11 is used when $k = 1, 1+1, \ldots, n-1$. (Podrecca and Sartor, 2023).

x_k^0 = true (initial) value

$\hat{x}_k^0$ = predicted value of the dataset

$$e(k+1) = \left|\frac{x^0_{(k+1)} - \hat{x}^0_{(k+1)}}{x^0_{(k+1)}}\right| x\ 100\% \tag{11}$$

The accuracy of the GM (1, 1) model is $p\circ$, as shown in Equation 12.

$$p\circ = (1 - \varepsilon) \times 100\% \tag{12}$$

The general requirement is $p\circ$ > 80%.

The GM (1,1) model is considered a helpful prediction model when it has limited data. This model, which is practical in implementation and needs very little data, can also be evaluated by calculating the error rate and how close the model's predictions are to the actual data. In the following section, the implementation and results of this study are explained in detail.

4. IMPLEMENTATION AND RESULTS

Implementation of the study was conducted using the GM (1,1) for prediction values of current expenditure, personnel expenditures, trade investments, number of patent applications, number of R&D personnel and foreign investments for the textile, main metal and automotive industries between 2022 to 2030. These models are applied separately for each industry and indicator, in total 18 times, and equations were formulated by using Microsoft Excel.

As mentioned earlier, implementations have been made for the textile, main metal, and automotive industries. For the textile industry, the first prediction model was established based on data obtained from the TurkStat for the years 2018-2021 to forecast the “current expenditure situation” in the textile industry. The second prediction model, again for the textile industry, was built based on "personnel expenditure" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The third prediction model for the textile industry was established based on "trade investment" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The fourth prediction model for the textile industry was built based on the "number of patent applications" data from the Turkish Patent and Trademark Office for the years 2019-2022, and predictions were made for the years 2022-2030. The fifth prediction model for the textile industry was established based on the "number of R&D personnel" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The sixth prediction model for the textile industry was built based on "foreign investment" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030.

Similarly, similar calculations have been conducted for the main metal industry. For the main metal industry, the first prediction model was established based on data obtained from the TurkStat for the years 2018-2021 to forecast the “current expenditure” situation in the main metal industry. The second prediction model, for the main metal industry, was built based on "personnel expenditure" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The third prediction model, for the main metal industry, was established based on "trade investment" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The fourth prediction model, for the main metal industry, was built based on the "number of patent applications" data from the Turkish Patent and Trademark Office for the years 2019-2022, and predictions were made for the years 2022-2030. The fifth prediction model, for the main metal industry, was established based on the "number of R&D personnel" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The sixth prediction model for the main metal industry was built based on "foreign investment" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030.

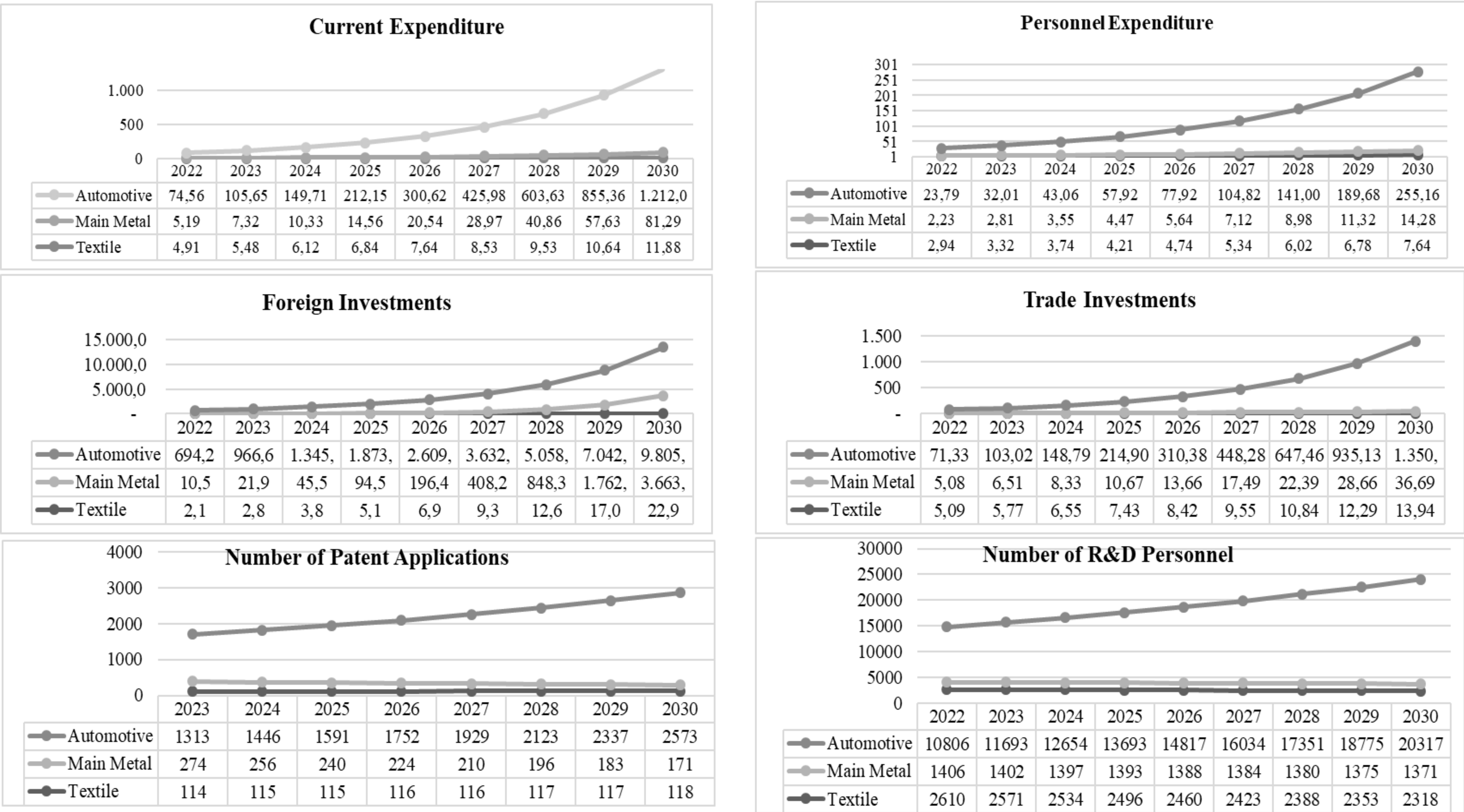
Finally, similar calculations have been applied to the automotive industry. For the automotive industry, the first prediction model was established based on data obtained from the TurkStat for the years 2018-2021 to forecast the “current expenditure” situation in the automotive industry. The second prediction model, for the automotive industry, was built based on "personnel expenditure" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The third prediction model, for the automotive industry, was established based on "trade investment" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The fourth prediction model, for the automotive industry, was built based on the "number of patent applications" data from the Turkish Patent and Trademark Office for the years 2019-2022, and predictions were made for the years 2022-2030. The fifth prediction model, for the automotive industry, was established based on the "number of R&D personnel" data from the TurkStat for the years 2018-2021, and predictions were made for the years 2022-2030. The sixth prediction model for the automotive industry was built based on "foreign investment" data from the TurkStat for 2018-2021, and predictions were made for 2022-2030.

Moreover, as mentioned before, calculating the error rate in a GM (1,1) model is an essential tool for understanding how well the model performs with real-world data, assessing the reliability of the model and conducting a statistical significance of parameters. These calculations are used to understand the model's effectiveness in practice and quantify the model's accuracy. For this reason, the error rate was calculated separately for each prediction made. A summary of the forecast results is presented in Table 2.

Table 2. Summary of the forecast results

Indicators	*Years*	*Textile Industry*	*Main Metal Industry*	*Automotive Industry*	*Indicators*	*Years*	*Textile Industry*	*Main Metal Industry*	*Automotive Industry*
Current Expenditure (Divided by 100M)	2022	4.91	5.19	74.56	Foreign Investments (Divided by 1M)	2022	2.1	10.5	694.2
	2023	5.48	7.32	105.65		2023	2.8	21.9	966.6
	2024	6.12	10.33	149.71		2024	3.8	45.5	1,345.8
	2025	6.84	14.56	212.15		2025	5.1	94.5	1,873.9
	2026	7.64	20.54	300.62		2026	6.9	196.4	2,609.1
	2027	8.53	28.97	425.98		2027	9.3	408.2	3,632.7
	2028	9.53	40.86	603.63		2028	12.6	848.3	5,058.0
	2029	10.64	57.63	855.36		2029	17.0	1,762.9	7,042.4
	2030	11.88	81.29	1,212.06		2030	22.9	3,663.6	9,805.5
Personnel Expenditure (Divided by 100M)	2022	2.94	2.23	23.79	Number of Patent Applications	2022	-	-	-
	2023	3.32	2.81	32.01		2023	114	274	1313
	2024	3.74	3.55	43.06		2024	115	256	1446
	2025	4.21	4.47	57.92		2025	115	240	1591
	2026	4.74	5.64	77.92		2026	116	224	1752
	2027	5.34	7.12	104.82		2027	116	210	1929
	2028	6.02	8.98	141.00		2028	117	196	2123
	2029	6.78	11.32	189.68		2029	117	183	2337
	2030	7.64	14.28	255.16		2030	118	171	2573
Trade Investments (Divided by 100M)	2022	5.09	5.08	71.33	Number of R&D Personnel	2022	2610	1406	10806
	2023	5.77	6.51	103.02		2023	2571	1402	11693
	2024	6.55	8.33	148.79		2024	2534	1397	12654
	2025	7.43	10.67	214.90		2025	2496	1393	13693
	2026	8.42	13.66	310.38		2026	2460	1388	14817
	2027	9.55	17.49	448.28		2027	2423	1384	16034
	2028	10.84	22.39	647.46		2028	2388	1380	17351
	2029	12.29	28.66	935.13		2029	2353	1375	18775
	2030	13.94	36.69	1,350.61		2030	2318	1371	20317

When these results are examined with an integrated perspective, it can be said that R&D and innovation activities in the automotive industry become prominent in every indicator, and forecast results show a continuous increase in the given time. On the other hand, although the textile and main metal industries are very different regarding market area and processing, their current condition and forecast results are similar for the selected indicators. In addition to this, based on error rates, it can be seen that all error rates of these calculations are under the error limit, which is 20%. That means this model gave results below the error rate required by the model for the implementation of the study. A graphical representation of the forecast results is presented in Figure 2.



Current Expenditure

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	74,56	105,65	149,71	212,15	300,62	425,98	603,63	855,36	1.212,0
Main Metal	5,19	7,32	10,33	14,56	20,54	28,97	40,86	57,63	81,29
Textile	4,91	5,48	6,12	6,84	7,64	8,53	9,53	10,64	11,88

Personnel Expenditure

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	23,79	32,01	43,06	57,92	77,92	104,82	141,00	189,68	255,16
Main Metal	2,23	2,81	3,55	4,47	5,64	7,12	8,98	11,32	14,28
Textile	2,94	3,32	3,74	4,21	4,74	5,34	6,02	6,78	7,64

Foreign Investments

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	694,2	966,6	1.345,	1.873,	2.609,	3.632,	5.058,	7.042,	9.805,
Main Metal	10,5	21,9	45,5	94,5	196,4	408,2	848,3	1.762,	3.663,
Textile	2,1	2,8	3,8	5,1	6,9	9,3	12,6	17,0	22,9

Trade Investments

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	71,33	103,02	148,79	214,90	310,38	448,28	647,46	935,13	1.350,
Main Metal	5,08	6,51	8,33	10,67	13,66	17,49	22,39	28,66	36,69
Textile	5,09	5,77	6,55	7,43	8,42	9,55	10,84	12,29	13,94

Number of Patent Applications

	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	1313	1446	1591	1752	1929	2123	2337	2573
Main Metal	274	256	240	224	210	196	183	171
Textile	114	115	115	116	116	117	117	118

Number of R&D Personnel

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Automotive	10806	11693	12654	13693	14817	16034	17351	18775	20317
Main Metal	1406	1402	1397	1393	1388	1384	1380	1375	1371
Textile	2610	2571	2534	2496	2460	2423	2388	2353	2318

Figure 2. Graphical representation of the forecast results

To start with the forecast results related to current expenditure, a significant difference is revealed between industries. While the automotive industry is expected to have a sharp increase in current expenditure related to R&D activities and reach around 121,200M ₺ in 2030, forecast results for main metal industry are revealed around 8100M ₺ and for textile only 1100M ₺. Furthermore, the main metal and textile industry is expected only slightly to increase for the given time.

Results related to personnel investments are similar to the current expenditure. The difference between industries is very high. While personnel expenditure is expected to be 25500M ₺ for the automotive industry in 2030, predictions for main metal and textile are only around 1100M ₺ and 600M ₺.

For trade investments and foreign investments, forecast results follow a similar pattern. For both indicators, the automotive industry comes forefront with approximate values of 135000M ₺ and 9805M $ in 2030. On the other hand, the difference between the main metal and textile industries is higher for these indicators. Significantly, foreign investments for the main metal industry are predicted as 3663M $; conversely, only 22M $ for the textile industry.

The number of patent applications is another critical R&D and innovation indicator that reflects the general approaches. An exciting outcome is revealed related to these indicators. Although a continuous increase is expected in the number of patent applications in the automotive industry, and it is predicted that applications will reach 2573 in 2030, a slight decreasing pattern is revealed for the main metal and textile industry.

Finally, forecast results related to the number of R&D personnel indicator show that future employment for the automotive industry is expected to increase to 20317 by 2030. On the other hand, main metal and textile have a slight decrease similar to the previous indicator. This result is because the number of patent applications and R&D personnel are interrelated indicators. When industries are compared for indicators, the textile industry precedes the main metal industry for only the number of R&D personnel.

Furthermore, cross-validation has been conducted to enhance the robustness of the analysis and evaluate the generalization ability of the GM (1,1) model. Cross-validation is a well-known data resampling method to forecast the true prediction error of models (Berrar, 2018). For the cross-validation of the GM (1,1) model, a forecast was made for 2018 to 2022 using the testing set as data between 2014 and 2017. For the given time, estimation has been conducted for current expenditures, personnel expenditures, trade investments, patent applications, and R&D personnel for the textile, main metal and automotive industries. Results of the forecasts are compared with the actual data between 2018 to 2022, the training set, and it is revealed that the GM (1,1) model is suitable method for the estimation of R&D and innovation indicators for the selected industries.

4.1. Analysing Performance of GM (1,1) Model Implementation

Performance analyses in forecasting methods include various factors when evaluating how effective a model is (Davis et al., 2019). First, performance analysis evaluates the model's ability to match real data. This is a critical way to determine how accurately the model makes predictions and how consistent it is with real-world data (Xie et al., 2023). In addition, performance analyses enable the comparison of different models and the determination of the strengths and weaknesses of each model (Xie et al., 2023). This makes it easy to choose the model that provides the best performance in the context of an application. There are other variants of the GM (1,1) model such as Fourier error corrections (EGM) or the Gray Verhulst model (GVM) (Anisah et al., 2023). Conducting a detailed performance analysis with different GM variants is critical for several important reasons. First, it helps determine how well each model fits certain data features and patterns (Zhang et al., 2023). By comparing their accuracy in predictions, it is possible to determine which variant best fits the unique features of the data set (Davis et al., 2019). Context fit is also a critical aspect; Understanding the strengths and weaknesses of each GM variant specific to its application context ensures whether the chosen model is suitable for a particular sector or industry. Additionally, comparative analysis provides the basis for informed decision making; This allows selecting a model that not only adapts to the available data set but also meets the specific requirements and objectives of the prediction task.

Deciding between the GM (1,1) model and alternatives depends on specific considerations tailored to prediction needs (Comert et al., 2021). The GM (1,1) model is known for its simplicity and effectiveness in scenarios with limited or irregular data. It is a practical choice when a clear understanding of the prediction process is essential (Nguyen et al., 2019). Conversely, models like EGM, incorporating Fourier error corrections, provide enhanced accuracy for datasets with pronounced cyclic patterns. The GVM introduces nonlinear growth modelling, offering flexibility for capturing more intricate data behaviours (Liu et al., 2023). Nevertheless, the GM (1,1) model excels in resource efficiency and a parsimonious approach, especially in cases with smaller datasets (Zhang et al., 2023). Its ability to provide reliable forecasts with minimal computational complexity makes it an appealing choice in contexts prioritizing simplicity, interpretability, and efficiency.

In addition to this, the importance of calculating the error rate in the GM (1,1) model is critical to conducting a statistical test to determine the statistical significance of the parameters of the GM (1,1) model. Error rates help to understand how accurate and reliable predictions the model makes (Wei et al., 2023). Error measures used when evaluating how compatible the model is with real data are essential tools that quantitatively measure the success of the model (Zhang et al., 2023). Error rates commonly used in the GM (1,1) model include metrics such as mean absolute error (MAE), mean square error (MSE), root mean square error (RMSE), mean absolute percentage error (MAPE) (Wei et al., 2023). These metrics evaluate the closeness of the model's predictions to the actual values from different perspectives. Calculating the error rate allows us to objectively assess the model's performance, developing a more robust understanding of the model's reliability and predictive ability (Li and Zhang, 2023). This is important for improving the model or comparing it with alternative models. In summary, calculating the error rate separately for each calculation as a result of the application proves the applicability of the method.

Performance analysis with other GM variants, particularly models such as the EGM or GVM, requires assessing the important factors driving model selection. In addition to the reasons for choosing the GM (1,1) model, there are several reasons that strengthen the logic behind this choice (Comert et al., 2021). Additionally, the fact that the GM (1,1) model has been used successfully in various fields in the past may support the reliability and applicability of the model behaviours (Liu et al., 2023). Computational efficiency can make GM (1,1) run faster than other more complex models, especially when working with large data sets or limited computational resources. Data fit determines how well the model can be fitted to specific characteristics in the data set; The GM (1,1) model may provide an advantage at this point thanks to its simplicity (Wei et al., 2023). Robustness and prediction accuracy should also be considered because these factors are important in determining how effective a model is under different conditions (Li and Zhang, 2023). In conclusion, opting for the GM (1,1) model may be a choice supported by both its simplicity and past success, but in all cases, the analysis, data set characteristics, and specific requirements must be considered.

However, in this study, a comparison was made between GM (1,1) and GVM for performance analysis to justify the applicability of GM (1,1) model. First of all, similar with GM (1,1) model implementation, GVM model is applied separately for each industry and indicator, in total 18 times, and equations were formulated by using Microsoft Excel. After that, error calculations are made. In this context, it is aimed to evaluate the prediction accuracy of both models by making error analysis according to the model results. Comparisons were made between simulated values and real values with MAPE, precision rate and relative error rate calculations. This is an important stage to understand how well the models fit the trends and variations in the data set. Therefore, the error comparison between the values, which are MAPE, Precision Rate and Relative Error Rates of the results of GM (1,1) and GVM models as shown in Table 3.

As shown in Table 3, in forecasting methods; if the MAPE is under 5, it means that highly accurate predictability. A 5-10 range is still good, but once you go beyond 20, it's like the model decided to take a scenic route through inaccuracies (Wei et al., 2023). Furthermore, the "Precision Rate (P)" serves to gauge how closely the forecasted values align with the actual ones (Li and Zhang, 2023). Moreover, when relative error rates and other metrics are considered, it is seen that GM (1,1) model is more suitable to implement for forecasting than GVM model. The following section includes suggestions and future insights for Türkiye by considering these forecast results.

Table 3. Comparison of performance metrics for GM (1,1) and GVM Models

		GM (1,1)	*GVM*	*GM (1,1)*	*GVM*	*GM (1,1)*	*GVM*
	Index	*Textile Industry*		*Main Metal Industry*		*Automotive Industry*	
Current Expenditure (Divided by 100M)	MAPE (%)	9%	24%	10%	20%	8%	30%
	Precision Rate (%)	91%	76%	90%	80%	92%	70%
	Relative Error Rate (%)	0.69%	9%	1%	50%	4%	60%
Personnel Expenditure (Divided by 100M)	MAPE (%)	6%	20%	7%	21%	6%	32%
	Precision Rate (%)	94%	80%	93%	79%	94%	68%
	Relative Error Rate (%)	0.36%	9%	0.88%	28%	1%	47%
Trade Investments (Divided by 100M)	MAPE (%)	10%	25%	11%	21%	9%	35%
	Precision Rate (%)	90%	75%	89%	79%	91%	65%
	Relative Error Rate (%)	0.12%	11%	6%	36%	8%	74%
Foreign Investments (Divided by 1M)	MAPE (%)	10%	45%	11%	22%	10%	18%
	Relative Error Rate (%)	90%	55%	89%	78%	90%	82%
	Error Rate (%)	13%	35%	9%	19%	4%	56%
Number of Patent Applications	MAPE (%)	4%	56%	2%	26%	3%	32%
	Precision Rate (%)	96%	44%	98%	74%	97%	68%
	Relative Error Rate (%)	1%	15%	0.32%	15%	1%	1%
Number of R&D Personnel	MAPE (%)	1%	19%	3%	11%	3%	26%
	Precision Rate (%)	99%	81%	97%	89%	97%	74%
	Relative Error Rate (%)	1%	9%	0.84%	7%	5%	9%

5. FUTURE INSIGHT for TÜRKİYE

As mentioned before, R&D and innovation activities are essential worldwide. In addition to providing countries and companies with a competitive advantage, innovative products and technologies create new job opportunities, increase employment, improve productivity, and support economic growth. Although R&D and innovation activities have become a critical issue in Türkiye, a developing country, sectoral differences have emerged. When the Automotive, textile and main metal industries are examined, it is seen that the values considered in terms of R&D and innovation activities differ. According to the forecasted results, the automotive industry in Türkiye emerges as an industry where R&D and innovation activities are given more importance in every parameter. Some future suggestions and insights are presented to expand R&D and innovation activities in the industry and throughout the country of Türkiye as in line with the established model and addressed forecast problem (Figure. 3).

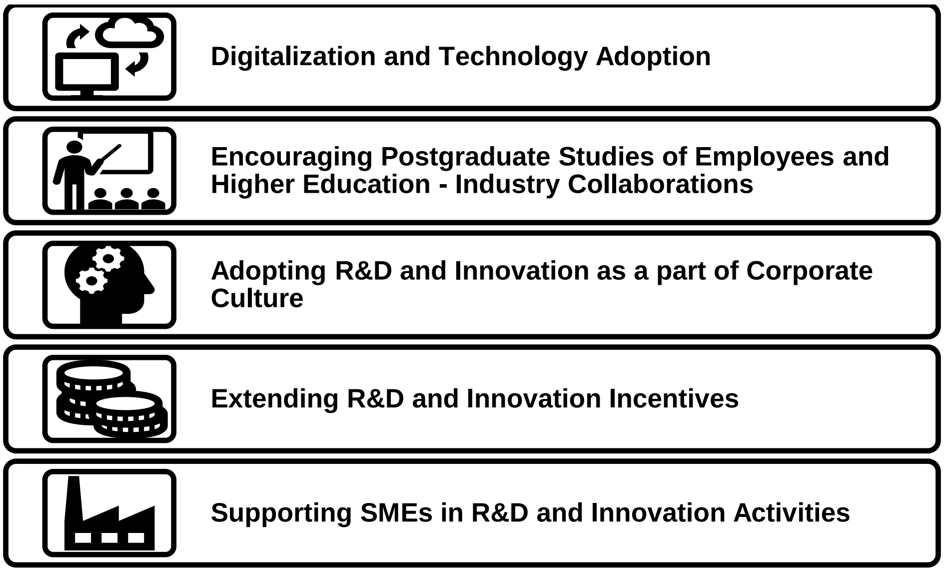


Figure 3. Suggestions and Future Insights for Türkiye

Digitization and adaptation to technology have become a priority worldwide. Digitalization must become the center for both factory-level and innovation activities. Therefore, expanding R&D investments in these areas is of great importance. In particular, R&D investments play a significant role in the digital transformation process of companies. By digitizing their business processes, companies can increase efficiency, improve the customer experience, and create new revenue models. It is essential to focus on R&D activities in digital technologies, cloud computing, big data analytics, artificial intelligence, and the Internet of Things. In addition, to remain competitive in the rapidly changing technological environment, companies must follow new technologies and adapt to these technologies. R&D investments should be used to monitor technology trends, provide early adaptation to new technologies and gain technology-oriented competitive advantages. In Türkiye, the Authority of Information and Communication Technology (BTK) presented the digital transformation targets for 2023 as increasing the number of SMEs that use cloud platforms, increasing the number of competence and digital transformation centers, and increasing the number of digitalization projects to develop new products and services (BTK, 2022). As it can be understood from these targets, digitalization and innovation activities are integrated into Türkiye while defining strategic goals.

Furthermore, numerical results showed that the automotive industry has the highest R&D investments among the industries covered. Due to its structure, this industry is very prone to digitalization and technology adaptation. Still, the low R&D investments in the main metal industry are due to the limited possibility of digitalization. The textile industry offers significant opportunities in digitalization and automation and has sufficient infrastructure. However, the textile industry is generally concentrated in developing countries based on cheap labor. In this case, the problem of not giving crucial importance and resources to R&D arises. As can be seen from the results, the reason for not experiencing high increases in R&D investments is cheap labor in the press.

As can be seen from the results, the automotive industry is superior in terms of all parameters. Especially in the projections made until 2030, a decrease is expected in the number of patent applications and personnel expenditures in the textile and main metal industries. The textile industry is affected by changing consumer preferences and increasing demand for more sustainable and innovative materials. In addition, the main metal industry is subject to fluctuations, often due to the demands of the construction, automotive and other manufacturing industries. The decrease in patent applications and personnel expenditures may be due to the reduction in the demand in the industry in a certain period or the decline in investments made in innovation activities. Therefore, a decrease is expected in new patent applications and expenditures on R&D activities. Postgraduate studies of employees need to be encouraged, mainly to prevent the reduction of patent applications and R&D personnel. In line with this, according to Türkiye Informatics Association's digital transformation index report of 2022, changes in curriculums of university education according to sectoral needs, increasing digital and innovative capabilities through higher education, and better integration between industries and educational institutions are essential to increase the performance of R&D and innovation activities (TÜBİSAD, 2022).

Furthermore, companies can enable their employees to develop their R&D skills by providing graduate education opportunities and supporting them with in-house training programs and may provide scholarships or financial aid. This helps employees achieve higher levels of education while reducing training costs. In addition, companies can provide flexible working arrangements such as flexible working hours or remote working so that employees can carry out their graduate studies. This helps employees to balance work life and education. With postgraduate training to motivate employees in this regard, it can be made a priority for employees to be promoted to higher positions or assigned to more strategic tasks.

Making R&D and innovation a part of corporate culture is vital for companies to achieve sustainable success. However, innovation culture in Türkiye is seen as very low according to TÜSİAD's High Technology Action Plan, published in 2023, and the reason behind that is presented as not being able to transform the digitally supported innovation knowledge into a skilled workforce (TÜSİAD, 2023). From this point of view, the corporate culture of R&D and innovation should be planned at different levels in terms of factory level. For example, the process of changing the corporate culture and adopting R&D and innovation should start with the commitment of the top management. Top management should set R&D and innovation as a strategic priority, direct resources toward this and inspire employees. In addition, effective communication and information sharing are essential for developing an R&D and innovation culture within the organization. It is necessary to share innovative ideas and encourage the flow of information within the company. Communication channels and platforms should provide an environment where employees can easily share their thoughts and experiences. In addition, a supportive infrastructure and adequate resources must be provided for adopting R&D and innovation. This includes technological infrastructure, budget, training programs, laboratories, and prototype production. Employees must be able to turn their innovative ideas into reality by accessing the necessary tools and resources.

Especially for the textile and main metal industries, R&D and innovation incentives should be created to increase current and personnel expenditures and provide indicators such as increasing patent applications. Supporting these industries in R&D and innovation activities is extremely important in delivering competitive advantage. Although these industries have high export rates and are suitable for technology infrastructure, their development becomes difficult if adequate support is not provided. The automotive industry is where technological innovations occur rapidly, and competition is intense. Therefore, as mentioned before, automotive companies must focus on R&D and innovation activities and develop innovative solutions.

When the numerical results of the study are examined, it is revealed that there is a lot of work in the automotive industry, but a need to develop them in terms of incentives.

Supporting SMEs in R&D and innovation activities is essential for increasing competitiveness, revealing innovation potential and sustainable growth. For this purpose, various support programs and policies for SMEs are implemented in many countries and regions. In Türkiye, the TUBITAK SME R&D start-up support program can be shown as an example, where SMEs are encouraged to be more competitive by improving their innovation capabilities (TÜBİTAK, 2023). However, these supports should be extended in terms of reaching more organizations and should be created as financial support, tax incentives, consultancy, cooperation, patent and utility model support. Financial support can be applied through state institutions, development agencies, and European Union funds. In addition, incentives such as tax deductions, tax exemptions or tax credits should be offered for R&D expenditures. To increase R&D and innovation activities at the SME scale, training on technical information transfer, patent application process, market research, and business plan creation should be established. Cooperation with universities, research centers, other SMEs or large-scale companies should be established.

6. CONCLUSIONS

R&D and innovation activities have recently become an issue that has affected countries' future. This issue needs to be addressed more, especially in emerging economies. Therefore, in this study, in terms of exports, three crucial industries, automotive, textile and main metal, were determined for Türkiye to examine the R&D and innovation activities in Türkiye. To analyze their R&D and innovation activities for Türkiye, or these industries, different indicators are determined by considering "R&D Investments" in the Turkish Statistical Institute's database. A total of six indicators, which are current expenditure, personnel expenditure, trade investment, foreign investment, number of patent applications and number of R&D personnel, are selected to analyze this study. To have a future-oriented idea based on the industry, each indicator for each industry has been forecasted until 2030 by using the GM (1,1) model. As a result, although an increase in R&D and innovation activities in the automotive industry is expected, especially for each indicator, these values are limited for textile and main metal. It is realized that especially these two industries need more support. Within the framework of these results, five main suggestions for the future are given as Digitalization and Technology Adoption, Encouraging Postgraduate Studies of Employees and Higher Education - Industry Collaborations, Adopting R&D and Innovation as a part of Corporate Culture, Extending R&D and Innovation Incentives, Supporting SMEs in R&D and Innovation Activities. For future research, comparison industries and indicators can be increased.

By comparing similar studies in the literature, it can be seen that Although no study on this subject has been found in terms of Türkiye, Ralphs and Mustapha (2023) discussed R&D innovation indicators in terms of South Africa. Similar with our study, they analysed the number of R&D personnel and R&D expenditures in their indicators. Moreover, Bate et al. (2023) focused on measures of innovation such as patent applications, human capital as in our study. Furthermore, for Türkiye's side, Çubuk focused on R&D and innovation capabilities for provisions of Türkiye contrast with our study. To sum up, different studies were examined in general and specific to this study, important indicators were determined and it was aimed to obtain a meaningful and guiding result for Türkiye. Furthermore, as previously mentioned, the GM (1,1) model has several variants, such as EGM or GVM. Therefore, these methods can be implemented if more datasets can be obtained. As a limitation of this study, collecting data on a country basis and being unable to find the appropriate data from the databases has forced the study.

Author Contributions

Melisa Özbiltekin-Pala: Literature Review, Conceptualization, Data Curation, Writing-original draft *Yeşim Deniz Özkan-Özen*: Conceptualization, Methodology, Analysis, Modelling, Writing-review and editing

Conflict of Interest

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Compliance with Ethical Standards

It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

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It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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