Rethinking Error Correction Model in Macroeconometric Analysis: A Relevant Review

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Abstract:

The cointégration methodology has bridged the growing gap between economists and econometricians in understanding dynamics, equilibrium and bias on the reliability of macroeconomic and financial analysis, which is subject to non-stationary behavior. This paper proposes a comprehensive literature review on the relevance of the error correction model. Econometricians and economists have shown that error-correction model is a powerful machine that provides the economic system and macroeconomic policy with a refinement in the econometric results[1].

Keywords: cointegration; error correction model; macroeconomics.

JEL Classification: C32; E10.

Introduction

The advent of time series analysis in econometrics[2] and economics has transformed economic thinking (especially macroeconomic thinking, which is why the time series are called "macroeconometrics[3]"), Sophisticated processes radically transformed the landscape of research sector and added rigor in macroeconomic analysis. Although its birth is the result of the great battle between Keynesians and monetarists (Johnston and Dinardo 1999), the analysis of time series is therefore at the heart of macroeconomics and has emerged as the essential tool of the economic policy assessment.

The pioneering work of Box and Jenkins (1976) was based on the ARIMA (pdq)[4]*. Auto Regressive Integrated Moving Average*, introduced to model process behavior based on past values subjected to random shocks over time. A random event called noise or disturbance affects the temporal behavior of this process and thus modifies time series[5] values. This model develops the forecast by exploiting statistical characteristics (mean, variance, autocorrelation function, autocovariance function, ...). To fill the shortcomings of the univariate models (ARIMA, ...), which only described the behavior of a series, not to explain, the analyzes of the multivariate time series were born, of which the most known and used is the VAR family. The father of this process is Christopher Sims, Nobel Prize winner in 2011.

It is clear that these models had become the cornerstone of any macroeconomic analysis. However, these are analyzing that require the stationarity of the series, which, its mean and its variance must be constant over time. For more understanding, a process is said to be stationary if it tends to return to equilibrium (its mean value or variance) after suffering the effect of a shock over time (mainly over long periods). However, in economics several phenomena make that macroeconomic variables over time have non-stationary characteristics, such as, GDP,

[1] I am so indebted to Jennifer Louise Castle for many helpful conversations and comments that helped further refine and scrutinize this research paper. I also thank Valerio Scalone

[2] The study of time series is a discipline that appeared relatively before econometrics, since already around 1905 they were used in astronomy and a little further in statistics and meteorology. Econometrics, on the other hand, is a discipline that was born around the 1930s by the Alfred Cowles Research Institute called the Cowles Commission and the learned econometrics society founded by Ragnar Frisch and his colleagues (Fisher, Ross, Schumpeter).

[3] According to Greene, macroeconometrics is a discipline that focuses on the analysis of time series that are typically aggregates such as GDP, money supply, prices, exchange rate, investment, and so on (2011).

[4] Where p is the order of the autoregressive process AR (p), d the degree of integration of a process I (d), and q the order of the moving average MA (q)

[5] This model is generally in the following form: $Z_t = \Delta^d X_t$; it is a development of the form: $\Delta^d X_t = \gamma + \emptyset_1 \Delta^d X_{t-1} + \cdots + \emptyset_p \Delta^d X_{t-p} + \varepsilon_t - \theta_1 \varepsilon_t - \cdots - \theta_q \varepsilon_{t-q}$. For more details see Lardic and Mignon (2002).

exchange rate, inflation, stock prices and so on, and the price to pay is to apply the difference filter or the transformation by the regression on the trend. This could have the consequence of moving away from reality and proposing strategies and policies based on erroneous or unreal results.

In view of all these difficulties, econometricians refined their research by developing non-stationary time series analyzes to fit the data, to forecast macroeconomic and financial series and to apply them to retroactive control systems. Thus the so-called ARCH models (AutoRegressive Conditionally Heteroscedastics) and the methodology of cointegration with some models (error-correction model, vector error correction model, and so on) were born. These models are relevant because of their closeness to reality and their powers to produce better short-term forecasts and certainly long-term forecasts aggregated in economically meaningful ways for macroeconomic policy analysis (Maddala and In-Moo Kim 1998).

As Granger (1986) put it: "A *test for cointegration can thus be thought of as a pre-test to avoid 'spurious regression' situations*". According to Granger, instead of stationaryizing the series a priori in order to avoid the fallacious regression situation, the best approach would be to test whether the regression residuals are stationary, so the error-correction model can be estimated with non-stationary series and give better results in the dynamics of the short and long-term relationship. Cointegration is the key word in the new econometrics, referring to the long-term relationship between economic variables.

This paper is intended to illustrate the relevance of the cointegration methodology to the error correction model, its implications for macroeconomic modeling and forecasting, and its fundamental role in explaining short- and long-term dynamics.

The organization of this paper is as follows. Section 2 reviews a selection of empirical studies with the error-correction model contributing to the economic analysis. Section 3 illustrates the cointegration methodology by exploiting the different cointegration tests and the dynamics of the error correction model. Finally, section 4 summarizes the paper with a conclusion.

1. Relevant Literature Review

In 2003, the Nobel Prize in Economics was awarded to two researchers who conducted their research in the 1980s and 1990s: Robert Engle and Clive Granger for their scientific contributions to "*methods of analysis of economic time series on the one hand with seasonal volatility for Engle and on the other hand with a common trend for Granger"* that have contributed to the improvement of forecasts of macroeconomic and financial variables (Lardic and Mignon 2003). In fact, the winners were awarded for their work relating respectively to ARCH type models and non-stationary so-called cointegration analysis. The great merit of Granger was to show that specific combinations of non-stationary time series can behave *"stationarily"* and thus make it possible to find statistically correct results. Granger discovered cointegration by trying to refute Hendry's (1977) criticism of his research with Newbold on nonsense regressions between nonstationary data (Granger and Newbold 1974, 1977). Although the initial estimation approach has been replaced by a plethora of methods, the concept of cointegration has led to a fusion of analyzes of long-term equilibrium relationships with empirical dynamic systems (Castle and Hendry 2016).

However, cointegration could not have happened without Hendry's criticism. Hendry's role is overlooked in the economic literature, while he is the essential link between Sargan's (1964) work on the formulation of analysis of stationary time series with error correction and that of Granger on spurious and nonsense regressions, which will lead to error correction models. This link will be made by the cointegration analysis (Meuriot 2015). These models have been shown to be very effective for short-term dynamic systems and subject to strong stochastic disturbances, but whose long-term dynamics are also constrained by existing equilibrium relationships in an economy, for example, the relationship between exchange rate and inflation rate, both short-term and long-term (which will be analyzed for illustrative purposes in the next section).

The pioneering work of Davidson *et al.* (1978) on the dynamic relationship between consumption and disposable income in the United Kingdom is a treating essay on the error correction model. The literature on the relevance of cointegration on the economic phenomenon has spectacularly exploded. The work of Engle and Granger (1987) that cointegration and the error-correction model is a relevant model for analyzing the relationship between nominal GDP and money supply (verification of monetary neutrality) and other variables such as inflation, consumption. They have developed and demonstrated the importance of the error-correction model in economic policy analysis. The revival of the debate on monetary neutrality led other researchers to test this relationship with the relevance of the error-correction model, Mehra economist at the Federal Reserve of Richmond, verified this hypothesis in 1989 using cointegration, its results validated monetary neutrality hypothesis with the broad money. However, the hypothesis seemed to be invalid for money (M1).

Kremers *et al.* (1992) analyzed the power of cointegration by showing that the error-correction model gives more efficient results. They found that when there is a cointegration relationship, the error-correction model is usually more powerful. Several empirical studies of money demand demonstrate this power of the error-correction model and its strategic implications for monetary policy making (Hendry and Ericsson 1991, Mehra 1991).

After studies on monetary neutrality and money demand, the tendency was towards efficient financial markets (Van Quang 2007) and exchange rate behavior. Godbout and Van Norden (1997) conduct three case studies. The first on cointegration and the projection of nominal exchange rates. The second is based on work related to the long-term validity of the monetary model for determining the exchange rate. The third study presents the existence of stochastic trends common to international stock markets.

Eslamloueyan and Darvishi (2007) used an unrestricted error correction model and the test approach of limits proposed by Pesaran *et al.* (2001) to study the short and long-term effects of bank credit on inflation in Iran. Their result indicates that there is a long-term relationship between inflation and its main determinants, namely bank credit, import price, real GNP and the parallel exchange rate. However, bank credit has no short-term effect on the movement of price levels in Iran. In addition, they show that the nationalization of banks and the implementation of interest-free or interest-free banking system in Iran have caused a structural change in the behavior of inflation.

Researchers investigated the behavior of long-term growth rate determinants using the error-correction model (Morales 1998, Özmen and Şanli 2018). A major empirical interest in growth studies is whether permanent changes in the fundamentals of the economy affect the long-run growth rate. However, a direct time series analysis of this hypothesis is not always feasible because the permanence of many such changes is rather debatable. For example, Lau (2008) explains why examining the long-term effects of temporary changes in the share of investment on per capita output indirectly provides the answer to the effects of permanent (possibly hypothetical) investment changes. Applying the error-correction model, he finds that a disruption in investment does not produce a positive long-term effect in each of the three countries - France, Japan and the United Kingdom - in which GDP per capita and investment are cointegrated.

Adouka *et al.* (2013) modeled the Algerian public expenditure demand function using error correction and vector error correction (VECM) models from 1970 to 2010. They sought to study the sensitivity of the economic activity in the face of changes in public spending and to measure the effect of income and productivity on the growth of public spending. They found that all the coefficients of the variables that explain the growth of public expenditures are not significant and that there is therefore no short-term relationship between public expenditure and GDP. But in the long run they captured the effect of spending on activity, and thus the relationship was stable and significant in the long run.

Pinshi and Sungani (2018) analyze the relevance of the pass-through effect of the exchange rate in the DRC and its implications on monetary policy regime for the period from January 2002 to March 2017. The main idea is to measure the degree of transmission of exchange rate variations to the change in the general price level in a context of macroeconomic instability that is unfavorable to the Congolese economy. Indeed, a strong and/or weak degree of pass-through would suggest that changes in the exchange rate have more / less effect on inflation. This could alter the central bank's predictions of the future reaction of inflation, which are decisive for monetary policy strategies and tactics. Based on the cointegration approach with the error-correction model, the main conclusion is that a change in the exchange rate will affect inflation more than proportionally, the degree of pass-through being relatively high. A depreciation of 1% causes a rise in the general price level of 0.38% in the short term. This effect is even wider in the long run, where the increase in the general price level is 1.66%. In addition, the adjustment to balance will take time (12 months and 2 weeks). Their study suggests Central Bank, on the one hand, to be vigilant and closely monitor exchange rate movements in order to take quick action and contain inflationary pressures and secondly, reflect on the strategies of the political economy by adopting a hybrid regime (monetary targeting and implicit and flexible targeting of the exchange rate).

In 2019, Ntungila and Pinshi analyze the short and long-term sensitivity of the Congolese economy to fluctuations in commodity prices and verify the resource curse hypothesis in the DRC. They use the method of Fully modified least squares (FM-OLS) to estimate the error-correction model. They find that the Congolese economy is adversely affected by commodity price shocks in the short and long term. The readjustment of the economy is slow and persistent. The short and long term relationship seems to validate the hypothesis (or paradox) of resource curse. They conclude that if there is not an ambitious launch of the structural reform process, the economy would remain in an eternal whirlwind of curse.

The authors have contributed in some way to the research landscape and to macroeconomic and financial understanding through the powerful error correction model and the cointegration approach. The relevance of this model to the problem of fallacious regression is a remarkable advance. What is extraordinary is that these econometricians know how to analyze macroeconomics and economic policy in a world characterized by the non-stationarity of variables, many have circumvented this problem with a price to pay and a risk of deviating from the real analysis, Engle, Granger and the other econometricians exploited this econometric weakness and were able to analyze against the current in the storm and swirl the error by using non-stationary variables to find relevant results.

2. Methodology: Relationship between Inflation and Nominal Exchange Rate

Consider two time series π_t and e_t, inflation rate and exchange rate, which are $I(d)$, that is, they have compatible properties in the long term. In general, any linear combination of π_t and e_t will also be $I(d)$. However, if there is a linear combination such that:

$$\pi_t - \theta e_t - \alpha = z_t \approx I(d-b), b > 0 \tag{1}$$

With $(1 - \alpha - \theta)$ called cointegration vector. The relationship between inflation and the exchange rate is cointegrated in the sense of Engle and Granger $(\pi_t, e_t \approx CI(d, b))$.

The concept of cointegration attempts to determine the existence of a long-run equilibrium towards which an economic system converges over time. If, for example, economic theory suggests the following long-term relationship between π_t and e_t in logarithm:

$$\pi_t = \alpha + \theta\, e_t + z_t \tag{2}$$

where: θ is an elasticity measuring the effect of a unit change in the exchange rate e_t on the inflation rate π_t. This relation defines the behavior of inflation is a function of the fluctuations of the exchange rate. Thus z_t is the distance at which the system is far from equilibrium at all times, that is, the equilibrium error (Dolado *et al.* 1990).

The statistical significance of the cointegrating coefficient θ is an indication of the existence of a long-term relationship between the rate of inflation and the exchange rate and that these have a common stochastic tendency whose fundamental characteristic is that the term estimated residual $\widehat{z_t}$ does not have a unit root (stationarity). However, this cointegrated relationship requires that each of two variables is not stationary in level, but that they become them after differential filtering (Pinshi and Sungani 2018).

2.1. Integration Tests

The aim of the integration or stationarity test is to examine empirically whether each series contains a unit root. These tests are mainly a descriptive tool used to classify the series into stationary and non-stationary. Since the integrated variables lead to nonstandard distributions and perhaps to fallacious regression results, the recommendation is as follows: *"If a data set appears to be non-stationary, assume that it is nonstationary and integrated. Once you have been able to categorize your variables as integrated steady-state trends, you are able to solve the long-term and short-term effects in your model"* (Sjö 2008).

The « t statistic » of Dickey-Fuller is based on the model estimation:

$$\Delta\pi_t = \alpha + \beta t + \vartheta\pi_{t-1} + \nu_t \tag{3}$$

In case of autocorrelation in the observed series, estimate the Augmented Dickey-Fuller (ADF Test) based on the following equation estimate:

$$\Delta\pi_t = \alpha + \beta t + \vartheta\pi_{t-1} + \alpha\pi_{t-1} + \sum_{j=1}^{p-1}\phi_j\, \Delta\pi_{t-j}\nu_t \tag{4}$$

The null hypothesis is that: $\pi_t = \pi_{t-1} + \nu_t$ where $\nu_t \approx ID(0, \sigma^2)$. According to the null hypothesis, ϑ will be negatively biased in a limited sample, so only one test is necessary to determine $H_0: \vartheta = 0[\pi_t \approx I(1)]$ against $H_1: \vartheta < 0[\pi_t \approx I(0)]$. This model is less restricted because it takes into account a deterministic trend.

It follows a distribution associated with that of the statistic t whose critical values are presented by Dickey and Fuller. The decision rule is such that we accept the null hypothesis of the existence of a unit root since: $t_{\widehat{\vartheta_1}} \geq t_{tabulée}$ (critical values).

2.2. Cointegration Test: Engle-Granger Approach

Once the variables have been classified as integrated of order $I(d)$, it is possible to establish models leading to stationary relations between the variables. There are several cointegration tests. Engle and Granger (1987) formulated one of the first cointegration tests. This test has the advantage of being intuitive, easy to achieve. The intuition underlying the test motivates him to play his role as the first cointegration test.

In order to test the existence of cointegration between the two series, it is imperative to use Engle-Granger's Augmented Dickey-Fuller cointegration test, or EG-ADF test (Stock and Watson 2012). The first step consists of a relation (2) from which the residual process $\widehat{z_t}$ must be extracted. The second step is to look for a unit root in the residual process of the cointegration regression above. To this end, configure an ADF test like:

$$\Delta\widehat{z_t} = \alpha + \vartheta\hat{z}_{t-1} + \sum_{j=1}^{k} \emptyset_j \, \Delta\hat{z}_{t-j} + v_t \tag{5}$$

where: k is the shift chosen according to the criteria of Akaike and Schwartz.

The assumptions are as follows:

$H_0: \vartheta = 0$ $(No\ existence\ of\ a\ cointegration\ relation)$

$H_1: \vartheta < 0$ $(Existence\ of\ a\ cointegration\ relation)$

The decision rule is such that the null hypothesis of non-cointegration will be rejected if the calculated McKinnon statistic is greater than the corresponding critical value. Otherwise, there would be no long-term link between the variables considered. The existence of a long-term relationship paves the way for the estimation of the Error Correction Model (ECM).

It should be noted that the Engle-Granger approach poses three main problems. First, since the approach involves an ADF test in the second step, all ADF test problems are also valid here, including the choice of the number of delays in the increase is a critical factor. Secondly, the test is based on the hypothesis of a cointegration vector, captured by the cointegration regression. Therefore, be careful when applying the test to models with more than two variables. If two variables are included, adding a third variable built into the model will not change the result of the test. If the third variable does not belong to the cointegration vector, the OLS estimate will simply set its parameter to zero, leaving the residual process unchanged. Two-variable test logical strings are often necessary (or sufficient) to solve this problem. Third, the test assumes a common factor in the dynamics of the system. To avoid this problem, it would be more prudent to rewrite the simplest version of the two-variable test (Sjö 2008). Another solution in front of more than two variables, it is better to apply the cointegration approach of "Johansen" which is one of the most powerful cointegrating tests.

There is a lot of work on managing structural breaks and outliers in the error correction model, as non-stationarity can result from changes in distribution and not just stochastic trends. Failure to model the offsets leads to processes which resemble stationary variables in difference I(1) but can be stationary in level I(0) with breaks.

However, the advantage of the Engle-Granger procedure is that it is easy to implement and therefore relatively inexpensive compared to other approaches. This may work quite well for two variables in particular, but remember that the common factor restriction is a severe restriction since any short-term dynamics are forced into the residual process. In this regard, one would expect the dynamic model advocated by Hendry, Banerjee and other econometricians to behave better.

2.3. Error Correction Model

In order to analyze the short-term and long-run dynamics of exchange rate changes on the behavior of inflation (*pass-through*) one can use an ECM. The value of ECM formulation lies in the fact that it combines flexibility in dynamic specification with long-term desirable properties. It could be perceived as capturing the dynamics of the system while integrating the equilibrium suggested by economic theory.

The greatest reliability of the ECM is that it does not suffer from serial correlation of residues; in addition, its regression coefficients offer a good economic interpretation (IMF 2013).

2.3.1. Engle and Granger Methodology

If all the above conditions are satisfied and the inflation rates and the exchange rate share a common stochastic trend, *i.e* they are cointegrated $(\pi_t - \hat{\theta}e_t - \hat{\alpha} \approx I(0)$, the ECM describing the relationship between the two series is written :

$$\Delta\pi_t = \tau_0 + \tau_1\Delta e_t + \gamma(\pi_{t-1} - \theta e_{t-1} - \alpha) + \mu_t \quad with\ \gamma < 0 \tag{6}$$

The term $\pi_{t-1} - \theta e_{t-1} - \alpha$ can be symbolized in z_{t-1} as the delayed error term, it represents the magnitude of the imbalance between the level of inflation π_t and exchange rate e_t in the previous period. The ECM indicates that the changes in π_t depend not only on the changes in π_t, but also on the magnitude of the imbalance z_{t-1}.

This equation can be rewritten:

$$\Delta\pi_t = \tau_0 + \tau_1 \Delta e_t + \gamma z_{t-1} + \mu_t \tag{7}$$

The parameter τ_1 represents the short-run elasticity of inflation relative to exchange rate fluctuations. The long-run elasticity is θ in equation (2).

The mechanism of error correction (the restoring force) or of catching up γ, expresses the speed of the adjustment towards the long-term equilibrium, must be significantly negative; otherwise, an ECM specification should be rejected. The slope coefficient of γ implies that, if in the preceding period the level of the inflation rate was 1% higher than that predicted by the long-run equilibrium ratio, there will be an adjustment to reduce the inflation level of γ during this period to restore the long-run equilibrium relationship between the inflation rate and exchange rate fluctuations.

2.3.2. Methodology at Banerjee and Hendry

In the same way that Engle and Granger identify and estimate the ECM, the methodology of Banerjee and Hendry (1992) also offers a good interpretation and approximates the Engle-Granger approach. The major difference is that unlike the first two-step ones, Banerjee and Hendry's approach proceeds in one step to estimate the ECM:

$$\Delta\pi_t = \tau_0 + \tau_1 \Delta e_t - \gamma \pi_{t-1} + \tau_2 e_{t-1} + \mu_t \tag{8}$$

The parameter τ_1 represents the dynamics of the short-term pass-through that is to say the short-term repercussions of the exchange rate variations on inflation and the parameter τ_2 characterizes the long-term pass-through equilibrium, where $-\tau_2/\delta$ represents the long-term elasticity that is the long-term impact of exchange rate changes on inflation. The parameter γ is the error correction mechanism (error correction coefficient) or the restoring force, it must be less than unity and negative. This parameter γ indicates the rate of adjustment of inflation π_t to its equilibrium level, *i.e.* the way in which inflation adjusts when there is an imbalance in the foreign exchange market. In addition $|1/\gamma|$ represents the duration by which price volatility is fully absorbed after adjusting the imbalance in the foreign exchange market.

Conclusion

The considerable gap between economists, who have a lot to say about equilibrium but relatively little about dynamics, and econometricians, whose models focus on the dynamic adjustment process, has been to some extent fulfilled by the concept of cointegration (Dolado *et. al*. 1990). Cointegration theory has significantly alleviated the problems of fallacious regressions due to the non-stationary behavior of macroeconomic and financial variables. This article provides a relevant review of the power of cointegration and the error correction model.

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