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RESEARCH ARTICLE

Investigation of Expected Inflation According to Adaptive Expectations Hypothesis Using Koyck Transformation: A Study on Türkiye

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Abstract

Inflation expectations have been researched theoretically and practically for more than a century and continue to be a favorite research topic for economists even today. The validity of the Rational Expectations Hypothesis has not yet been proven by empirical research, and many studies show that it is invalid. This situation drew attention again to the validity of the Adaptive Expectations Hypothesis. In this study, inflation expectations for Türkiye in the 2013m6-2023m7 period, under the assumption of the Adaptive Expectations Hypothesis, were tested first by applying the Nerlove (1958) model and secondly by applying the Koyck transformation within the framework of the Friedman-Cagan model. As a result of the study, although evidence was found that the Adaptive Expectations Hypothesis is valid in Türkiye according to the Nerlove (1958) model, it was observed that there was a weak relationship between actual inflation and expected inflation. The second model was applied to avoid hesitation in accepting the hypothesis. With the Koyck transform model, it has been determined that individuals in Türkiye learn from past inflation values in forming inflation expectations. The speed of this learning is 77%. It was concluded that individuals form their inflation expectations by using 77% of current and past inflation data. The intended history includes the current period, the first and second lags. In terms of expectations, the effect of the third lag is zero.

Keywords: *Inflation, Expected Inflation, Adaptive Expectations, Koyck Transformation Model.*
Jel Codes: *E30, E31, E37*

Uyarlanabilir Beklentiler Hipotezine Göre Beklenen Enflasyonun Koyck Dönüşümü Kullanılarak İncelenmesi: Türkiye Üzerinde Bir Çalışma

Özet

Enflasyon beklentileri yüzyılı aşkın süredir teorik ve uygulamalı olarak araştırılmakta ve günümüzde dahi iktisatçıların gözde araştırma konusu olmaya devam etmektedir. Rasyonel Beklentiler Hipotezinin günümüzde geçerliliği ampirik araştırmalarla kesin kanıtlara ulaşmamıştır ve geçerli olmadığına dair birçok çalışma da bulunmaktadır. Bu durum dikkatleri tekrar Adaptif Beklentiler Hipotezinin geçerliliğine çekmiştir. Bu çalışmada Türkiye için 2013m6-2023m7 döneminde Adaptif Beklentiler Hipotezi varsayımı altında enflasyon beklentileri ilk olarak Nerlove (1958) modeli ve ikinci olarak Friedman-Cagan modeli çerçevesinde Koyck dönüşümü uygulanarak test edilmiştir. Çalışma sonucunda Nerlove (1958) modeline göre Türkiye'de Adaptif Beklentiler Hipotezinin geçerli olduğuna dair kanıtlar bulunmuş olsa da gerçekleşen enflasyon ve beklenen enflasyon arasında zayıf bir ilişki olduğu görülmüştür. Hipotezin kabulü noktasına tereddüt oluşmaması için ikinci model uygulanmıştır. Koyck dönüşümlü model ile Türkiye'de bireylerin enflasyon beklentilerinin oluşumunda enflasyonun geçmiş değerlerinden öğrenme gerçekleştirdikleri tespit edilmiştir. Bu öğrenmenin hızı %77'dir. Bireylerin cari ve geçmiş enflasyon verilerinin %77'sini kullanarak enflasyon beklentilerini oluşturdukları sonucuna ulaşılmıştır. Kastedilen geçmiş, cari dönem ile birinci ve ikinci gecikmeleri kapsamaktadır. Beklentiler açısından gecikmeli verinin 3. gecikmesinin etkisi sıfırdır.

Anahtar kelimeler: *Enflasyon, Beklenen Enflasyon, Uyarlayıcı Beklentiler, Kocyk Dönüşüm Modeli.*
Jel Kodu: *E30, E31, E37*

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1. INTRODUCTION

Since Fisher (1930) introduced inflation expectations into the calculation of real interest rates, inflation expectations and their relationship with macro variables have been studied, and empirical evidence has been sought. Nerlove (1958) developed the "partial correction term" with the model in which Nerlove equalized demand and supply quantities. This term is defined as a coefficient compensating for the difference between expected and actual inflation and expressing a learning rate value. The works of Fisher and Nerlove are fundamental approaches that changed the static expectations of the classical economic view and laid the foundations for extrapolative expectations. The best-known version of the extrapolative expectations model is adaptive expectations. In the Adaptive Expectations Hypothesis (AEH), developed by Cagan (1956) and Friedman (1957), the prediction of a variable depends on past data and the learning rate of that variable. According to Friedman, commodity prices adjust faster than wage prices. As a result of asymmetric information and money illusion, individuals cannot accurately predict changes in current prices and demand wage increases with a lag. According to Friedman, workers and employers follow real wages. Still, since fixed-term employment contracts bind workers, it takes time for any increase in inflation to be reflected in wages. In this situation, wages remain low for a certain period of time, and the labor supply does not decrease (Bocutoğlu, 2013: 184). However, when individuals eliminate the money illusion and renew their contracts, they will increase inflation expectations. As this situation will be reflected in wage demands, unemployment will return to natural unemployment (Bocutoğlu, 2013: 191). According to this approach, actual inflation and expectations will increase. Thus, a positive relationship between actual and expected inflation is expected.

As noted above, according to the AEH, individuals use past inflation values when forming inflation expectations. Another variable that best represents a variable is the lagged values of the variable. Individuals do not have the information to accurately assess the factors that affect inflation, how these factors affect inflation, how evolving conditions change the situation, the effects of external shocks, or the policies of central banks. This situation arises because individuals do not have complete information (Ünsal, 2013: 301). For this reason, economic units use past inflation values when estimating inflation expectations. Nerlove summarized the situation as follows. "The most readily available and least costly information about the future value of a variable is its past value" (Nerlove, 1983: 1255). In adaptive expectations, inflation expectations are based on a sole source of information. Researchers have criticized it for not considering other macro variables and not valuing policy changes (Svendsen, 1993: 12). This criticism gave rise to the Rational Expectations Hypothesis (REH). The study, the foundations of which were laid by Muth (1961), was developed by Lucas and Prescott (1971) (Sargent, 2008: 194). The basic idea is that, in contrast to adaptive expectations, economic units make predictions by considering all available information and do not make systematic errors.

After the articles of Muth (1961), Lucas (1976), and Sargent and Wallace (1975), the AEH lost popularity. (Evans and Ramey, 2006: 249; Chow, 2011: 5). However, some of the comparative studies in the international literature state that the AEH remains valid and/or is more appropriate than the Rational Expectations theory (Turnovsky, 1970; Carlson and Parkin, 1975; Figlewski and Watchel, 1981; Thornton, 1982; Chow, 1989; Beladi et al., 1993; Sabrowski, 2008; Pfajfar and Zakelj, 2014; Chen, 2016; Yao et al. 2022). In addition, some studies conducted on Türkiye also provide evidence that AEH is valid (Togan, 1987; Başçı, 1990; Metin and Muslu, 1995; Metin and Muslu, 1999; Us and Özcan, 2005; and Özcan, 2016). Studies by Greenwood and Shleifer (2014) and Adam et al. (2017) find that investors' consideration of past stock values successfully predicts today's returns. Studies by Jurgilas and Lansing (2013) and Ling et al. (2015) show that changes in current house prices are compatible with price movements in the previous year. These are microeconomic examples of the validity of Adaptive Expectations between price expectations and their realizations.

Chow (1989) and Chow (2011) are studies that make comparisons between AEH and REH. The results of both studies conclude that Adaptive Expectations are valid. The studies highlight the importance of using a geometric decreasing function when testing the Adaptive Expectations model. The geometric decreasing function expressed by Chow is the Koyck transformation developed by Koyck (1954). Koyck model, unlike other studies in the literature, AEH is more suitable. This suitability stems from the fact that the model is created with the lagged value of the variable based on the hypothesis. The Koyck model offers a distributed lags model weighted at various levels with decreasing geometric form. This methodologically different study will contribute to the literature.

2. LITERATURE REVIEW

There are very few studies in the literature that strictly apply the AEH. After the Rational Expectations revolution started by Muth (1961) and developed by Lucas (1976) and Sargent and Wallace (1975), Adaptive Expectations lost their popularity (Evans and Ramey, 2006: 249; Chow, 2011: 5).

Turnovsky's (1970) study examines US price expectations after the Korean War. The study made essential inferences from the Norlevo (1958) model, widely used in adaptive expectations. It has been stated that the model is incomplete if there is a trend in price changes. Suppose the coefficients in the model created by combining monthly data, averages, and lags are more significant than one. In that case, the prediction result will probably still increase the predictions above the last period's prediction to allow for the trend, and a high result will be obtained. Another important and valuable conclusion from the study is that it assumes that the units that form inflation expectations can expect a constant price increase due to the high information cost in periods when price increases are low. This means a small adaptation coefficient for periods when prices are relatively stable.

Carlson and Parkin (1975) examined expected inflation using survey data for the UK in 1961m1-1973m6. It is stated that inflation increases due to the study applying Rose's (1972) wage-inflation model on the basis of regressive expectations increase inflation expectations. In addition, it was concluded that the learning coefficient increased in periods when inflation was high. It is stated that to reduce the expected inflation rate, the actual inflation rate must be reduced. It is emphasized that such a decrease can occur through the error-learning process.

Figlewski and Watchel's (1981) study examines US inflation expectations obtained from Livingston surveys over a 30-year time series with adaptive, regressive, and Rational Expectations models. Multiple regressions were created in the study using the partial correction model for adaptive expectations. The Adaptive Expectations model created was based on the work of Nerlove (1958). The coefficient value (0.297) is positive. As a result of the study, they concluded that Adaptive Expectations are more appropriate. While the partial correction coefficient was 0.55 on average in 1954-1965, it became 0.51 after 1966. These results show that the learning coefficient does not change despite the acceleration of inflation. Economic factors are responsible for the observed change in the forecast error rate, which is expected to persist over time. This result is consistent with the hypothesis that respondents believe high inflation (and significant forecast errors) are caused primarily by non-recurring shocks rather than permanent factors and do not reflect this in their expectations.

Thornton (1982) used the ML (Maximum Likelihood Method) method in the study in which the effect of money demand on income and interest expectations was examined with Adaptive Expectations and partial correction coefficient, using monthly data for the 1952-1972 period for the US. As a result of the study, it was determined that the unpredictable part of money demand was 0.4, the unpredictable part of income was 0.7, and the unpredictable part of interest was 0.5. The results show that the error-learning levels of expectations are high. When the same application was made for rational expectations, the ratios were 0.05, 01, and 0.04, respectively. The author states that Adaptive Expectations are more appropriate due to their high correction coefficients.

In Chow's (1989) study, AEH and REH are compared in the US. In the study, the equations of expectations were examined not for inflation but for interest rates (20-year treasury bond interest as data) and stock prices (S&P 1871-1986 as data). Estimation results indicate that the expectations are in line with the AEH. Chow used the Koyck transformation by using the lagged values of the variables when modeling adaptive expectations. Additionally, the author recommended the Koyck rotation model for future studies examining adaptive expectations.

Beladi et al. (1993) investigated whether inflation expectations are adaptive or rational for Germany (1921:5-1923:8), Hungary (1921:10-1924:2), and Poland (1922:1-1924:1). The study was analyzed using the Chow (1989) approach. The study concluded that inflation expectations in Germany are in line with adaptive expectations; in Hungary, they are in line with rational expectations; and in Poland, they are not in line with both expectations. It should be noted that money supply was used as the dependent variable in the model applied for adaptive expectations.

Sabrowski (2008) tested adaptive and Rational Expectations for Germany. The study divided inflation expectations into categories such as gender, age, education, and employment status. As a result of the study, it was determined that Adaptive Expectations were more appropriate to the data. In addition, the partial correction coefficient is positive but very low. It shows that these units create inflation expectations by learning from the mistakes, but the effect is shallow.

Pfajfar and Zakelj (2014) are experimental economics studies consisting of 216 subjects. Although inflation expectations were discussed within the framework of the New Keynesian model in the study, rational and Adaptive Expectations were evaluated together. As a result of the study, it is stated that it is not appropriate to consider only one model. Although 40% of the expectations are rational, 20% align with adaptive expectations.

Chen (2016) applied the OLS method and Koyck transformation in his study investigating the causes of inflation in Singapore's 1990-2014 data period. As a result of the study, it was concluded that Adaptive Expectations for inflation are valid.

Yao et al. (2022) study examine the effects of price changes on the stock market with the GARCH model using adaptive and rational expectation models. In the study, it was determined that the Adaptive Expectations model was more appropriate. The study emphasizes that the more mature a market is, the lower the proportion of investors making expected corrections and the higher the probability of investors making stable investments. The correction coefficient in Adaptive Expectations is essential in the volatility of stock returns.

When studies on Türkiye are examined, studies are proving the validity of AEH. Togan's (1987) study examines the effects of money and interest on inflation in Türkiye. Friedman's (1956) money demand function was used in the study. Friedman states that expected inflation is a negative function of money demand. The study reveals that expected inflation affects money demand negatively and significantly. This result shows that harmonization expectations in Türkiye are valid for 1960-1983. In Başçı (1990) study, substantial evidence for the literature was obtained. In the study conducted for Türkiye, the money demand function, which is Friedman's (1956) model, was discussed. This model estimates the relationship between expected inflation and money demand. The study used two separate time periods: 1963-1975 and 1976-1988. Imperfect information was used in the first period, and complete information was used in the second. As a result of the study, it was concluded that Adaptive Expectations were more compatible for the first period and Rational Expectations for the second period. Another result is that the formation of incomplete information is more valid than the formation of complete information. This result provides additional evidence for the validity of the Adaptive Expectations model, which assumes that economic agents consider past data values. In their study, Metin and Muslu (1995) used the Çağan model in their monthly data analysis from 1986-1995. The study tests the existence of adaptation expectations in Türkiye. As a result of the study, it has been proven that there is a long-term relationship between money balances and inflation. Thus, it was concluded that AEH is valid in Türkiye. Metin and Muslu's (1999) article examined the existence of adaptive expectations with monthly data for the 1986-1995 period for Türkiye using Cagan's (1956) money demand function.

Additionally, Sergent (1977) tested the validity of Rational Expectations with the money demand model. As a result of the cointegration test applied in the research, it was concluded that AEH was valid for Türkiye, and REH was not valid. The US and Özcan (2005) study examined inflation expectations in Türkiye. In the study, which approached the subject based on the Philips curve, both autoregressive and distributed lag regression models were applied with the legs of the output and inflation variables. As a result of the study, statistical significance in lags is considered evidence of AEH's existence. Özcan (2016) study tested the validity of Adaptive and Rational Expectations for Türkiye and Kazakhstan. The theoretical approach applied in the research parallels the studies of Metin and Muslu (1995) and Metin and Muslu (1999). It was concluded in the study that the Cagan model is valid for both countries, and the learning rate coefficients are Türkiye (0.09) and Kazakhstan (0.06). These results provide evidence for the validity of AEH for Türkiye and show that the Türkiye learning rate is higher than in Kazakhstan.

Studies conducted to test the validity of REH on Türkiye have different theoretical approaches and applied different econometric methods. Bilgili's (2001) study tests the validity of the REH using the 12-month inflation expectation survey data announced by the Central Bank of the Republic of Türkiye (CBRT) for Türkiye. The monthly data study for 1987-2001 examined the relationship between output and inflation expectations using the Box-Jenkins method. As a result of the study, it was concluded that the survey participants did not adequately consider the output level when estimating inflation expectations. This result indicates that Rational Expectations are not valid for Türkiye.

REH is based on the assumption that economic agents use the entire set of information when forecasting inflation. Some studies have examined the structure of expectations through information formation. The macroeconomic variables that Kara and Küçük Tuğer (2005) study use as an information set are interest rate, budget deficit, industrial production, exchange rate, and domestic debt stock. CBRT inflation expectations survey was used in the study. However, expectations are created in three different dimensions representing different times. The purpose here is to assume that there may be changes in the rationality of expectations at different levels. Unbiasedness and efficiency tests were used in the study. The study concluded that the lagged values of exchange rate changes are not statistically significant on inflation expectations. In addition, it has been concluded that the assumption that economic units use the entire information set is invalid, and the imperfect information assumption is valid. Thus, it was concluded that the REH is not valid for Türkiye. Another study that tests the use of the complete information for Türkiye is the article by Yıldız and Günsoy (2021). The study applied efficiency and unbiasedness tests for inflation expectations in Türkiye in the 2006-2017 data period. The study concluded that while the efficiency hypothesis is valid for inflation expectations, the unbiasedness hypothesis is not. Thus, it was concluded that REH is not valid in Türkiye.

Some studies testing the validity of REH for Türkiye apply unbiasedness, efficiency, orthogonality, and consistency tests as empirical methods. Soybilen and Yazgan (2017) study tested the existence of unbiasedness in inflation expectations in Türkiye. In the application for the 2006-2012 period, expected inflation 1, 2, 12, and 24 months ahead inflation expectations were used. As a result of the study, it was determined that all inflation expectation levels were biased. Thus, it was concluded that

REH is not valid in Türkiye. Abdioğlu and Yılmaz's (2013) study tested the validity of the REH by considering the relationship between inflation, interest, and exchange rate for Türkiye. Unbiasedness, efficiency, orthogonality, and consistency tests were applied to assess the significance of the 2005-2012 data. It has been concluded that economic units make systematic mistakes. Since the REH is based on the basic assumption that economic units do not make systematic errors, it has been concluded that the REH is not valid for Türkiye.

Kara and Küçük Tuğer (2010) study examined the structure of expectations in Türkiye with monthly data and CBRT survey data for the period 2001-2007. Unbiasedness and efficiency tests were applied in the study. It has been concluded that REH is not valid in Türkiye.

Additionally, the results of the study support the AEH learning model. Oral's (2013) study examines expected inflation in Türkiye with monthly data for 2004-2011. In the study, analysis was carried out with a cointegration test and error correction model using expected inflation and actual inflation variables. As a result of the study, although a long-term relationship was detected between expected and actual inflation, it was concluded that REH is not valid for Türkiye because the unbiasedness assumption, one of the assumptions of the REH, is not valid.

Kara and Küçük Tuğer (2005); Kara and Küçük Tuğer (2010); Abdioğlu and Yılmaz (2013); Oral (2013); Soybilen and Yazgan (2017) and Yıldız and Günsoy (2021) papers are studies that applied same tests for Türkiye in different data periods. The results of the studies are that REH is not valid.

When the literature is evaluated in general, the studies on AEH are relatively less than the studies on REH. The reason for this situation is that REH is more popular. The econometric methods of the studies in the literature are primarily based on a regression model. It is seen that including lagged values of inflation data in the model is widely used in the literature, especially to accept or reject the validity of expectation hypotheses. Although many studies have added lagged values to their models, it has been determined that the effect of lags on the dependent variable is fixed-weighted due to the empirical methods used. Due to the decreasing geometric form of the Koyck model used in this study, the contribution of lags decreases with each lag compared to the first lag. This methodological difference will likely contribute to the literature.

3. EXPECTED INFLATION ACCORDING TO ADAPTIVE EXPECTATIONS

Expectations are present at every stage of life and fundamentally influence the future behavior of individuals. Inaccurate predictions can negatively affect the natural flow of life. For example, an expectation error in the demand for education can reduce the quality of education by creating inadequate educational spaces for students. An error in predicting traffic density can lead to heavy congestion due to insufficient roads being built. These examples can be multiplied in social life. Expectations are also significant in economic life (Harvey, 1994: 203). From a microeconomic point of view, the failure of firms to predict accurately the decline in future orders may lead to inventory accumulation and lay-offs in the longer term. Macroeconomically, errors in expectations of aggregate demand growth can lead to lags in expansionary policies and inflationary pressures as demand outstrips supply. Inflation expectations have been on the world economic agenda for almost one hundred years, as they depend on price changes based on the concepts of growth, unemployment, demand, and supply, which are the essential components of the economy. The first empirical study of inflation expectations was developed by Fisher (1930).

$$\pi_t^e = i_t - r_t \tag{1}$$

Equation (1) π_t^e refers to the real and i_t nominal interest rates. Fisher assumed that expected inflation equals the difference between nominal and real interest.

Keynes suggests that positive economic activity is a behavioral trait arising from individuals' optimistic outlook, not expectations. In this case, when an economic action is planned, individuals' expectations are formed according to the desired outcome (Harvey, 1994: 202). For example, someone who wants to invest may keep their other economic expectations positive depending on their desire to make a profit. This expectation can be considered irrational when evaluated through relevant academic studies.

In the study by Nerlove (1958), the partial correction coefficient was calculated in the equation examining the balance between supply and demand in the short run. The study stated that the difference between inflation and expected inflation was proportional to this coefficient. This coefficient was used in Adaptive Expectations by Friedman (1957) and Cagan (1956). Thus, the equation for expected inflation in Adaptive Expectations is expressed in equation (2).

$$\pi_t^e = \pi_{t-1}^e + \lambda \left(\pi_{t-1} - \pi_{t-1}^e \right) \tag{2}$$

In equation (2), π_t^e is the expected inflation in period t; π_{t-1}^e is represents the one-lagged value of expected inflation. In this case, $(\pi_{t-1} - \pi_{t-1}^e)$ refers to the one-lagged difference between expected and actual inflation. This term is also called unpredictable inflation (Nerlove, 1958: 232).

The idea behind creating the equation in this way is that Friedman (1957) assumes that there is a worker error model in explaining adaptive expectations. According to Friedman, the employer follows relative prices by monitoring price changes. On the other hand, workers form inflation expectations according to the purchasing power of money. Thus, while the employer notices the situation immediately when the general price level is high and adjusts prices using relative prices, the worker notices the situation later. As a result, inflation expectations rise later. As a result of this worker error, actual inflation increases first, and expected inflation follows later (Bocutoğlu, 2013: 184).

Moreover, in the case of inflation expectations, economic units form their expectations by considering only past inflation data. Another critical aspect of the theory of Adaptive Expectations is the assumption of asymmetric information. According to this concept, it is difficult for workers to access information that would allow them to make accurate inflation forecasts. As a result, unpredictable inflation occurs. In other words, although workers form an expectation by looking at past inflation data, errors occur due to asymmetric information. Although these errors are subject to correction in each forecast period, since they make systematic errors, there is an error equal to the correction margin. For this reason, Cagan (1956) and Friedman (1957) used the λ coefficient, which completes the model in equation (2).

$$\pi_t^e = \pi_t + (1 - \lambda)\pi_{t-1}^e \tag{3}$$

it is possible to write the Nerlove (1958) model shown in equation (2) as equation (3) as another representation of adaptive expectations. The equation is also known as the Friedman model. Expressed as expected inflation is the weighted average of $(1 - \lambda)$ ratios, the actual value in period t, and the expected inflation rate in the previous period. In the case of $\lambda = 0$, the lagged value of $(\pi_t^e - \pi_{t-1}^e = \pi_t)$ expected inflation is equal to actual inflation. If $\lambda = 1$, $(\pi_t^e = \pi_t + \pi_{t-1}^e)$ expected inflation is equal to actual inflation. Thus, λ = 0 indicates autonomous expectations and $\lambda = 1$ static expectations (Mlambo, 2012: 6). The validity of Adaptive Expectations is valid if the partial correction term (0< λ< 1) takes a value between 0 and 1.

Cagan (1956) and Friedman (1957) developed the equation specified in equation (4) with the idea that economic units adjust their expectations in the light of their past and learn from their own mistakes.

$$\pi_t^e - \pi_{t-1}^e = \pi_t - \pi_{t-1}^e \tag{4}$$

The equivalence, expressed as Koyck's transformation, is based on equation (4). Koyck substituted the $Y_t = \beta_0 + \beta_1 X_t + \mu_t$ equation, which is a simple regression equation, into equation (4), took the lag of 1 for all variables in the resulting equation, and then multiplied the variables in the resulting equation by the expression (1-λ). The final Koyck transformation equation obtained is shown in equation (5). Equation (5) is not a pure Koyck transformation, but a version adjusted for expected inflation (Gujarati and Porter, 2012: 630).

$$\pi_t^e = \lambda\beta_0 + \lambda\beta_1 \pi_t + (1-\lambda)\pi_{t-1}^e + \mu_t - (1-\lambda)\mu_{t-1} \tag{5}$$

4. KYOCK TRANSFORMATION BASED ON A PARTIAL CORRECTION MODEL

The term partial correction term (λ) was first used by Nerlove (1958). As we have seen, based on the theory of adaptive expectations, the prediction of inflation expectations can only be made using the lagged values of inflation.

$$\pi_t^e = (\beta_0 + \beta_1 \pi_{t-1} + \beta_2\pi_{t-2} + \beta_2\pi_{t-3} + \cdots. + \beta_n\pi_{t-n} + \mu_t) \tag{6}$$

In equation (6), it is stated that the expected inflation according to Adaptive Expectations is estimated according to the lags of inflation. This distributed lag model is infinite. Although individuals' inflation expectations are expressed in n, they are uncertain. Although the length of the data sets a limit in an empirical study, it is essential to determine the number of lags because the length of the lag cannot be as long as the size of the data. Furthermore, increasing the number of lags reduces the degrees of freedom and causes multicollinearity problems in such distributed lag models. In addition, the estimates made with the OLS are biased (Waud, 1968: 216).

This is the situation where the lags have a decreasing effect, as shown in equation (7). Closer lags are more effective than further lags. This geometric relationship is known as the Koyck transformation.

$$\pi_t^e = \alpha + \beta_0 \pi_t + \beta_0\lambda\pi_{t-1} + \beta_0\lambda^2\pi_{t-2} \dots . \beta_n\lambda^n\pi_{t-n} + \mu_t \tag{7}$$

Equation (7) expresses the structure of a model with distributed lags, in which the effects of lags are gradually reduced, as suggested by Kyock. λ^n expressions have been added to this equation, adjusted for expected inflation. As the number of lags increases, the exponential power of the λ term increases. This indicates that the effect of the term on the dependent variable is decreasing. As mentioned earlier, adding lagged values as independent variables to an infinite number of models leads to the problem of multicollinearity. Koyck suggested dropping equation (6) for one period as a first step (Gujarati and Porter, 2012: 632).

$$\pi_{t-1}^e = \alpha + \beta_0 \pi_{t-1} + \beta_0\lambda\pi_{t-2} + \beta_0\lambda^2\pi_{t-3} \dots . \beta_n\lambda^n\pi_{t-n} + \mu_t \tag{8}$$

Koyck (1954) suggested multiplying the equation by the λ term as the second step.

$$\lambda\pi_{t-1}^e = \lambda\alpha + \beta_0 \lambda\pi_{t-1} + \beta_0\lambda^2\pi_{t-2} + \beta_0\lambda^3\pi_{t-3} \dots . \beta_n\lambda^n\pi_{t-n} + \mu_t \tag{9}$$

The third step is subtracting equation (8) from equation (9).

$$\lambda\pi_t^e - \lambda\pi_{t-1}^e = \alpha(1-\lambda) + \beta_0\pi_t + (\mu_t - \lambda\mu_{t-1}) \tag{10}$$

If equation (10) is taken as $(\mu_t - \lambda\mu_{t-1}) = v_t$ and rearranged, equation (11) is obtained. Its adaptation to Adaptive Expectations is given in equation (11).

$$\pi_t^e = \lambda\beta_0 + \lambda\beta_1\pi_t + (1-\lambda)\pi_{t-1}^e + v_t \tag{11}$$

This process is known as the Koyck transformation. The transformation process is adapted to expected inflation according to the AEH. The Koyck transformation involves creating a series with distributed lag sequential dependence by solving the multilinear link problem. In addition to the Koyck transformation, the average lag is calculated as $\lambda\,(1-\lambda)$ when the β coefficient is positive. This number of lags represents the total power of the dependent variable of the variables added to the model exponentially (Waud, 1968: 205; Gujarati and Porter, 2012: 626).

Since the β_2 parameter in the estimation of equation (11) is $(1-\lambda)$, the estimation result is the ((β_2 = $(1-\lambda)$) and λ value. The equation is simplified by dividing equation (11) by the λ value. This gives the Koyck coefficients (Klein, 1955: 524).

Koyck (1954) states that β coefficients will have the same sign, and their effects on the dependent variable will decrease over time. Thus, the effect of the independent variables decreases geometrically. In a case where λ expresses the decreasing effect of lags, $1-\lambda$ is the adjustment rate.

$$\beta_k + \beta_0(1-\lambda)\lambda^k\,, \qquad (0 < \lambda < 1) \tag{12}$$

In practice, by determining the appropriate lag length, the value of the exponential parameters is calculated and added to the model according to equation (12). Once these processes have been completed, the Koyck conversion process is complete.

5. METHODOLOGY

This section presents the M-estimation method developed by Huber (1973), one of the Robust Least Squares (R-OLS) estimators.

In equation (12), X represents a given number of observations, and β represents unknown parameters. Thus, the errors obtained from parameter estimation are subtracted from each observation value, and their squares are taken to express the total again. This is the OLS estimate.

$$\sum_{i=1}^{m}\left(x_i - \sum_{j=1}^{n}\varepsilon_{ij}\beta_j\right)^2 = min! \tag{13}$$

The OLS estimator is an estimator that tries to minimize squared errors (to avoid the loss of negative values) when making a prediction. This situation is illustrated in equation (13). For the results obtained from the estimator to be effective, there must be no relationship between the independent variables and the error term (no autocorrelation), the errors must be normally distributed, and there must be no heteroscedasticity problem (Gujarati, 2016: 167). However, in OLS forecasting, the heterogeneity of the error variance and the long-tail distribution of the errors have almost indistinguishable effects and weaken the effectiveness of the estimator. In regression, even an outlier observation in the data set can cause this effect.

For this reason, some operations are required to remove the distorting effects of outliers on the OLS estimator (Huber, 1973: 799). There are many methods in statistics where outliers are corrected according to the normal distribution. Since this study uses a robust regression of the M-regression type proposed by Huber (1973), this estimator will be mentioned.

Huber type M regression is based on the maximum likelihood (ML) technique. Whereas in OLS estimation, the square of the errors is minimized, in this method, p(ε), which is a function of the errors, is minimized. The minimization rules are given in equation (14) (Huber, 1973: 800).

$$\sum_{i=1}^{m} p\left(x_i - \sum_{j=1}^{n} \varepsilon_{ij}\beta_j\right)^2 = min!$$

$$(a)\quad |x| < \varepsilon\,,\quad p(x) = \frac{1}{2}x^2 \qquad ;(b)\quad |x| \geq \varepsilon\,,$$

$$p(x) = \varepsilon|x| - \frac{1}{2}\varepsilon^2 \tag{14}$$

Equation (14) expresses the function of reconsidering errors with the Huber approach. If the values of the estimation parameters are smaller than the observation value, procedure (a) is applied; if they are larger, procedure (b) is applied. The aim is to obtain a value that minimizes the difference between the error and the observation ($\Delta_i = x_i - \Sigma_j c_i \theta_j$). P=1, ε=1 is a particular case and provides predictions with well-defined asymptotic properties (Huber, 1973: 800). In the M-estimator method, ε*1.5MSM is used. MSM is calculated as shown in equation (15) (Yorulmaz, 2003: 12).

$$MSM = \frac{median|\varepsilon_i - median\,(\varepsilon_i)|}{0.6745} \tag{15}$$

The estimation of the parameters of the M regression is carried out according to the following instructions. This order of operations is expressed in the study of Yorulmaz (2003); I) Constant and slope coefficients (βn) and error terms are obtained with the least squares estimator. II) The MSM value is calculated. III) Corrected errors are obtained using the p(ε) function. IV) New constant and slope coefficients are obtained by re-running the OLS estimator with the corrected lines. V) The old β coefficients and the new β coefficients are compared. If the difference is less than 0.001, the transaction is canceled. If the difference is more significant, the new coefficient values are written instead of the old ones, and the process is started again by calculating the MSM and error term (Yorulmaz, 2003: 32; Zaman and Alakuş, 2015: 74).

6. EMPIRICAL FINDINGS

In this section, after introducing the data used in the study, the levels of stationarity of the data are determined. Then, the results of the R-OLS estimator for the Nerlove (1958) model are reported and evaluated. Then, the results of the R-OLS estimator for the Koyck transformation model are reported and evaluated.

Table 1: List of variables used in the study.

Variable	Explanation	Source
Expected Inflation (π^e)	Probability Distribution of Annual Consumer Inflation Expectations Ahead of 12 Months	CBRT- EVDS
Actual Inflation (π)	Consumer Price Index (CPI) (annual percentage change)	CBRT- EVDS
Unexpected inflation $\pi_{t-1} - \pi_{t-1}^e$	It expresses the difference between actual and expected inflation's first lags.	The author calculates

Variables were obtained using the Electronic Data System (EVDS) of the CBRT. Monthly data were used for the study period between June 2013 and August 2023. No selection was made on the data size. The entire length presented by the data source is covered. Logarithmic transformation was applied to the data obtained due to the problem of heteroscedasticity. The variables used in the study are listed in Table 1.

Table 2: Results of the unit root test

PP				
	Level		First Difference	
	Constant	Constant and trend	Constant	Constant and trend
(π^e)	-1.7939	-7.4212***	-22.9535***	-11.9016***
(π)	-0.4487	-2.0778	-6.7107***	--6.7572***
$\pi_{t-1} - \pi_{t-1}^e$	-0.7696	-2.4888	-11.0397***	-11.0545***
ADF				
	Constant	Constant and trend	Constant	Constant and trend
(π^e)	-1.3761	-4.4933***	-19.3700***	-19.2887***
(π)	-0.4307	-2.4113	-7.2398***	-7.2704***
$(\pi_{t-1} - \pi_{t-1}^e)$	-0.4312	0.3440	-5.6891***	-5.6926***

Note: The symbol *** indicates a 1% significance level.

In Table 2, Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests were applied for the variables. As a result of the tests examined with both constant and constant trends, it was determined that the expected inflation (π_e) variable was stationary at the I (0) level, while the actual inflation (π) and the unpredictable inflation $(\pi_{t-1} - \pi_{t-1}^e)$ variable were stationary at the I(I) level.

Table 3: Results of the unit root test with structural break

ZA					
		Constant	Constant and trend	Constant	Constant and trend
(π^e)	t stat Bre. Date	-3.40 2014m8	-5.88*** 2015m6	-20.19*** 2014m4	-20.11*** 2014m4
(π)	t stat Bre. Date	-0.43 2022m7	-3.43 2021m10	-8.07*** 2021m12	-5.05** 2021m11
$(\pi_{t-1} - \pi_{t-1}^e)$	t stat Bre. Date	-2.08 2015m2	-4.52 2018m10	-7.08*** 2022m09	-7.05*** 2018m10

Note: The symbols ** and *** indicate 5% and 1% significance levels, respectively.

Structural breaks in the data were examined with the Zivot Andrews Unit Root Test with Structural Break (ZA) test. Table 3 shows the ZA results. There is a structural break in each variable, and it is seen that the breaks occur at different dates. As a result of the structural break test, no change was observed in the stationarity levels of the variables. In the estimators to be applied in the continuation of the study, the differences of the non-stationary variables will be taken, and the application will be carried out.

Initially, the OLS estimator was preferred for the research method. However, as a deviation from the basic assumptions was found to affect the effectiveness of the OLS estimator, we continued to work with the Robust estimator.

Table 4: Regression result for partial correction model

Variables	Coefficient	St. Dev.	t stat.	Prob.
π_{t-1}^e	0.900	0.036	24.45	0.000
$\lambda\, \Delta(\pi_{t-1} - \pi_{t-1}^e)$	0.007	0.001	4.48	0.000
Constant	0.351	0.134	2.61	0.000

R^2	D.R^2	Rw^2	D.Rw^2	Rn Sq.	Scale	Jarque-Bera
0.69	0.69	0.86	0.86	614 (0.00)	0.08	0.43 (0.80)

Note: Robust OLS (R-OLS) estimator has been applied. The application was the robust estimator M- Estimator, covariance type Huber Type I, maximum iteration 500.

Nerlove states that the validity condition of the model is that the partial recovery coefficient must be positive and between 0 and 1 ($0 < \lambda \leq 1$) (Nerlove, 1958: 231). If the sign of the coefficient is wrong or statistically insignificant, it means that the Adaptive Expectations are invalid (Waud, 1968: 216). Since the coefficient is between 0.007 and the expected value, it can be said that Adaptive Expectations are valid. The value of λ can also be considered as a learning coefficient. A value that is close to 1 indicates the extent to which the mistakes made in inflation expectations have been learned in the period under consideration (Shepherd, 2012: 4). The fact that the value is 0.007 means that 0.007% of the mistakes made by individuals in forming their inflation expectations during the period under study are corrected depending on the actual inflation. Although Adaptive Expectations are valid, the learning correction rate is very low. As a result of the regression, the lagged values of expected inflation positively impact the current value of expected inflation.

Although it is valid that it fulfills the necessary conditions for the AEH, the fact that the partial correction coefficient is very low requires caution in accepting the hypothesis. For this reason and following the advice of the studies of Chow (1989) and Chow (2011), we wanted to re-analyze the Friedman model by subjecting it to the Koyck transformation. The results are presented in Table 5.

Table 5: Result of the regression of the expected inflation model with the Koyck transformation

Variables		Coefficient		St. Dev.	t stat.	Prob.
$\lambda\beta_0$		0.345		0.016	21.53	0.000
$\lambda\Delta\beta_1\pi_t$		0.065		0.009	7.25	0.000
$(1-\lambda)\pi^e_{t-1}$		0.903		0.004	20.52	0.000
R^2	D.R^2	Rw^2	D.Rw^2	Rn Sq.	Scale	Jarque-Bera
0.71	0.70	0.83	0.86	421.36 (0.00)	0.10	0.45 (0.79)

Note: Robust OLS (R-OLS) estimator has been applied. The application was the robust estimator M- Estimator, covariance type Huber Type I, maximum iteration 500.

Table 5 shows that both the constant and the slope parameters are positive and significant. Increases in inflation and unanticipated inflation increase expected inflation. However, the results of the estimators are not used directly, and the final equation obtained by adding exponential variables to the model is evaluated.

$$\pi^e_t = 0.345 + 0.065\Delta\pi_t + 0.097\pi^e_{t-1} + v_t \tag{16}$$

The results of the estimator coefficients applied according to the $\pi^e_t = \lambda\beta_0 + \lambda\beta_1\pi_t + (1-\lambda)\pi^e_{t-1} + v_t$ Koyck transformation were recalculated by dividing by the partial correction coefficient (0.097). Equation (17) was then obtained.

$$\pi^e_t = 3.56 + 0.67\Delta\pi_t + \mu_t \tag{17}$$

Table 6: β coefficients according to different exponential levels

$\beta_k = \beta_0(1-\lambda)\lambda^k$ or $\beta_k = \beta_0\lambda^k$		
β_k	$\beta_0\lambda^k$	Coefficient Value
β_0	(0,903) (0.097)	0,09
β_1	(0,903) $(0.097)^2$	0,01
β_2	(0,903) $(0.097)^3$	0,00
β_3	(0,903) $(0.097)^4$	0,00

In the Koyck approach, the β_k coefficient must be calculated in geometric form to obtain the final model. According to the $\beta_0\lambda^k$ values calculated in Table 6, although there was an effect of 0.09 in the first lag, the effect decreased to 0.01 in the second lag. The effect of the third lag is zero. The effect is expected to decrease to zero gradually for functions with geometric shapes. This is because the most significant effect occurs at the nearest lag. Accordingly, when two lags are added to the model, the Koyck transformation is complete. The final model is shown in equation (18).

$$\pi_t^e = 3.56 + 0.67\pi + 0.09\,\pi_{t-1} + 0.01\pi_{t-2} + \mu \qquad (18)$$

When evaluating the equation, it can be accepted that the AEH is valid because the partial correction coefficient is positive and takes values between 0 and 1.

When comparing the Nerlove and Koyck models, we consider the Koyck model more appropriate because the partial coefficient term obtained from the Nerlove model is relatively low, and the Koyck model is reasonable.

In evaluating the results, individuals learn from past inflation values while creating inflation expectations. This learning occurs in 3 periods: 2 lag periods and one current period. When individuals consider past inflation values as learning, they do not consider them three or more periods back. The learning rates are also 0.67 for the current period, 0.09 for the previous period, and 0.01 for the two previous periods. There is a total learning coefficient of 0.77. 77% of individuals' inflation expectations are determined by current and previous periods' inflation data.

7. CONCLUSION

The first motivation for this study is the abundance of studies suggesting that the REH is not valid for Turkiye (Bilgili, 2001; Kara and Küçük Tuğer, 2005; Kara and Küçük Tuğer, 2010; Abdioğlu and Yılmaz, 2013; Oral, 2013; Soybilen and Yazgan, 2017 and Yıldız and Günsoy, 2021). The second motivation is that there is evidence for the valid of the AEH in recent international studies (Turnovsky, 1970; Carlson and Parkin, 1975; Figlewski and Watchel, 1981; Thornton, 1982; Chow, 1989; Beladi et al. 1993; Sabrowski, 2008; Pfajfar and Zakelj, 2014; Chen, 2016; Yao et al. 2022).

In the study, predictions were first made with the partial correction model of Nerlove (1958), which laid the first foundations of expectations research. As a result of this model, since the sign of the partial correction coefficient is positive and its value is between 0 and 1, there is no problem accepting the adaptive expectations. Still, the value being close to 0 has necessitated a cautious approach to accepting the hypothesis. Subsequently, when the equation known as the Friedman-Cagan model was re-estimated with the Koyck transformation in the direction suggested by the studies of Chow (1989) and Chow (2011), evidence was obtained for the more vital acceptance of the AEH.

When the final results were evaluated, it was concluded that economic units in Türkiye consider past inflation values when forming their expectations. It was found that economic units learn from past inflation values in their inflation expectations. Findings obtained from the Koyck Transformational model: The effect of current period inflation on expected inflation is 67%, the effect of the first lag of inflation is 9%, and the effect of the second lag is 1%. The effect of the 3rd lag of inflation on expected inflation is 0. Thus, the total effect of inflation on expected inflation is 77%.

Studies show that they use the inflation variable with a lag in their regression equations. However, this usage is primarily a form of constructed regression with fixed weights. The Koyck Transformation model used in this study defines a separate weighting measure for each lag used. Thus, the effect decreases from the first lag, and the effect is reset at a certain lag. The contribution of this study to the literature stems from its empirical approach.

According to AEH, inflation expectations of economic units are determined according to the past and current values of inflation data. If inflation expectations have been on a decreasing trend so far, the future value of inflation expectations will continue to decrease in line with past data. This is the harmony that comes from the nature of AEH. If the central bank manages to reduce inflation for a long time, inflation expectations will also enter a decreasing trend.

According to AEH, the only data that individuals evaluate is inflation itself. The reason for this is not the lack of interest of economic units. The main reason is that although economic units are aware of policy changes, they cannot create the necessary reaction for a certain period due to the illusion of money. This situation represents a temporal lag. This means that in an economy where AEH is valid, a short-term monetary policy will have little or no effect. Thus, short-term expansionary monetary policies will not affect inflation.

Another dimension of the money illusion is the labor market. According to Friedman, inflation increases and real wages decrease due to expansionary monetary policy. Employees realize the situation and reduce the labor supply, thus increasing unemployment. This indicates that unemployment increases with increasing inflation. However, due to the rigidity of employment contracts, unemployment will not decrease during the contract period. Inflation will increase during the contract period, and unemployment will remain unchanged for a while. In Türkiye, employment contracts and wage update activities vary between 6 and 12 months. As a policy recommendation, expansionary policies to be implemented during these periods will not affect the labor market. However, attention should be paid to the timing of such an application. AEH is an approach that allows such short-term shock applications.

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