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The Role of R&D Expenditures, Information and Communication Technology Products Exports and High-Technology Products Exports on Turkey's Technological Development

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Ar-Ge Harcamalarının, Bilgi ve İletişim Teknolojik Ürün İhracatının ve Yüksek Teknolojili Ürün İhracatının Türkiye'nin Teknolojik Gelişimi Üzerindeki Rolü

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Abstract

In this study, an analysis of technological development in Turkey between 2007 and 2020 was conducted using a Bayesian approach in regression analysis. Within this scope, variables affecting the Gross Domestic Product (GDP), such as Research and Development (R&D) expenditures, Information and Communication Technology (ICT) product exports, and High-Technology Product Exports (HTE), were examined. The parameters of these variables were estimated using data documents compiled from the Organisation for Economic Co-operation and Development (OECD), Global Economic Data (CEICDATA), and the official data site of the World Bank. Both classical and Bayesian methods were employed in the analysis of the obtained data. Multiple linear regression analysis encountered multicollinearity issues. Therefore, the Bayesian regression method, which is not affected by multicollinearity, was preferred over the classical method. Multiple linear Bayesian regression analyses was conducted using the WinBUGS program, and the parameters of our variables were obtained. According to the analysis results, it was determined that R&D expenditures, information and communication technology product exports, and high-technology product exports have a positive and significant relationship with Turkey's technological development.

Keywords: *Regression analysis, Bayesian regression analysis, technological development, Monte Carlo method, WinBUGS programme.*

Makale Bilgileri

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Öz

Çalışmada, regresyon analizine Bayesci bir yaklaşım uygulanarak 2007-2020 yılları arasında Türkiye'deki teknolojik gelişimin analizi yapılmıştır. Bu kapsamda, gayrisafi yurt içi hasılayı etkileyen, Ar-Ge harcamaları, bilgi ve iletişim teknolojik ürün ihracatı ve yüksek teknolojili ürün ihracatı değişkenleri incelenmiştir. Bu değişkenlerin parametrelerini tahmin etmek için gerekli veri dokümanları Ekonomik İş Birliği ve Kalkınma Örgütü (OECD), Küresel Ekonomik Veri (CEICDATA) ve Dünya Bankası resmi veri sitesinden derlenmiştir. Elde edilen bu verilerin analizinde klasik ve Bayesyen yöntem kullanılmıştır. Çoklu doğrusal regresyon analiz sonucunda çoklu doğrusallık sorunu ile karşılaşılmıştır. Bundan dolayı klasik yöntem yerine çoklu doğrusallıktan etkilenmeyen Bayesyen regresyon yöntemi tercih edilmiştir. Çoklu doğrusal Bayesyen regresyon analizi WinBUGS programı yardımıyla analiz edilerek değişkenlerimize ait parametreler elde edilmiştir. Elde edilen analiz sonuçlarına göre Ar-Ge harcamalarının, bilgi ve iletişim teknolojik ürün ihracatının ve yüksek teknolojili ürün ihracatının Türkiye'nin teknolojik gelişimi üzerine pozitif yönlü ve anlamlı bir ilişkisi olduğu tespit edilmiştir.

Anahtar Kelimeler: *Regresyon analizi, Bayesyen regresyon analizi, teknolojik gelişim, Monte Carlo yöntemi, WinBUGS programı.*

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1. Introduction

When we talk about technological development, the first thing that comes to mind is the equipment and tools used. However, it encompasses every aspect of the design and project mechanisms in any field, from the beginning of the concept to the usage stage.

Due to technological advancements, the geographical and political barriers between the countries are removed. Technological innovation made in any country quickly reach other countries, and adaptation to these innovations and the rapid utilization of technology occur in those countries as well. In addition, state policies have begun to take shape and form in line with technological development as directed by technological development (Golgeci et al., 2022). In this way, the trade mobility with developed countries enhances the ability of countries to compete with each other technologically and ensures that the level of development increases exponentially. And so, following the development of technology of high-tech countries, preparing the necessary background, purchasing these technologies, improving these technologies if it is possible, exporting and producing similar products will contribute to the growth of these countries. Thus, countries that can follow technological development progress daily in the light of science renew themselves and continue to develop by increasing the speed of adaptation.

For adaptation to technological development to be successful, many steps must be coordinated together. One of the most crucial steps is producing and exporting technological products with high economic returns. When these products, which have high economic returns, are exported, it is observed that the GDP per capita in that country increases to a certain extent. This situation shows a positive relationship between the exported products and that country's economic growth and development (Sahin, 2019).

Economic development in the states of the world has started to be mentioned with ICT products, considering the speed and scope of the internet in recent years, because countries and companies using science and technology products have realized that productivity has increased (Watanabe et al., 2015). This increase in productivity has led to increased technological products used and exported within the countries. Thus, it has positively contributed to the technological development of those countries. Especially in recent years, the developments in the field of informatics and technology have increased the need for a qualified workforce in the process of integrating technological developments into production tools and in the use of these technological tools, together with the increase in the use of technology and the expansion of the usage area (Doğan, 2022).

Technological developments create the necessary infrastructure for a country’s economic growth. It is possible by supporting the institutions and organizations that will support technological development, following the technological developments that have taken place in the states of the world, and by strengthening the communication network and exchanging information with its stakeholders. Adapting to technological progress and following the technological investments that will be made or planned in science and technology are the most critical factors that accelerate technological development (Dam and Yıldız, 2016).

2. Technological Development

Technological development eliminated historical and geographical disadvantages and made trade easier between countries (Sinha and Sengupta, 2022), and the state policies began to be determined in parallel with technological development (Golgeci et al., 2022). Although the attitude of state administrators is influential among the most significant improvers of quality of life, the level of technological development of countries is determinant (Brewer et al., 2005).

GDP is one of the most critical variables in determining the growth and development level of a country’s economy. In addition, the period when the country’s economy is stationary can also be determined with the help of this variable (Ntantanis and Pohlman, 2020). Since GDP is the monetary

equivalent of the price of services and goods produced in a country in a certain period, it is one of the sources used to determine the economy's mobility.

The relationship between the technological development of the countries and the innovative capabilities of that country is significant, and it is directly related to the R&D studies and the budget allocated for R&D. The reason for this is that the link between technological development and economic growth is meaningful, and the key point of it is the expenditure on R&D, which is applied in real economics (Karakostas, 2022). Besides, R&D investments and expenditures support the technological development of countries and contribute to moving the position of other countries to a further and better point (Algan et al., 2017).

The export of high-technology products is one of the areas where the states gain an advantage in international trade and a competitive environment. In addition, innovation studies are the basis for producing and exporting high-tech products. When innovation and technological development are considered together, these products with high economic returns indicate economic growth. In this way, the fact that technological product exports are high in technologically developed countries is conducive to the growth and revival of the countries' economies (Karakostas, 2022).

Technological development has been changing faster and more comprehensive than in previous years, and new developments have been experienced (Doğan, 2022). This development in the world's states has started to be mentioned together with ICT products if the speed and scope of the internet are considered. The use of science and technology products is an essential factor in the increase in productivity (Watanabe et al., 2015). Regarding technological development and economic growth, the importance of ICT expenditures and the contribution of investments in ICT products to the country's economy are pretty high (Welfens and Perret, 2014).

In the study, multivariate linear regression analysis and multivariate linear Bayesian regression were used to determine the effect of our variables on R&D expenditures, high technology product exports, information, and communication technology exports, which are accepted as the parameters of technological development in Turkey, the relationship between the variables and the direction of the relationship analysis has been used.

3. Purpose of the Study

This study examines the effect of technological development variables on Turkey's GDP. In this way, the country's economic growth will be analyzed in terms of the competitiveness of the world states and the adequacy of the country in terms of innovation. The analysis results are significant in that they contain information that guides the policymakers in the country in making strategic decisions. Because technological development is unthinkable without innovation and R&D studies. R&D is critical for developing new products, technologies, and services. These developments will encourage foreign trade and increase exports. This increase will contribute positively to the increase in the competitiveness of the country and its technological development. Although the variables used in the study are used by many researchers with different methods, the difference in the method we use will contribute to the studies done in this field.

The contribution of R&D, HTE, and ICT variables to Turkey's technological development is significant. Thus, our study aims to test the effect of these variables by using Bayesian regression analysis.

4. Literature Review

To investigate the technological development (Mohamed et al., 2022) and economic growth (Jahanger et al., 2022) of the countries, from the technological development parameters, R&D expenditures (Güneş, 2019; Özcan and Özer, 2017; Inekwe, 2015; Algan et al., 2017; Uskov, 2020;

Zhang and Yang, 2022) export of high tech products (Şeker, 2018; Şeker, 2019; Kozlova and Didenko, 2022) information and the effects of communication technology export (Tunalı and Güz, 2021; Miller and Miller, 2021) were examined in their studies. In some studies, the classical method and Bayesian method were used to investigate the relationship between dependent variable and independent variables (Taufiq et al., 2019; Zhang and Yang, 2015; Papananiasa et al., 2019; Kaya, 2019; Doğan, 2017; Foley, 2018; Temiz, 2017). In addition, in some of the studies, the classical approach and the Bayesian approach were compared (Yardımcı, 2000; Gündoğdu, 2016; Özbay, 2017; Yurtçu, 2018; Çiftci and Genç, 2020).

As far as we know, in the studies in the literature, no study has been found that examines the effects of technological development indicators on the gross domestic product with our methods. The most crucial difference between the study and the existing literature is the variables and method used. Some studies in the related literature are as follows.

4.1. Studies On R&D

In Inekwe's (2015) study, we examined 66 countries with low, middle, and high levels of economic development between 2000 and 2009. In this study, while the effect of R&D expenditures on economic growth was significant in countries with medium and high levels of economic development, this effect was insignificant in countries with low levels of development. The research analyzed the lowest square GMM and dynamic system GMM model using the pooled mean group method.

In the study of Algan et al. (2017), to investigate the effect of developing technological innovations and science on Turkey's economic growth between 1996 and 2015, the number of patent applications, R&D expenditures, and GDP variables were analyzed using the Granger Causality test, and the differences between the variables were analyzed, and the relationships between variables were determined.

In the study of Özcan and Özer (2017), the effect of R&D expenditures and number of patents on economic growth between 1995 and 2013 was analyzed using data from 23 OECD countries and the panel data method. In this analysis, it has been concluded that R&D expenditures and the number of patent applications have a meaningless effect on economic growth in the short term. Still, it has been concluded that this effect will be meaningful in the long term.

In the study of Güneş (2019), the effect of R&D expenditures on the economic growth of 32 OECD countries between 2000 and 2014 was analyzed using panel data. In addition, unit root and Granger Causality tests were performed in the analysis. Although the analysis shows a positive relationship between economic growth and R&D expenditures, no causality relationship has been found.

In the study of Uskov (2020), to analyze the economic situation of Russia from a scientific and technological point of view, the GDP ratio and scientific and technical developments, R&D funds, industrial and technological investments, and economic decisions were examined comparatively, together with the developing technology. In addition, the relationship between the economic development of developed countries and developing technology was examined, and comparisons were made. This study used comparative dialectical logic, empirical experience, and theory-based analysis.

4.2. Studies On HTE

In the study of Şeker (2018), to examine the effects of Turkey's technological development, exported high-tech products, the number of patents, and the industrial production index on technological transfer and foreign investments between 2010 and 2015, the data belonging to the variables obtained from 11 OECD member countries were analyzed with the panel data method.

In the study of Şeker (2019), the variables of domestic patent numbers, capital investments, and exports of high-tech products were used to measure the change in Turkey's economic complexity index between 1989 and 2017. Relationships between variables were analyzed with Gregory-Hansen and Johansen cointegration tests. As a result of this analysis, it is predicted that investments will be made in Turkey in developing technological innovations. High-tech products that can be exported will increase the economic complexity index.

In the study, using panel data analysis, Oğuz and Gökhan, (2020) examined the effect of R&D expenditures on the export of high-tech products in OECD countries between 1996 and 2016. As a result of the analysis, it has been tested that R&D expenditures significantly affect the export of high-tech products. Besides, they expressed their opinion that more investments should be made in R&D expenditures to increase the positive effect.

The study of Kozlova and Didenko, (2022) examined how the quality of life of people in the G7 and E7 countries was affected by the advancing technology. When comparing these countries, the human development index, Gini index, international poverty line, consumer price index, number of patent applications, technical cooperation grants, number of technicians working in R&D, and number of high technology exports were used as variables. The analysis used the Dickey-Fuller, Student t, Ljung-Box Q tests, and the least squares method. The study concluded that technological development's effect on the quality of life can be used in social development strategies.

4.3. Studies On ICT

In Miller and Miller (2021) study, the integration of the Russian economy into these innovations was examined in the face of developing scientific and technological innovations. An organizational model that equips technological integration with new technological developments and transforms it globally is proposed. Various statistical methods were used to analyze and synthesize the relationship between the variables and the structural-functional method, as well as to determine the trends and properties of the variables.

In the study of Tunalı and Güz (2021), in the panel data analysis using data from 79 countries between 2010 and 2016, the effect of the information and communication technologies index on economic growth was investigated through five different models. As a result of the analysis, it has been determined that there is a positive relationship between economic growth and the ICT development index.

Çütcü and Akkur (2022) in their study, conducted the Lee- Strazicich unit root test, the Hatemi-J Cointegration test, and Hacker and Hatemi-J Causality analysis to analyze the relationship between the knowledge economy and foreign trade balance between 1984 and 2019. As a result of the analysis, a significant long-term relationship was determined between Turkey's economic growth and the knowledge economy.

4.4. Studies On Bayesian

In the study of Uzun (2020), how to apply Bayesian hypothesis tests to population ratio, population mean, and difference of two populations was examined in detail, and the results obtained with the help of Matlab, R, and SPSS programs were compared by supporting this study with examples. Claims were tested using Bayesian and classical hypothesis methods on accurate data. As a result of the analysis, it was concluded that the Bayesian method is an alternative method that can be used instead of the classical method.

In Koç (2020) study, estimations were obtained on accurate data, using the classical and Bayesian methods to test which approach best predicts the parameters of the Weibull distribution. The best result for all samples was obtained through the Bayesian approach using MCMC.

In Erkan's (2019) study, the variable of causal relationships was compared with Bayesian estimation and the maximum likelihood method using structural equation models. It was emphasized that choosing an approach by researchers is practical in complex, multilevel, nonlinear, serial categorical, semi-parametric, and lost data that the classical approach cannot be used. The comparison to accurate data in the study showed that the Bayesian approach gives better results than the classical approach.

In the study of Zerey (2018) on the closing prices of stocks in the BİST 30 index, the prices were compared by calculating the risk and return values using the classical and Bayesian approaches. Suggestions were made regarding which stocks should be preferred.

In his study, Foley (2018) estimated US GDP growth using the Bayesian approach to linear regression using Matlab and R program. Since the estimated range is wide, when other models that can be used are investigated, it was concluded that applying Bayesian regression to the R model would be more appropriate.

5. Data, Model Specification, And Methodology

5.1. Bayesian Approach

The Bayesian approach begins with the experiment that Bayes mentioned in the problem of the Doctrine of chance. The Bayes Theorem, named after him, was put forward by the 18th-century mathematician priest Thomas Bayes. In the Bayesian approach, trying to reach the causes by reasoning from the available data is the most immense contribution to this problem. Here, mathematical notation and terminology can easily explain the order of events and the concepts used (Bernardo and Smith, 2000).

With the Bayesian method, the estimation of complex models and nested hierarchical models, which are difficult to adapt to the classical model, can be made comprehensively (Congdon, 2006). In addition, the applicability of Bayesian models has increased thanks to the improvement in computer algorithms by doing finite sample extraction in small sample groups, incomplete or incorrectly measured data, and unobserved data (Dubois and Prade, 1988). It has been proven to give a reasonable estimation of parameters (Richardson and Best, 2003).

5.2. Determination Of Pre-Distribution

The most important distinguishing feature between the classical and Bayesian methods is the use of a priori distribution. While it is questioned by the classical approach whether apriori represents our data, it should be questioned whether the non-usage of apriori affects the study. Here, the Bayesian approach’s ability to combine data with past experiences in a logical framework and contain information on updating our parameter belief is essential (Mccarthy, 2007).

The non-informative pre-distribution is a distribution used when there is no prior knowledge about the parameter. Its use is quite common as it allows Bayesian conclusions in estimating parameters for which we haven’t got any information (Gelman and Hill, 2007). Informative pre-distribution means that we have a degree of belief about the parameter. It includes choosing an appropriate prior distribution family for each model and finding parameter values that will reflect the available data well (King et al., 2010). In applying the Bayesian approach, there should be harmony between the maximum likelihood function, prior knowledge distribution, and final information distribution, as in Table 2.1 (Karadağ, 2011).

Table 1. Conjugate Families

Likelihood functions	Preliminary information distribution	Latest information distribution
Binom	Beta	Beta
Uniform	Pareto	Pareto
Normal ($\sigma^2$is known)	Normal	Normal
Normal (μ is known)	Reverse Gamma	Reverse Gamma
Poisson	Gamma	Gamma
Exponential	Gamma	Gamma
Gama	Gamma	Gamma
Bernoulli	Beta	Beta
Normal	Normal-Gamma	Normal- Gamma

Source: Karadağ (2011).

5.3. Bayesian Regression Analysis

The method in the Bayesian approach, in which the researcher's degree of belief about the situation, which is the research subject, is evaluated as a priori knowledge, is different from the classical approach. The posterior distribution is obtained by combining a priori information with the available data. In the Bayesian approach, we aim to obtain the posterior distribution of the parameter. The a priori distribution, which doesn't provide information, obtains the posterior distribution when prior information is unavailable. When the a priori distribution that does not give information is used, the result is similar to the results obtained from the classical approach and gives approximate results. The informative prior distribution will be used if we know the observation data before obtaining the observation values. It is a narrower interval than the confidence interval of the posterior distribution parameters obtained using the informative prior distribution and gives more reliable results about the parameter (Judge et al., 1986).

To obtain the posterior distribution using the Bayesian Approach;

While θ parameter is a random variable and parameter θ is certain, the similarity function is $f(y|\theta)$.

The density function of θ^{th} random variable is written as,

$$h(\theta, y) = f(y|\theta).g(\theta) = g(\theta|y).f(y) \quad (1)$$

(1) equation is designed as

$$g(\theta|y) = \frac{f(y|\theta).g(\theta)}{f(y)} \quad (2)$$

And Bayesian theorem is obtained. Here $g(\theta|y)$, defines posterior distribution for θ parameter. $f(y|\theta)$ similarity function is mathematically the same as the likelihood $\ell(\theta|y)$ for θ. And it is as

$$\ell(\theta|y) = f(\theta|y) = \prod_{i=1}^{n} f(y_i|\theta) \quad (3)$$

From here

$$g(\theta|y) = \frac{f(y|\theta).g(\theta)}{f(y)} = \frac{f(y|\theta).g(\theta)}{\int f(y|\theta).g(\theta)d\theta} \quad (4)$$

$f(y) = \int f(y|\theta).g(\theta)d\theta$ is the normalization constant for the Bayesian approach and is equal to 1 (Judge et al., 1986). If necessary, adjustments are made again without writing this constant and equation (3) is written into the place of equation (4) the expression.

$$g(\theta|y) \propto f(y|\theta).g(\theta)$$

$$g(\theta|y) \propto \ell(\theta|y).g(\theta) \quad (5)$$

Here, the symbol $'\propto'$ indicates that it is proportional symbol (Greenberg, 2008). The expression given (5) is verbally called as

$$posterior\ distribution \propto likelihood\ function\ x\ prior\ distribution$$

Here, $e \sim N(0,\delta^2 I)$, has a normal distribution with error mean of zero and radial of δ^2, and if the equation (5) is adopted to the linear model $y = x\beta + e$

$$g(\beta,\sigma|y) \propto \ell(\beta,\sigma|y).g(\beta,\sigma) \quad (6)$$

$$\ell(\beta,\sigma|y) = (2\pi\sigma^2)^{-T/2}\exp[-\frac{(y-x\beta)^{\iota}(y-x\beta)}{2\sigma^2}]$$

$$= (2\pi)^{-T/2}\sigma^{-T}\exp[-\frac{(y-x\beta)^{\iota}(y-x\beta)}{2\sigma^2}] \quad (7)$$

In this equality

$$b = (x^{\iota}x)^{-1}x^{\iota}y \ , \quad \hat{\sigma}^2 = -\frac{(y-xb)^{\iota}(y-xb)}{v} \ , \quad v = T-K$$

İf we substitute values in equation (7) and do not write the normalization constant

$$\ell(\beta,\sigma|y) = \sigma^{-T}\exp\{-\frac{1}{2\sigma^2}[\ v\hat{\sigma}^2 + (\beta-b)^{\iota}x^{\iota}x(\beta-b)\ ]\} \quad (8)$$

This obtained likelihood function is used to obtain the posterior distribution for informative and non-informative a priori distributions (Judge et al., 1986).

5.3.1. Obtaining Non-Informative A Priori And Posterior Distributions

For a priori that does not give information for parameters $\beta\ and\ \sigma$, the proportional expression of

$$g(\beta,\sigma|y) \propto \delta^{-1} \quad (9)$$

is used. Under the assumption that β,σ parameters are independent, it can be written as

$$g(\beta,\sigma) = g(\beta)g(\sigma) \propto \delta^{-1} \quad (10)$$

Here $-\infty < \beta < \infty$ and $0 < \sigma < \infty$ and if $g(\beta)$ is considered constant, $g(\sigma) \propto \sigma^{-1}$ (Judge et al., 1986).

Here,

As

$$\int_{-\infty}^{\infty} g(\ \beta)d\beta = \infty \ , \quad \int_0^{\infty} g(\ \sigma)d\sigma = \infty$$

The likelihood function given by equation (8), does not given information given by equation (9) is substituted in the posterior dustribution that is given with equation (6) and necessary arrangements are made posterior distribution is obtained as

$$g(\beta,\sigma|y) \propto \ell(\beta,\sigma|y).g(\beta,\sigma)$$

$$\propto \sigma^{-(T+1)}\exp\{-\frac{1}{2\sigma^2}[\ v\hat{\sigma}^2 + (\beta-b)^{\iota}x^{\iota}x(\beta-b)\ ]\} \quad (11)$$

This obtained posterior density function summarizes all our knowledge about posteriority, but when we consider various marginal and posterior densities and if we rearrange (11) we get

$$g(\beta,\sigma|y) = g(\beta|\sigma,y).g(\sigma|y) \quad (12)$$

$$g(\beta|\sigma,y) = (2\pi)^{-K/2}\sigma^{-K}|x^{\iota}x|^{1/2}\exp\{-\frac{1}{2\sigma^2}[\ (\beta-b)^{\iota}x^{\iota}x(\beta-b)\ ]\} \quad (13)$$

and

$$g(\sigma|y) = \frac{2}{\Gamma\left(\frac{v}{2}\right)}\left(\frac{v\hat{\sigma}^2}{2}\right)^{v/2}\frac{1}{\sigma^{v+1}}\exp\left(-\frac{v\hat{\sigma}^2}{2\sigma^2}\right) \quad (14)$$

The marginal posterior density function σ given by equation (14) is an inverted gamma distribution through the parameters v and $\hat{\sigma}^2$. Since σ is unknown, if the equation (13) is rearrenged according to parameter β and integrated to parameter σ.

$$\begin{aligned} g(\beta\,|y) = & \int_0^\infty \mathrm{g}(\beta,\sigma\,|y)\;d\sigma \\ = & \int_0^\infty \mathrm{g}(\beta|\sigma,y).\,g(\sigma|y)\,d\sigma \\ \propto & \int_0^\infty \sigma^{-(T+1)}\exp\{-\frac{1}{2\sigma^2}[\,v\hat{\sigma}^2+(\beta-b)^{\iota}x^{\iota}x(\beta-b)\,]\}\,d\sigma \\ \propto & \left[1+\frac{1}{v}(\beta-b)^{|}\frac{x^{|}x}{\hat{\sigma}^2}\,(\beta-b)\right]^{-(K+v)/2} \end{aligned} \quad (15)$$

is obtained. If it is desired to obtain posterior information over a single parameter

for β_1,

$$g(\beta_1|y) \propto \left[1+\frac{1}{v}\left(\frac{\beta_1-b_1}{\hat{\delta}\sqrt{a_{11}}}\right)\right]^{-(1+v)/2} \quad (16)$$

İt is a univariate 't' distribution whose average mean is b_1 and variance $[\frac{v}{v-2}]\,\hat{\delta}^2 a_{11}$. Also b_1 is the first element in b and a_{11} is the first diagonal element of th $(x^{|}x)^{-1}$ matrix.

for σ,

$$\begin{aligned} g(\sigma|y) = & \int_0^\infty \mathrm{g}(\beta,\sigma\,|y)\;d\beta \\ \propto & \frac{1}{\sigma^{v+1}}\exp(-\frac{vs^2}{2\sigma^2}) \end{aligned} \quad (17)$$

can be obtained (Judge et al., 1986).

5.3.2. Obtaining The Posterior Distribution with The Informative A Priori Distribution

We can include a priori information in our analysis thanks to Bayesian analysis. We need a conjugate distribution when doing this merge. In this way, a mathematically compatible natural conjugate function that will represent our prior knowledge should be determined. When this function is a prior distribution that can easily combine with the likelihood function, the results obtained in the posterior distribution are similar to the prior distribution.

Since the likelihood function given in (8) is a function of the parameters $\beta\ and\ \sigma$, the natural conjugate function is a gamma function.

$$\ell(\beta,\sigma|\mathrm{y}) \propto h_1(\beta|\sigma,\mathrm{y})h_2(\sigma|\mathrm{y}) \quad (18)$$

$$h_1(\beta|\sigma,\mathrm{y})=\exp\{-\frac{1}{2\sigma^2}[\,(\beta-b)^{\iota}x^{\iota}x(\beta-b)\,]\} \quad (19)$$

$$h_2(\sigma|\mathrm{y}) = \sigma^{-T}\exp(\frac{v\hat{\sigma}^2}{2\sigma^2}) \quad (20)$$

and, a priori information for ($\beta^{|},\sigma$)

$$\begin{aligned} g(\beta,|\sigma) &= (2\pi\sigma^2)^{-K/2}|A|^{1/2}\exp\{-\frac{1}{2\sigma^2}[\,(\beta-b)^{\iota}x^{\iota}x(\beta-b)\,]\} \\ &= (2\pi)^{-K/2}\sigma^{-T}|A|^{1/2}\exp\{-\frac{1}{2\sigma^2}[\,(\beta-b)^{\iota}x^{\iota}x(\beta-b)]\} \end{aligned} \quad (21)$$

and

$$g(\sigma) = \frac{2}{\Gamma\left(\frac{\bar{\nu}}{2}\right)}\left(\frac{\bar{\nu}\bar{s}^2}{2}\right)^{\bar{\nu}/2} \quad (22)$$

Combining (21) and (22), and subtracting normalization constant,

$$g(\beta,\sigma) \propto \ \sigma^{-K-\bar{\nu}-1}\exp\{-\frac{1}{2\sigma^2}[\ \bar{\nu}\bar{s}^2 + \left(\beta-\bar{\beta}\right)^{|}A(\beta-\bar{\beta})\ ]\} \quad (23)$$

Normal gamma a priori density isobtained. If this equation is integrated to σ

$$g(\beta) \propto [1+\frac{1}{\bar{\nu}}\left(\beta-\bar{\beta}\right)^{|}\frac{A}{\bar{s}^2}\ (\beta-\bar{\beta})]^{-(K+\bar{\nu})/2} \quad (24)$$

The a prior density for β is obtained. Substituting the natural conjugate of (23) with the probability function (7) in the equation (6)

$$g(\beta,\sigma|y) \ \propto \ \ \sigma^{-T-K-\bar{\nu}-1}\exp\{-\frac{1}{2\sigma^2}[\ \bar{\nu}\bar{s}^2 + \left(\beta-\bar{\beta}\right)^{|}A(\beta-\bar{\beta})]\} \quad (25)$$

posterior density function is obtained (Koehrsen, 2018).

5.4. Monte Carlo Simulation Method (MC)

Our study used the MCMC method based on Bayesian theory and the WinBUGS program to make statistical inferences. This program provides the derivation of the data drawn from the final probability distribution with the Monte Carlo Simulation Method. Thus, the final probability distribution can be obtained precisely or approximately (Ekici, 2005). Monte Carlo Markov Chains (MCMC), which allows us to find samples independent of each other from the posterior distribution; as the sample size goes towards infinity, our expected value according to the law of large numbers either gets very close to its actual value or its real value is obtained (Hahn, 2014).

The Monte Carlo method is a computational algorithm to optimize numerical integration or probability distribution. It is a powerful tool for simulating the behavior of analytically complex situations to model or solve. Sometimes, it is also applied to situations that have analytical solutions. It is preferred over analytical solutions because the MC method has an advanced computer infrastructure that allows us to easily calculate results closer to the analytical solution by adjusting the working time on the computer as we want. As the number of parameters increases, reaching an analytical solution becomes difficult and sometimes impossible (Hahn, 2014). It was observed that the values obtained with the Monte Carlo simulation were close to absolute data values, worked very fast in programming, and better results were obtained even in simple Monte Carlo models (Hahn, 2014).

WinBUGS, a program that can be practically calculated in Bayesian regression analysis, provides the opportunity to work with other programs even though it is an independent program and can work in an integrated manner with the R program. In addition, WinBUGS is widely used because it is an effective software for detecting the uncertainty of model parameters in estimations and removing this uncertainty (Mccarthy, 2007).

6. Results

6.1. Empirical Model

In our study, the Bayesian method has been used to estimate the parameters of the technological development in Turkey and to examine and predict the change of our dependent variable, GDP, according to our independent variables, R&D expenditures, exports of high-tech products, exports of information, and communication technology. In this context, our model is

$$GDP=\beta_1 + \beta_2 * RD + \beta_3 * HTE + \ \beta_4 * ICT + \varepsilon_i \quad (26)$$

6.2. Empirical Results

6.2.1. Analysis of The Model with Multiple Linear Regression

To test the explanatory effect of the independent variables R&D, HTE and ICT on the GDP dependent variable, the analysis was performed with the help of the SPSS22 program.

Table 2. *Correlation Table*

	GDP	R&D	HTE	ICT
Pearson Correlation GDP	1.000	0.987	0.934	-0.262
R&D	0.987	1.000	0.888	-0.380
HTE	0.934	0.888	1.000	0.008
ICT	-0.262	-0.380	0.008	1.000
Sig. (1-tailed) GDP	.	0.000	0.000	0.182
R&D	0.000	.	0.000	0.090
HTE	0.000	0.000	.	0.489
ICT	0.182	0.090	0.489	.

Source: Created by the author using data from OECD, CEICDATA and World Bank (2023).

Table 2 shows that the correlation coefficient between independent variables is more remarkable than r>.80. This means a multicollinearity connection between the variables. Therefore, this high relation between independent variables causes the coefficient of determination to be significant. In this case, some of the independent variables are affected by each other. The effect of dependent variables on the dependent variable decreases, and this effect cannot be determined precisely.

Table 3. *Parameter Test Result Table*

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-Order	Partial	Part	Tolerance	VIF
1(Constant)	4.902	0.863		5.679	0.000	2.978	6.825					
R&D	0.521	0.076	0.856	6.835	0.000	0.351	0.691	0.987	0.908	0.212	0.061	16.326
HTE	0.099	0.066	0.174	1.500	0.165	-0.048	0.246	0.934	0.429	0.046	0.072	13.974
ICT	0.079	0.074	0.061	1.061	0.314	-0.087	0.244	-0.262	0.318	0.033	0.291	3.441

a. Dependent Variable: GDP
Source: Created by the author using data from OECD, CEICDATA and World Bank (2023).

Table 3 shows that the VIF values of our variables R&D and HTE are more significant than five. This means that there is multiple linear dependence between the variables. In cases of multicollinearity, independent variables will be insufficient to explain the dependent variables. For this, some variables should be sought for the multicollinearity problem. As a result, regression analysis can interpret the study with this model as meaningless.

6.2.2. Analysis of The Model with Multiple Linear Bayesian Regression

In order to test the explanatory effect of the independent variables R&D, IIT and ICT on the dependent variable of GDP, the posterior distribution parameters were obtained by taking the logarithm of Turkey's data with the help of the WinBUGS program.

The uncertainty of what results we will encounter before the model analysis points to the importance of the priors to be selected. Markov gradually produces samples from the posterior distribution of the distribution parameters after a selected combustion process in his chains. Since the first 1000-5000 chain burns are usually sufficient in multiple linear regression models (Hahn, 2014), a born with the first 1000 iterations is allowed in our study. Thus, Markov chains plotted the trace graphics after the 1001st step, and in this way, posterior distribution parameters were obtained. When determining the number of iterations, a sufficient number of Markov chains should be allowed, considering the deviation from the initial values of the chain and the MC error. It was noted that the MC error was less than 0.5 (Hahn, 2014). The Monte Carlo method used in our analysis is beneficial due to its basic features, such as working very fast with the WinBUGS program, approximating the numerical data we obtained based on simulation to the actual value, and application to small and simple models.

6.2.2.1. A Priori Distribution

To obtain Turkey's a priori distribution, the definite preliminary distribution normal distribution was chosen for the Turkey model since the data of Turkey show a normal distribution. The parameters of the uncertain preliminary distribution were ensured to be identical to the uncertainty by taking the average of the parameters of Turkey's a priori distribution as 0 and the precision as 0.001 (Ekici, 2005). This selection referenced previous studies and books on this subject (Hahn, 2014). Since the program works with precision, precision was preferred instead of variance, and gamma distribution was used for precision. Here b [j]'s are the uncertain a priori distribution with a mean of and a precision of 0.001, and the precision is a gamma distribution with a parameter value of 0.001, and it is shown as

b[j] ~ dnorm(0, 0.001)

tau ~ dgamma(0.001, 0.001)

6.2.2.2. Posterior Distribution

In order to obtain the posterior distribution, the uncertain preliminary distribution values selected as the preliminary distribution of the Turkey data and the data for Turkey were with the help of our model (26) and WinBUGS programs and necessary operations are performed, the posterior distribution data of the Turkey model is obtained. These data were given through tables and graphics, and conclusions were drawn.

Table 4. *Complementary Statistic Table*

node	Mean	sd	MC error	2.5%	median	97.5%	start	sample
b[1]	4.817	4.194	0.00347	-3.554	4.82	13.16	1001	1499000
b[2]	0.5277	0.3715	3.058E-4	-0.2113	0.5272	1.27	1001	1499000
b[3]	0.09382	0.3229	2.632E-4	-0.551	0.09421	0.7353	1001	1499000
b[4]	0.08584	0.361	2.972E-4	-0.6328	0.08591	0.807	1001	1499000
tau	476.2	211.8	0.2215	155.7	445.0	972.5	1001	1499000

Source: Created by the author using data from OECD, CEICDATA and World Bank (2023).

Considering the MC error in the Descriptive analysis table of the posterior distribution of Turkey, the significance levels of our independent variables are less than 0.05, and it can be interpreted that the independent variables explain the dependent variable. At the same time, the signs of the coefficients of the independent variables are positive, as expected, and it can be concluded that the independent variables affect the dependent variable positively, so the effect of technological development is positive.

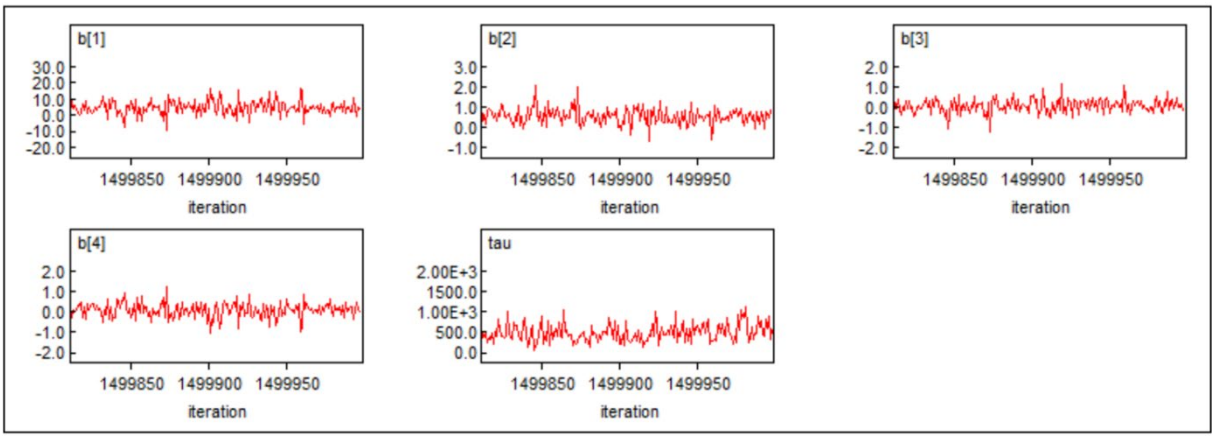

Figure 1. Trace Plot

The Markov chain displays 200 iterations at a specific interval. When the trace drawing created by these chains is examined in Figure 1, we can interpret that the search speed of the Turkey model is relatively high while approaching the posterior distribution by looking at the oscillating movements. When Figure 1 is scrutinized, we conclude that the trace plot searches our model's posterior distribution with the desired search speed level.

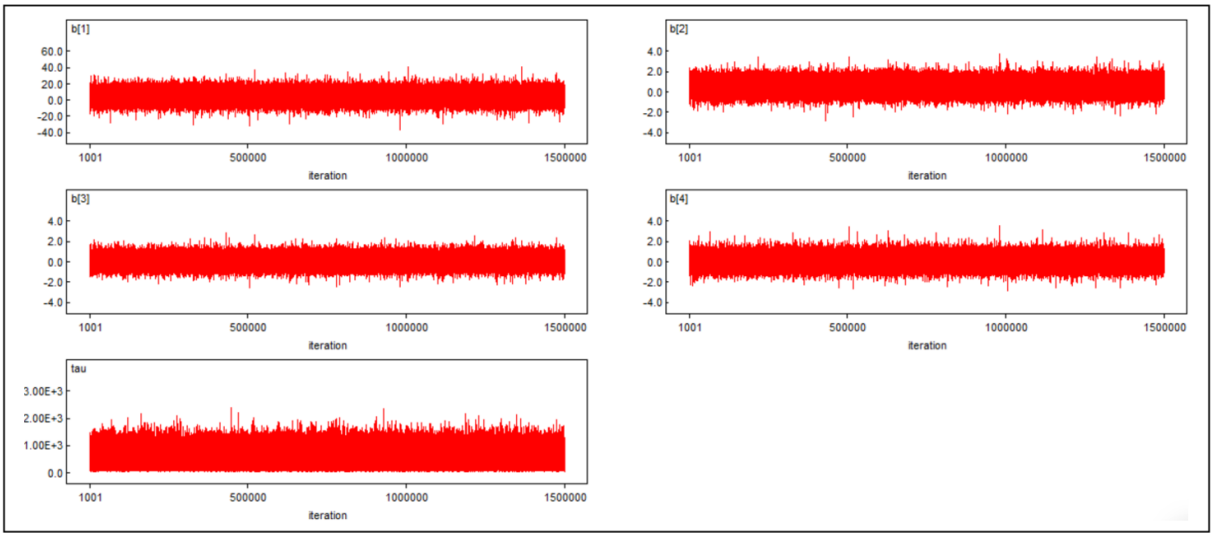

Figure 2. Multi Chain Tracking Motion Graph; 1001-1500000

We can observe from Figure 2 that the posterior distribution produces values around the point where it converges consistently along the chain and that all chains are well-mixed. For instance, we can interpret that parameter b[1] produces values close to 4.817 in the range (-3.554, 13.16). It is observed from Figure 2 that the other parameters produce values around the mean posterior value of the parameter in the same way.

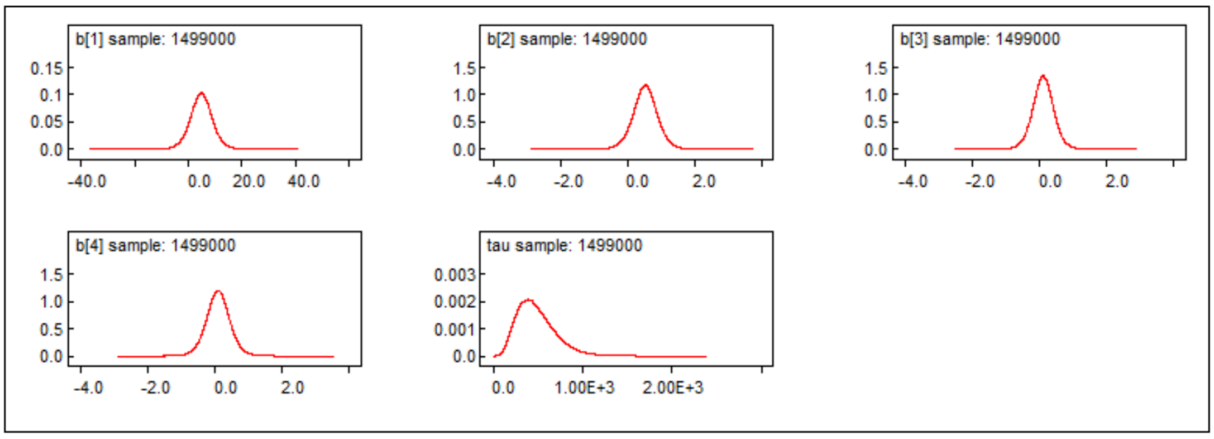

Figure 3. Kernel Density Plot

The densities of the parameters, the precision, and the Kernel density plots are as in Figure 3; here, it is observed that the parameters are normally distributed, and the precision is skewed.

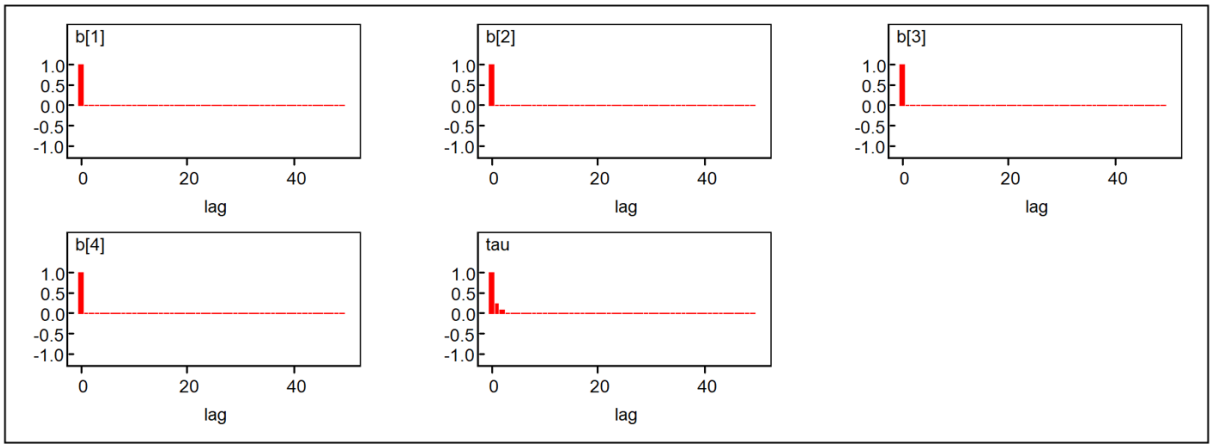

Figure 4. Autocorrelation Plot

Looking at Figure 4, it is observed that the autocorrelation is zero for all parameters and is in the ideal situation. This gives us the idea that the autocorrelation is zero in the transitions from one iteration to another during the performance of Markov chains, and the chains are derived independently. Thus, it has been observed from this drawing that there is no dependence between the simulation values. The fact that the chains are independent allows us to obtain the maximum possible information about the parameters we want about the posterior distributions.

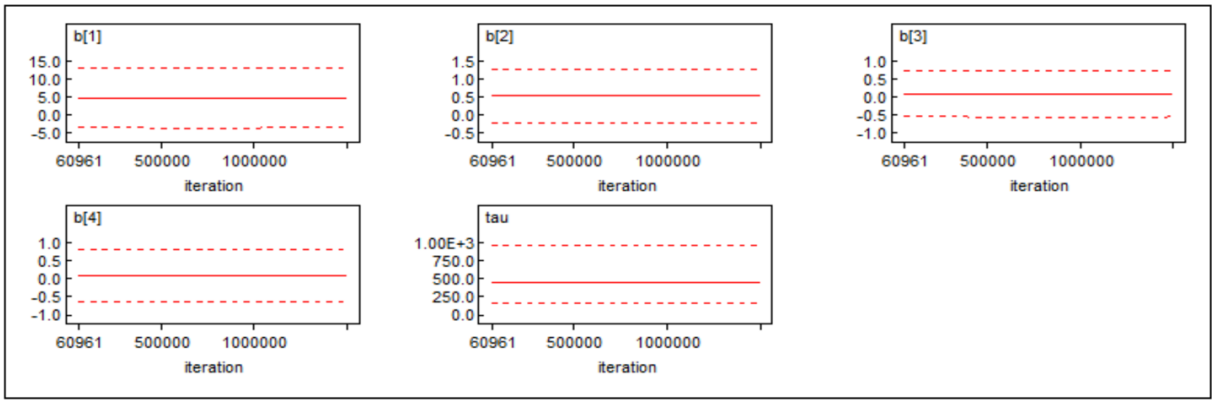

Figure 5. Working Quantities Graph

Figure 5 shows that the parameter values and precision were generally constant throughout the study, within the 95% confidence interval. For example, parameter b[1] produced constant values along the value of 4.817 and converged to a particular value.

6.3. Model Control

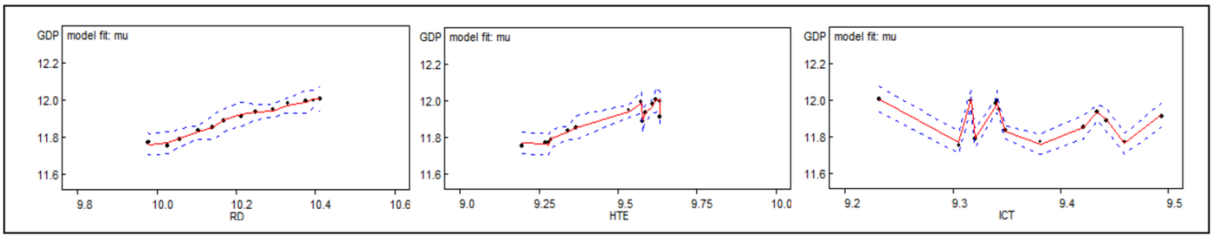

Figure 6. Model Control

We control our model with the help of the WinBUGS comparison menu. The points on the graph represent our dependent variable, dotted lines represent the independent variable's %2.5 and %9.5 quantile range, and straight lines represent the %50 quantile value (Hahn, 2014). It is observed that the independent and dependent variables take values close to each other; that is, they are consistent. In Figure 6, all values fall between the quantile range of %2.5 and %97.5, and the %50 values are very close to the quantile value. This shows that the independent variables in our model are sufficient to explain the dependent variable.

7. Conclusion and Discussion

R&D's expenditures in Turkey significantly impact information and communication technology exports, high technology exports, technological and economic growth, and development. In this context, the model coefficients in our study using Bayesian regression analysis were positive. In addition to the positive model signs, when other variables are kept constant, for a one-unit increase in GDP, R&D shows an increase of 0.5277 units, HTE shows an increase of 0.09382 units, and ICT shows an increase of 0.08584 units. This increase means that R&D, ICT and HTE, technological development indicators, significantly and positively affect GDP. In addition, in the model control, it is observed that the independent variables are at a sufficient level to explain the dependent variable.

In the study, Bayes optimization, which has a powerful strategy to examine and solve large and complex data systems where traditional optimization methods are ineffective, was used to examine the probability distributions of our variables (Ekici, 2005; Doğan, 2017).

In this study, it was found that the Bayesian approach became more useful with the combination of a well-chosen a priori knowledge and advanced computer infrastructure, similar to the studies of (Scheines et al., 1999; Song and Lee, 2004; Kruschke et al., 2012; Zhang and Yang, 2015; Gündoğdu, 2016; Temiz, 2017; Foley, 2018; Yurtçu, 2018).

The Bayesian approach is a method that continues to improve its estimation as new data comes in after the first estimation data is generated, constantly renewing itself and strengthening its estimations. Although this method looks at the world intuitively, its developing infrastructure and the tried and tested method used in it have made it possible for this approach to find a wide area of use. The Bayesian approach can work without prior knowledge, and a value close to the results obtained with other methods is obtained. However, studies have observed that the value range obtained with a well-chosen a priori is closer to the expected range (Kruschke et al., 2012). In future studies, research can be done to compare more methods and find the most suitable one.

In the classical method, there was a high correlation between the independent variables, and it was observed that there was a multi-linear dependence between the variables. In this case, solving

our model with the classical method of analysis is statistically meaningless; therefore, it has been observed that the Bayesian approach provides the desired conditions for our model. In addition, posterior distributions were obtained despite the small data and multiple linear dependences. This shows that the Bayesian approach can be applied to models that cannot be solved with the classical approach.

As a result, Bayesian regression analysis found that the independent variables contributed to Turkey's technological development. Furthermore, similarly, the importance of these variables that contribute a positive impact on economic and technological development was emphasized in many studies (Algan et al., 2017; Petralia et al., 2017; Özcan and Özer, 2017; Güneş, 2019; Şeker, 2019; Mehmood et al., 2022; Mora-Apablaza and Navarrete, 2022).

7.1. Argument

Many factors, such as the readiness of the country's infrastructure for technological development, the budget allocated to research and development, the investment made, the attitudes of the country managers, and underground riches, are practical. Countries should prepare the infrastructure needed to produce the products developed by closely following the technological developments and transfer the technological developments they regard as necessary to their own countries.

When the data obtained from the official websites of the Organisation for Economic Co-operation and Development (OECD), Global Economic Data (CEICDATA), and the World Bank between 2007 and 2020 are examined, it is observed that the GDP increased from 590.33 billion dollars to 1.020 trillion dollars, R&D increased from 34.397 thousand dollars to 80.819 thousand dollars, and HTE increased from 1.860 billion dollars to 4.170 billion dollars. In this study, it has been confirmed by the analysis that the increase in these variables, which directly affect technological development, contributes to the positive increase in technological development in Turkey. From this point of view, ensuring the continuity of the positive increase in these variables is very important. Investments and expenditures should be made a state tradition and supported and accepted by everyone.

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