Applied Economics and Finance; Vol. 13, No. 2; 2026
ISSN 2332-7294 E-ISSN 2332-7308
Published by Redfame Publishing

Public Capital and Economic Output (Labor Productivity) in Mexico: A Vector Error Correction Model with Impulse Response and Variance Decomposition Functions, 1960-2022

Miguel D. Ramirez[1]

[1] Professor of Economics, Emeritus, Department of Economics, Trinity College, Hartford, CT, United States

Correspondence: Miguel D. Ramirez, Professor of Economics, Emeritus, Department of Economics, Trinity College, Hartford, CT, United States.

Received: August 15, 2026 Revised: September 30, 2026 Accepted: November 20, 2026

Available online: November 24, 2026 URL: https://doi.org/10.11114/aef.v13i2.9550

Abstract

This paper investigates whether there is a long-run relationship between the private (public) capital stock and economic output (labor productivity) in Mexico over the 1960-2022 period. Several important findings are uncovered. First, it is established that the underlying private production function exhibits constant returns to scale and that the included regressors are non-stationary in level form (controlling for the presence of a single break via the Breakpoint Unit Root ADF test). Second, the non-stationary, I(1), variables included in the underlying production function have a stable and long-term (cointegrating) relationship even in the presence of a regime (shift and trend) break. Next, the VECM methodology determined that some of the included variables can be treated as weakly exogenous, viz., the of stock public capital and the labor force. Fourth, the Block Granger causality tests, along with the generalized impulse response functions (IRFs) and variance decompositions (VDCs) suggest that there is precedence or "causality" from the labor force, private capital, and public capital to economic output, and "double causality" between public and private capital, and precedence from output and the labor force to private capital (and only from the labor force to public capital). From a policy standpoint, the results suggest that across-the-board cuts in public spending to meet targeted fiscal deficits as a proportion of GDP should be made carefully (paying attention to their composition) so as not to undermine public capital (infrastructure) spending which, in turn, may negatively affect long-run growth and labor productivity.

Keywords: Block Granger causality test, Breakpoint Unit Root ADF test, Gregory-Hansen cointegration single-break test, Impulse response function (IRF), public capital stock, Johansen Cointegration test, labor productivity, KPSS no unit root test, Variance decompositions (VDCs), and vector error correction model (VECM)

JEL classification: C22, O40, O54

1. introduction

The important question of whether public capital (infrastructure) spending in the form of roads, bridges, ports, airfields, and reliable sources of energy is complementary to private capital and economic output has been investigated by a number of researchers in the field (see Albala-Bertrand and Mamatzakis, 2001; Aschauer, 1989, 1990; and 2000; Barro, 1990; Bom and Ligtthart, 2014; Cardoso, 1993; Ezzahid and Rafik, 2024; Ligthart, 2002; Lin, 1994; Looney, 1985; Mamatzakis, 1999; Pereira and Andraz, 2013; Ram, 1986; 1996; and Ramirez, 2000; 2002). As far as developing nations are concerned, the extant studies are constrained by the lack of reliable data for a sufficiently long period of time (or time span) to establish economically meaningful and statistically robust results. Mexico, along with a few other countries in Latin America (e.g., Argentina and Chile), are exceptions because they have sufficiently long and rich sources of data which enables researchers to determine whether a long-run (positive) relationship exists between the public (private) capital stock and economic (labor productivity). In this study, we utilize a standard neoclassical production function to empirically estimate the effects of the private and public capital stock on economic output and labor productivity in Mexico over the 1960-2022 period. From the outset, it should be pointed out that that these are incomplete results since we do not take into account the financing of public investment which entails taxes and borrowing (domestic and foreign), both of which may "crowd out" private capital formation and thus introduce distortions and costs that may exceed the social rate of return to public investment (Aschauer, 2000; Barro and Sala-i-Martin, 1995; Ezzahid and Rafik, 2024; Goldfajn et al., 2021; Killick 1995; and Solis, 1981)

The paper is organized as follows. First, a brief survey of the extensive literature on the complementarity hypothesis is provided. Second, the economic model and VECM methodology utilized in this study is presented. Next, the empirical model and the data utilized in this study are outlined. This is followed by standard unit root and cointegration tests utilizing the Johansen (1988;1990) and Gregory and Hansen (1996) tests. The VECM estimation results and generalized impulse response functions (IRFs) are presented in the fifth section utilizing the Pesaran and Shin (1998) methodology. The concluding and discussion section reports the major findings and limitations of this study, as well as policy implications and avenues for future research.

2. Literature Review

The literature examining the complementarity hypothesis is vast and this short highly selective review provides a brief survey of some of the major contributions. Aschauer (1989;1990; 2000) along with Barro (1990;1995) and Ram (1986) were the first to tackle this hypothesis both theoretically and empirically. In particular, Aschauer was among the first researchers to test the complementarity hypothesis for the United States and found, using a Cobb-Douglas generalized conceptual framework, that expenditures on economic infrastructure (roads, bridges, and ports) exerted a positive and statistically significant impact on private capital formation and total factor productivity for the period 1949-1985. Barro's seminal contribution stems from introducing in a rigorous fashion the impact of government expenditures on infrastructure in an endogenous (AK) growth model directly. He showed that government expenditures on economic infrastructure exert an inverse-U effect on the marginal productivity of capital and economic growth and provides cross-country regressions for the 1965-75 and 1975-85 periods which tend to support this hypothesis. That is, public investment spending on economic infrastructure stimulates private investment spending and growth up to a certain threshold before it becomes a drag on growth via excessive and distortionary taxation in the form of income taxes. Ram (1986), on the other hand, introduces the impact of public infrastructure spending in the form of an externality in a two-sector production function (Feder-type) model. He utilizes an extensive data set for 115 countries for the 1950-80 period and finds that, on average, public capital "crowds in" private capital, particularly in developing nations where basic infrastructure, broadly defined, is severely lacking. Cardoso (1993) utilizes a panel study for several major countries in Latin America covering the years 1970-85 and finds that, on average, cuts in public infrastructure spending are statistically associated with steep cuts in private investment spending, controlling for key variables such as the terms of trade and the real exchange rate. Ramirez (2000) utilizes cointegration and unit root analysis for Chile and finds that during the period covering 1960-1995 public and private investment spending, along with export growth, exerted a positive and statistically significant effect on labor productivity growth, ceteris paribus. Interestingly, he also reports that government consumption spending exerts a negative effect. Bertrand and Mamatzakis (2001) also undertake a time-series study for Chile using a VECM methodology and find that public infrastructure capital is strongly complementary to private capital both in the short and long run, particularly during the period of liberalization and institutional improvement associated with the return to democracy (1984-1995). Ramirez (2002), in another highly cited paper, utilizes an Engle-Granger error-correction model for Mexico covering the 1955-94 period and finds that public capital expenditures have a positive and significant effect on labor productivity growth, ceteris paribus. Finally, Bom and Lighthart (2014) employ a meta-analysis of 578 estimates from 68 studies over the 1983-2008 period and report that the overall average output elasticity of public capital is 0.106, and that it rises to 0.122 in the long run (controlling for publication bias and focusing only on central government capital expenditures), thus supporting the complementarity hypothesis.

3. Economic Model and Econometric Methodology

Following the lead of Albala-Bertrand and Mamatzakis (2001), Aschauer (1989;1990; 2000), Barro (1990;1995), Ezzahid and Rafik, (2024), Herzer & Nowak-Lehmann, 2006: Lin (1994), Mamatzakis (1999), Ram (1986), Ramirez (2000; 2002), and Solis (1981), this study employs a Cobb-Douglas production function that treats public (infrastructure) capital as a separate input:

$$Y = AK^{\alpha}L^{\beta}G^{\gamma} \quad (1)$$

where Y is real output, K is the private domestic capital stock, L is the labor force, G is the public capital stock, and A is a "Harrod-neutral" technology variable. When A increases over time, a unit of labor becomes more productive. α and β are assumed to be less than one, such as there are diminishing returns to labor and the stock of domestic private capital. It is also assumed that private production is supported by the flow of services from the public (infrastructure) capital stock (G), and that these services are a stable proportion of public capital.

Taking natural logs of Eq. 1, we obtain:

$$\ln Y = \ln A + \alpha \ln K + \beta \ln L + \gamma \ln G + \varepsilon \quad (2)$$

where ε is an error term that is normally distributed.

It is also possible to estimate the effect of public capital on labor productivity if the underlying private production function exhibits constant returns to scale ($\alpha + \beta = 1$)[1]; in this case, Eq. 2 is transformed by subtracting L from both sides to obtain:

$$y\text{-}l = a + \alpha(k\text{-}l) + \gamma g + \varepsilon \quad (3)$$

where lower case letters denote logs (a=lnA), y-l is labor productivity, k-l is the ratio of private capital to labor, and g is the public capital stock. The latter enters the production function as a complementary input, and it is expected that $\gamma > 0$.

3.1 Econometric Methodology

To use the VECM methodology, we must first determine whether there exists a stable and non-spurious (cointegrated) relationship among the I(1) regressors via the standard Johansen methodology (1988). The Johansen method was chosen over the one originally proposed by Engle and Granger (1987) because it is capable of determining the number of cointegrating vectors for any given number of non-stationary series (of the same order), its application is appropriate in the presence of more than two variables, and more important, Johansen (1988) has shown that the likelihood ratio tests used in this procedure (unlike the DF and ADF tests) have well-defined limiting distributions. In general, the Johansen method utilizes a vector autoregressive (VAR) model which can be written as follows:

$$\Delta Z_t = \phi + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-1} + \varepsilon_t \quad (4)$$

where ϕ is the vector (4x1) of constant terms, Δ is the difference operator, Z_t is the 4x1 vector of variables (y, l, k_p, and k_g) in the model, $\boldsymbol{\Gamma}$ is the coefficient matrix [$\boldsymbol{\Gamma}$i = -I + A_1 +A_2 +…. Ai [(i=1,2 … P- 1 (3)]. ε_t is the vector (4x1) of disturbance term. Π is the (4x4) coefficients matrix [Π= I-A_1 - A_2 -…. A_4]. The rank of the matrix, Π, for the level terms, shows the long-run relationship between Z_t variables; that is, when it of reduced rank it denotes the number of linearly independent and stationary linear combinations of variables. As shown by Johansen and Juselius (1990), there are two test statistics for evaluating the number of cointegrating vectors (CVs) (or the rank of Π) in the VAR model. The first is trace test (Tr). In trace test, H_0, or the null hypothesis, is that there are at most r CVs which implies the number of CVs is less than or equal to r, (r=0, 1, 2, 3). The second test statistic is the Maximum-Eigen value test. Under this test, the presence of r CVs can be assessed against the H1 or r+1 CVs. Therefore, H_o for testing numbers of CVs can be set as H_o: r = 0 against the alternative hypothesis $H_{A:}$ r=1, H_0: r = 1 against the H_A: r = 2, H0: r = 2 against the H_A: r = 3.

As far as the estimated labor productivity function in eq. (6a) is concerned, the system of equations in matrix form is given as follows:

$$\begin{pmatrix} \Delta(y-l)t \\ \Delta(kp-l)t \\ \Delta gt \end{pmatrix} = \begin{pmatrix} \mu 1 \\ \mu 2 \\ \mu 3 \end{pmatrix} + \sum_{i=1}^{k-1} \begin{pmatrix} \Gamma 11 & \Gamma 12 & \Gamma 13 \\ \Gamma 21 & \Gamma 22 & \Gamma 23 \\ \Gamma 31 & \Gamma 32 & \Gamma 33 \end{pmatrix} x \begin{pmatrix} \Delta(y-l)t-i \\ \Delta(kp-l)t-i \\ \Delta(g)t-i \end{pmatrix} + \begin{pmatrix} \alpha 1 \\ \alpha 2 \\ \alpha 3 \end{pmatrix} (\beta 1\ \beta 2\ \beta 3) \begin{pmatrix} y-l \\ kp-l \\ g \end{pmatrix} + \begin{pmatrix} \varepsilon 1 \\ \varepsilon 2 \\ \varepsilon 3 \end{pmatrix} \quad (5)$$

Where the μ's are constants and the ε's are i.i.d. error terms. The estimation of the matrix Γ contains information on the short-run adjustments to changes in the included variables, while the matrix Π contains information on the long-run adjustments (α's).

4. Empirical Model

The most general formulation of the production (labor productivity) functions for estimation purposes is, respectively, given below,

$$y = \alpha + \beta_1 l + \beta_2\, kp + \beta_3\, kg + \beta_4\, D_1 + \beta_5 D_2 + \varepsilon_t \quad (6)$$

or

[1]The Wald test on the underlying private production function suggested that the null hypothesis of constant returns to scale cannot be rejected at conventional levels (Chi-square = 0.978, p-value= 0.323).

$$y\text{-}l = \alpha + \beta_1 (kp\text{-}l) + \beta_2 g + \beta_3 T + \beta_4 D_1 + \beta_5 D_2 + \mu_t \quad (6a)$$

y represents the natural log of real GDP (1970 pesos); l, as indicated above, refers to the natural log of the EAP; k_p denotes the natural log of the stock of private capital (1970 pesos); g denotes the log of the stock of public capital (1970 pesos); T is a time trend; D_1 is a dummy variable that equals 1 for the economic (pandemic) crises years of 1976, 1982-83, 1987, 1995, 2001, 2009, 2020, and 0 otherwise; D_2 equals 1 for the petroleum-led expansion of 1978-81, and 0 otherwise; Finally, ε_t and μ_t are normally distributed error terms.

4.1 Data

Mexico has a sufficiently long (and official) time series data set (extending back to the decade of the fifties and sixties) for a number of key variables, including private investment spending, public capital (infrastructure) formation, and the economically active population (proxy for the labor force), so that using a perpetual inventory method capital stock data can be generated for the different types of capital. Thus, there are enough annual data points (63) to test empirically whether these flows have a beneficial or adverse impact on economic growth and labor productivity. Figure A1 in the Appendix shows the erratic and deficient performance (since 1981) of the growth rate in Mexican real GDP over the 1960-2022 period.

The economic data used in this study were obtained from official government sources such as INEGI (various issues), Nacional Financiera, S.A., La Economia Mexicana en Cifras, the Banco de Mexico, Informe Anual (various issues), and Solis (1981). Private and public investment data for Mexico have been obtained from Bouton and Sumlinski (2001), International Finance Corporation, Trends in Private Investment in Developing Countries: Statistics for 1970-2000. All the data utilized in this study are in real 1970 pesos and the private and public capital stock data were generated using a standard perpetual inventory model assuming an estimate of the rate of depreciation of 5 percent.[2]

4.2 Unit Root Analysis

This study first utilized conventional unit root tests to test deterministic and/or stochastic trends that render the variables in question non-stationary, i.e., they have means, variances, and covariances that are not time invariant. Engle and Granger (1987) showed that the direct application of OLS or GLS to non-stationary data produces regressions that are mis-specified or spurious in nature. The variables in question were first evaluated for a unit root (non-stationarity) by using an Augmented Dickey-Fuller test (ADF) (Dickey-Fuller, 1981) with a constant and deterministic trend.

It is important to acknowledge that when dealing with historical time series data for developing countries such as Mexico or Argentina investigators are often constrained by the small number of time series observations (usually in annual terms). This is not the case in this study where the sample size (63) is well above the threshold level of 50 observations recommended by Granger and Newbold (1986); failure to meet this threshold compromises both the power of the unit root (and cointegration) tests and distorts the size or significance of the tests [(see Asteriou, 2021; Charemza and Deadman, 1997; and Harris, 1995).

5. Estimations and Results

Adhering to the Dolado et al. (1990) procedure, Table 1 (part A) below presents the results of running an Augmented Dickey-Fuller test (one lag) on the variables in logarithmic form with a constant and a deterministic trend.[3] The results indicate that the null hypothesis of non-stationarity cannot be rejected for any of the variables in level form with a deterministic trend, suggesting that the variables in question do not exhibit a deterministic time trend throughout the period under review. In other words, the customary practice of detrending the data by a single trend line will not render the data in question stationary because the trend line itself may be shifting over time (Charemza and Deadman, 1997). When the ADF test is applied to these variables in first differences under the assumption of a constant and deterministic time trend, all the variables, except for the g variable, become stationary at the five percent level of significance. The Dolado procedure determined that the g variable should be tested without a trend and with a constant, and it is

[2] The stocks of private domestic and public capital were generated via a standard perpetual inventory model. The initial stocks of private domestic and public capital were estimated by aggregating over 10 years of gross investment and assuming a rate of depreciation of 5%. The unavailability of data prevented the use of the recommended 20 years. A depreciation rate of 10 % was also used and the results were qualitatively the same. See Figure A2 in the Appendix for a visual representation of the log of the stocks of private and public capital, respectively. For further details, see Ramirez, 2000; Looney, 2001, and Solis, 1981.

[4]The Dolado et al. procedure starts by estimating the most general (unrestricted) model (with a constant and a trend) before moving to the next more restricted model (a constant only), and so on. The order of the lag length was determined by applying the Schwartz Bayesian Criterion (SBC).

stationary in first difference at the 6 percent level (p-value: 0.0631).

In view of the low power of the ADF unit root tests when the data generating process is stationary but with a root close to the unit root, Table 1 (part B) presents the results of running a KPSS stationarity test (Kwiatkowski et al., 1992). This test has a no unit root (stationary) null hypothesis, thus reversing the null and alternative hypotheses under the Dickey Fuller test. It is used as a confirmatory test because in the presence of insufficient information, due to a small sample size, it defaults to the stationary data generating process. The reported results in both level and differences under the assumption of a deterministic trend are broadly consistent with those reported in Table 1 (part A), with g marginal at the 5 percent level. For example, the null hypothesis of no unit root can be rejected for all the variables in level form at the 5 percent level of significance, i.e., they follow a random walk with (positive) drift. In the case of first differences, however, the null hypothesis of stationarity cannot be rejected for all variables at least at the 5 percent level. Thus, the evidence presented suggests that the variables in level form follow primarily a stochastic trend as opposed to a deterministic one, although the possibility that for given subperiods they follow a mixed process cannot be rejected (Asteriou, 2021; Harris, 1995).[4]

Table 1. Part A. ADF Unit Root Tests for Stationarity with constant and time trend, Sample Period 1960-2022.

Variables	Level	First Difference	5% Critical Value
y	-1.34	-8.88*	-3.48
l	-0.02	-7.64*	-3.48
kp	-0.77	-3.63*	-3.48
g	-2.65	-2.81[a]	-3.48

Note: MacKinnon (1996) critical values for rejection of hypothesis of a unit root. * Denotes significance at the 5 percent level; [a]The Dolado procedure determined that for the g variable the trend should be excluded because it was statistically insignificant. The 5% and 10 % critical values for the ADF statistic without a trend but with a constant are, respectively, -2.91 and -2.59. The p-value for the ADF statistic for the g variable is: 0.0631.

Table 1. Part B. KPSS (LM) No Unit Root Tests for Stationarity with constant and time trend, Sample Period 1960-2022

Variables	Levels	First Difference	5% Critical Value1
y	0.24*	0.04	0.15
l	0.22*	0.14	0.15
kp	0.19*	0.08	0.15
g	0.87*	0.34	0.46[a]

[1] Asymptotic critical values for rejection of null hypothesis of no unit root (LM-Stat.). *Denotes significance at 5 percent level.

5.1 Cointegration Analysis with Structural Breaks

[5] Table 2. below reports the Johansen maximum L.R. (Trace) test for cointegration for only the output equation. The first column of the table gives the eigenvalues in descending order, while the second column reports the corresponding trace statistics generated from the maximum L.R. test statistic. The next two columns report, respectively, the 5 percent

[4] The power of conventional unit root tests is significantly reduced when the stationary alternative is true and a structural break is ignored (see Perron, 1989); that is, the investigator may commit a Type II error. To address this potential problem, we utilized the Eviews 14.0 B*reakpoint Unit Root ADF test* developed by Perron and Vogelsang (1998), and the unit root hypothesis could not be rejected for any of the included variables in level form at the 5 percent level. The p-values and break years (in parenthesis) for the y, l, and kp variables (with intercept and trend) in level form are, respectively: 0.99 (1977), 0.91 (1979), and 0.99 (1964). The Breakpoint p-value and break year for the g variable in level form with only an intercept is: 0.192 (1971). All the variables in question (accounting for one single break) are stationary in difference form (results are available upon request). [a]The test for the g variable is undertaken without a trend.

[5.] The Johansen and Juselius (1990) method determined that there exists a stable and unique long-run relationship among the variables in logarithmic form. Utilizing the Pantula (1989) selection procedure, it was determined that *Model 3* should be chosen because it is the *last* significant estimate *before* the null of no cointegration *cannot* be rejected. In *Model 3* the cointegrating eq. includes a constant as well as the short-run dynamic eq. The likelihood ratio (LR) test suggests that the null hypothesis of no cointegration can be rejected at the 5% level [trace statistic = 58.90 > critical value (5%) = 47.86]; and Max-Eigen statistic = 33.79 > critical value (5%) =27.58]. In the case of the *labor productivity* function the Pantula principle determined that *Model 4* (cointegrating trend and dual constant) should be chosen; in this case, the likelihood ratio (LR) test indicates that the null hypothesis of no cointegration can be rejected at the 5% level [trace statistic = 52.54 > critical value (5%) = 42.92; and Max-Eigen statistic = 31.57 > critical value (5%) =25.82].

critical and p-values, while the last column gives null hypotheses, ranging from no cointegrating relationships up to at most three cointegrating vectors. It can be seen from the L.R. ratio statistics that, in the presence of a constant in the cointegrating and VAR equation, there exists a linear combination of the I (1) variables that links them with a stable and long-run relationship. In fact, the p-value reported the table shows that the null hypothesis of no cointegrating vector can be rejected at least at one percent level.

Table 2. Johansen Cointegration (Trace) Test, 1960-2022

Eigenvalue	Likelihood Ratio	5%	P-value	No. of CE(s)
0.421	**47.85**	**56.50***	**0.005**	**None**
0.155	22.00	29.79	0.315	at Most 1
0.114	11.38	15.49	0.272	at Most 2
0.057	3.72	3.84	0.054	at Most 3

Estimations undertaken with Eviews 14.0; *denotes significance at 5 percent level. Series: y, l, k_p , and g. Test assumptions: Intercept in CE and in VAR; D_1, and D_2 are treated as exogenous variables.

Cointegrating Equation (CE): Unrestricted constant (Model 3)

$$CE = y(-1) - [0.537*l(-1) + 0.541*kP(-1) + 0.292*g(-1)] \quad (7)$$

$$(5.86)* \qquad (4.68)* \qquad (4.38)*$$

T-ratios are in parenthesis and the signs are reversed because of the normalization procedure. Comparable results were obtained for the labor productivity function (which includes a trend variable), and they are reported below:

Cointegrating Equation (CE): Cointegrating Trend and Unrestricted constant (Model 4)

$$CE = (y-l)(-1) - [0.477*(kp-l)(-1) + 0316*g(-1) - 0.018T] \quad (8)$$

$$(3.93)* \qquad (4.50)* \qquad (3.02)*$$

The signs in eq. (8) are reversed due to the normalization process. Notice that the sign on the trend variable is negative in eq. (8) above, and it suggests that Mexican labor productivity has fallen 1.8 percent per year (on average) over the 1960-2022 period. Before moving on to the VECM results, it should be noted that Gregory and Hansen (1996) have shown that ignoring structural breaks also reduces the power of conventional cointegration tests, similar to conventional unit root tests. Thus, this study undertook a confirmatory G-H cointegration test with level shift and the results, and the results are consistent with those of the Johansen cointegration test.[6] Finally, the residuals for all of the reported equations were also checked for normality via the Jarque-Bera test, and the null hypothesis that the residuals are normally distributed could not be rejected for any of the reported equations at the 5 percent level.

5.2 VECM Results

An unrestricted VECM was estimated using y, l, kp, and g variables to examine whether a system-wide error correction mechanism exists for these variables. The VECM is estimated based on Model 3 with 1-3 lags (without the exogenous dummy variables). The unrestricted VECM finds negative and significant adjustment coefficients for two eqs., D(y) and D(Kp), where the "D" operator denotes the change in the variable. This means that these variables (y and Kp) work as an endogenous system in which there is a short-run adjustment mechanism back to the equilibrium relationship after a shock. For example, in the D(y) eq., a 10 percent deviation from the long-run economic output relationship is corrected by about 2.6 percent on an annual basis, while a similar deviation generates a 1.3 percent correction in the D(kp) eq. See summary below.

Error Correction System:

	D(y)	D(l)	D(kp)	D(g)
Error Correction Coefficient	-0.256	0.031	-0.127	0.185
t-statistics	(-2.966)*	(0.232)	(-4.501)*	(1.244)
Adj. R-squared	0.757	0.296	0.802	0.896
Schwarz info. Criterion	-3.410	-3.860	-5.568	-4.415

[7] The G-H cointegration test was performed with endogenously determined level (intercept) shift *and* trend and obtained a minimum ADF* stat. = -5.63 [break point=1992] which is smaller than the tabulated 5 % critical value [-5.77 (1%); -5.28(5%); -5.02(10%)] reported by Gregory and Hansen. Thus, the null hypothesis of no cointegration with endogenously determined break is rejected at the 5 percent level of significance. The Rats program selects the break date where the modified [trimmed] ADF* = inf ADF (τ) test statistic is at its minimum. All estimations were undertaken with Rats 11.0 and are available upon request.

The VECM framework enables researchers to impose zero restrictions on the adjustment coefficients of each equation, thus determining which variable can be treated as weakly exogenous and omitted from the system; the hypothesis of a zero restriction cannot be rejected for each variable is set at the 5 percent level. The VECM framework also allows one to impose restrictions on the number of cointegrating vectors; in this study a restriction of one cointegrating vector was imposed, viz., b (1,1) =1, and we failed to reject the null hypothesis of unique one cointegrating vector at a p-value of 0.495. As can be seen below, the labor force (l) and public capital (g) variables had a p-value greater than the 0.05 threshold, so they are treated as exogenous (excluded) from the system. In other words, in this simple four equation system, y and kp are treated as endogenous. A summary of the exogeneity tests is given below.

Ho: weakly exogenous variable

		Chi-Square statistics	Probability
D(y)	a (1,1) =0	4.893	0.046
D(l)	a (2,1) =0	0.877	0.349
D(kp)	a (3,1) =0	6.300	0.012
D(g)	a (4,1) =0	0.998	0.317

To investigate further the "causal" relationship among these variables, we performed a Granger Block Causality test on the included variables. This test examines all four equations and tries to determine whether the presumed exogenous variables can be excluded from each equation. This test finds "causality" or precedence in the D (y), D(kp) and D(g) eqs. at the 5% level; viz., from D(l), D(kp) and D(g) to D(y) in the first eq., from D(y), D(l) and D(g) to D(kp) in the third eq., and from D(l) and D(kp) to D(kg) in the fourth equation (see Table A1 below). Comparable results were obtained when using 1 and 2 lags, as well as for the labor productivity function. All estimations undertaken with Eviews 14.0.

Turning to Figure A2 below, it shows the generalized—not Cholesky--impulse responses of the four variables to both a unitary shock in their own values and the rest of the variables over a 10-year period. The Cholesky decomposition is arbitrary and sensitive to the ordering of the variables; thus this study employed a generalized decomposition process first proposed by Pesaran and Shin (1998). It constructs an orthogonal set of innovations that does not depend on the VAR ordering. It can be seen that the response of the natural log of real GDP (LRGDP1 or y) to a one standard deviation (SD) innovation in private capital (LKP4 or kp) or (LEAP1 l) is significant and sustained after 2 to 3 periods, while the reverse line of "causation" is considerably smaller and dissipates after 3 to 4 years. The figure also shows that the lagged response of real GDP to a one (SD) innovation in public capital (LKG4 or g) is also significant (after 2 periods) and sustained until 4 to 5 years before waning. The figure also suggests that there appears to be double "causation" between private and public capital in terms of their, respective, lagged responses to each other's one (SD) innovation in their values. The graph suggests that a one (SD) innovation in private capital generates a sustained and positive effect on the labor force (LEAP1 or l) after 2 to 3 years, and the response is significantly less in the case of a one (SD) innovation in public capital. This study also traced the variance decompositions (VDCs) of each variable over a 10-year period. The VDCs gives information about the relative importance of each one (SD) shock to the endogenous variables in the VECM. The results given in Table A2 below suggest that, after 10 years, a unitary innovation in private capital explains 20 % of the accumulated forecast error of real GDP, while a unitary innovation in public capital explains about 26 percent of the accumulated forecast error of real GDP. The reported VDCs also suggest that the accumulated response of public capital to a unitary innovation in private capital, and vice-versa are, respectively, 21 % and 17%. There is also a significant accumulated response of public capital (25.7 %) to a unitary shock in real GDP, and less so in the accumulated response of private capital (8.5 %) to a unitary innovation in real GDP, ceteris paribus.

Before concluding, this econometric exercise generated estimates for a labor productivity growth function of the following form:

$$\Delta y_t = \alpha + \beta_1 \Delta kp_{t-i} + \beta_2 \Delta g_{t-i} + \beta_3 ECT_{t-1} + \beta_4 T + \beta_5 D_1 + \beta_6 D_2 + \varepsilon_t \quad (9)$$

where lower case letters denote natural logarithms of the relevant variables in per worker (EAP) terms, and Δ is the difference operator; y denotes the natural log of output per worker (1970 pesos); Δy_t is the labor productivity growth rate and it is defined as, (ΔlnY - Δln); k_p denotes the natural log of the stock of private capital per worker (1970 pesos); g denotes the natural log of public capital (1970 pesos); ECT is the error-correction term obtained from the unique cointegrating vector of the system; Δk_{pt} is the growth rate in the private capital stock per worker and is defined as (ΔlnK_p - ΔlnL); T is a time trend and it was included in the regression because the Pantula principle (see footnote 5 above) determined that Model 4 should be utilized when estimating the labor productivity function; and D_1 is a dummy

variable that equals 1 for the economic and political crises years of 1976, 1982-83, 1987, 1995, 2001, 2009, 2020, and 0 otherwise, while D_2 equals 1 for the petroleum led expansion of 1978-81. Figure A3 in the Appendix shows the actual and in-sample forecasts generated by an error correction model for the labor productivity equation. The Theil inequality coefficient of 0.269 is well below the recommended threshold of 0.30, and the bias proportion (0.000), variance proportion (0.110), and covariance proportion (0.889) are remarkably close to their theoretical values (0,0,1). As is evident from the graph the in-sample forecasts can track the turning points of the actual series relatively well, and they show the downward trajectory of labor productivity for Mexico since 1980-81. Stability diagnostics for the residuals from eq. 8 were also undertaken, and Figure A4 below shows that the cumulative sum of square (CUSUMSQ) test of the residuals are within the 5% critical bounds without crossing upper or lower bounds, suggesting that the chosen model is structurally stable. Finally, residual diagnostic tests reported in Table A3 below (viz., the Breusch-Godfrey serial correlation test and the Breusch-Pagan-Godfrey Homoskedasticity test) for the labor productivity growth equation suggest that the model does not exhibit either serial correlation or heteroskedasticity. The correlogram shown in Figure A5 provides clear visual evidence that the residuals are white noise (see p-values for Q-stat.).

6. Discussion and Conclusion

This paper utilized a VECM methodology to address the important question of whether there is a long-run relationship between the private (public) capital stock and economic output (labor productivity) in Mexico over the 1960-2022 period. Most studies in the literature for emerging nations have an insufficient number and/or time span of observations to test the complementarity hypothesis. Mexico, and a few other developing nations (e.g., Argentina and Chile) are the exception. Several important findings were revealed. First, it was established that the underlying private production function exhibits constant returns to scale and that the included regressors are non-stationary in level form (controlling for the presence of a single break via the Breakpoint Unit root Test developed by Perron and Vogelsang, 1998); testing for structural breaks is a novel and major contribution of this paper relative to other papers published on this topic on Mexico and other Latin economies such as Chile and Argentina. Second, the non-stationary, I(1), variables included in the underlying production function have a stable and long-term (cointegrating) relationship even in the presence of regime (shift and trend) break. The latter is also an important and novel contribution of this study on the Mexican economy. Third, the VECM methodology revealed that the output and private capital variables are endogenous, while the labor force and public capital variables can be treated as weakly exogenous. Fourth, the the Block Granger causality tests, along with the generalized impulse response functions (IRFs) and variance decompositions (VDCs) suggest that there is precedence or "causality" from the labor force, private capital, and public capital to economic output, and "double causality" between public and private capital, and precedence from output and the labor force to private capital (and only from the labor force to public capital). Insofar as the extant literature on Mexico is concerned, this is one of the first studies to explicitly test for complementarity between public and private capital (and causality) using the Block Granger methodology, and the reported findings are broadly consistent with those found in the extant literature (see Albala-Bertrand & Mamatzakis 2001; Aschauer, 1989; and Bom & Ligthart, 2014. Moreover, the estimates from the labor productivity growth function show that it can track the turning points and overall trajectory of in-sample labor productivity relatively well.

As indicated in the introduction, one of the limitations of this study is that it does not account for the financing of public capital spending which, via additional taxes and public borrowing (and a Ricardian equivalence effect), may "crowd out" private investment and consumption spending, thus negating the stimulative effects of public capital formation on real per capita income. In order to address this problem, a general equilibrium framework a la Barro and Sala-i-Martin (1995) would have to be utilized where the relation between the size of the government sector (in an endogenous AK model) and the economy's per capita growth rate is U-shaped (inverted). Keeping in mind the partial equilibrium approach utilized in this study, which is prevalent in the empirical literature, the policy implications suggest that across-the-board cuts in public spending to meet targeted fiscal deficits as a proportion of GDP should be made carefully (paying attention to their composition) so as not to undermine public capital (infrastructure) spending which, in turn, may negatively affect long-run growth and labor productivity. Another limitation of this study arises from its single-country scope and the presence of macroeconomic structural breaks between 1960 and 2022, which may restrict the applicability of the estimates to different institutional and historical contexts.

Finally, in terms of future avenues for research, the reported findings in this study need to be supported by sectorial (panel-cointegration) analysis which focuses on whether public capital expenditures are more (or less) complementary to private capital spending in the primary, industrial, and service sectors of the Mexican economy. Another important area of investigation opened up by this study, provided that the data is available for the period under review, is to test whether government consumption expenditures (e.g., wages, salaries and benefits paid to government administrators and workers) are more likely to substitute rather than complement private investment spending, ceteris paribus.

Acknowledgments

The author would like to thank the reviewers and the editor for their helpful comments and suggestions for improvement of the original draft.

Author Contributions

Not applicable

Funding

Not applicable

Competing Interests

Not applicable

Informed Consent

Obtained.

Ethics Approval

The Publication Ethics Committee of the Redfame Publishing.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and Peer Review

Not commissioned; externally double-blind peer reviewed.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.

Open Access

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).

Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

References

Albala-Bertrand, J. M., & Mamatzakis, E. C. (2001). Is public infrastructure productive? Evidence from Chile. *Applied Economics Letters, 8*(3), 195-199. https://doi.org/10.1080/13504850150504595

Aschauer, D. A. (1989). Public investment and productivity growth in the Group of Seven. *Federal Reserve Bank of Chicago, Economic Perspectives, 13*, 17-25.

Aschauer, D. A. (1990). Is government spending stimulative? Contemporary Economic Policy, 8(4), 30-46. https://doi.org/10.1111/j.1465-7287.1990.tb00300.x

Aschauer, D. A. (2000). Public capital and economic growth: Issues of quantity, finance, and efficiency. *Economic Development and Cultural Change, 48*(2), 391-406. https://doi.org/10.1086/452464

Asteriou, D., & Hall, S. G. (2021). *Applied econometrics. Red Globe Press.*

Barro, R. J. (1990). Government spending in a simple model of endogenous growth. *Journal of Political Economy, 98*(5), 103-125. https://doi.org/10.1086/261726

Barro, R. J., & Sala-i-Martin, X. (1995). *Economic growth. McGraw-Hill.*

Bom, P. R., & Ligthart, J. E. (2014). What have we learned from three decades of research on the productivity of public capital? *Journal of Economic Surveys, 28*(5), 889-916. https://doi.org/10.1111/joes.12037

Bouton, L., & Sumlinski, M. (2001). *Trends in private investment in developing countries: Statistics for 1970-2000.* International Finance Corporation. https://doi.org/10.1596/0-8213-3874-9

Cardoso, E. (1993). Private investment in Latin America. *Economic Development and Cultural Change, 41*(4), 833-848.

Charemza, W. W., & Deadman, D. F. (1997). *New directions in econometric practice: General to specific modelling, cointegration and vector autoregression.* Edward Elgar.

Goldfajn, I., Martinez, L., & Valdez, R. O. (2021). Washington Consensus in Latin America: From raw model to straw man. *Journal of Economic Perspectives, 35*(3), 109-132. https://doi.org/10.1257/jep.35.3.109

Dolado, J., Jenkinson, T., & Sosvilla-Rivero, S. (1990). Cointegration and unit roots. *Journal of Economic Surveys, 4*(3), 249-273.

Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica, 55*(2), 251-276. https://doi.org/10.2307/1913236

Ezzahid, E., & Rafik, H. (2024). Analyzing the impact of public capital on private capital productivity in a panel of African nations. *Economies, 12*(5), 118. https://doi.org/10.3390/economies12050118

Gregory, A. W., & Hansen, B. E. (1996). Tests for cointegration in models with regime and trend shifts. *Journal of Econometrics, 70*(1), 99-126.

Harris, R. (1995). *Using cointegration analysis in econometric modelling.* Prentice-Hall.

Herzer, D., & Nowak-Lehmann, F. D. (2006). Is there a long-run relationship between exports and imports in Chile? *Applied Economics Letters, 13*(15), 981-986. https://doi.org/10.1080/13504850500425832

Johansen, S. (1988). Statistical analysis of cointegrating vectors. *Journal of Economic Dynamics and Control, 12*(2-3), 231-254.

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—With applications to the demand for money. *Oxford Bulletin of Economics and Statistics, 52*(2), 169-210. https://doi.org/10.1111/j.1468-0084.1990.mp52002003.x

Killick, T. (1995). IMF programmes in developing countries. Routledge. https://doi.org/10.4324/9780203400357

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., & Shin, Y. (1992). Testing the null hypothesis of stationarity against the alternative of a unit root. *Journal of Econometrics, 54*(1-3), 159-178. https://doi.org/10.1016/0304-4076(92)90104-Y

Ligthart, J. E. (2000). *Public capital and output growth in Portugal: An empirical analysis (*IMF Working Paper No. 00/151). International Monetary Fund. https://doi.org/10.5089/9781451842777.001

Looney, R. E. (1985). *Economic policymaking in Mexico.* Duke University Press.

Nacional Financiera, S. A. La economía mexicana en cifras. Nafinsa.

Pantula, S. G. (1989). Testing for unit roots in time-series data. *Econometric Theory, 5*(2), 256-271. https://doi.org/10.1017/S0266466600012421

Pereira, A. M., & Andraz, J. M. (2013). On the economic effects of public infrastructure investment: A survey of the international evidence. *Journal of Economic Development, 38*(4), 1-37. https://doi.org/10.35866/caujed.2013.38.4.001

Perron, P., & Vogelsang, T. J. (1998). Additional tests for a unit root allowing for a break in the trend function at an unknown time. *International Economic Review, 39*(4), 1073-1100. https://doi.org/10.2307/2527353

Pesaran, M. H., & Shin, Y. (1998). Generalized impulse response analysis in linear multivariate models. *Economics Letters, 58*(1), 17-29. https://doi.org/10.1016/S0165-1765(97)00214-0

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics, 16*(3), 289-326. https://doi.org/10.1002/jae.616

Ram, R. (1986). Government size and economic growth. *American Economic Review, 76*(1), 195-203.

Ram, R. (1996). Productivity of public and private investment in developing countries: A broad international perspective. *World Development, 24*(8), 1373-1378. https://doi.org/10.1016/0305-750X(96)00036-8

Ramirez, M. D. (2000). Public capital formation and labor productivity growth in Chile. *Contemporary Economic Policy, 18*(2), 159-169. https://doi.org/10.1093/cep/18.2.159

Ramirez, M. D. (2002). Public capital formation and labor productivity growth in Mexico. *Atlantic Economic Journal, 30*(4), 366-379. https://doi.org/10.1007/BF02298779

Solís, L. (1981). *La realidad económica mexicana: Retrovisión y perspectivas. Siglo XXI Editores.*

Appendices

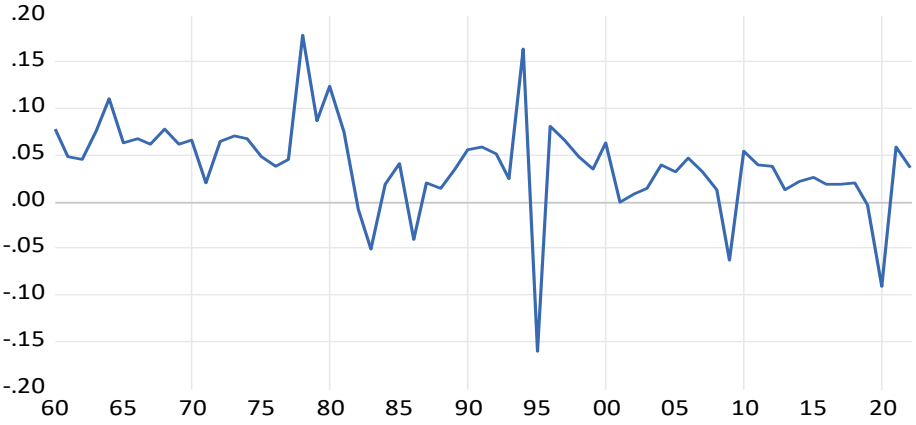


Figure A1. Percentage Change in Real GDP for Mexico, 1960-2022.

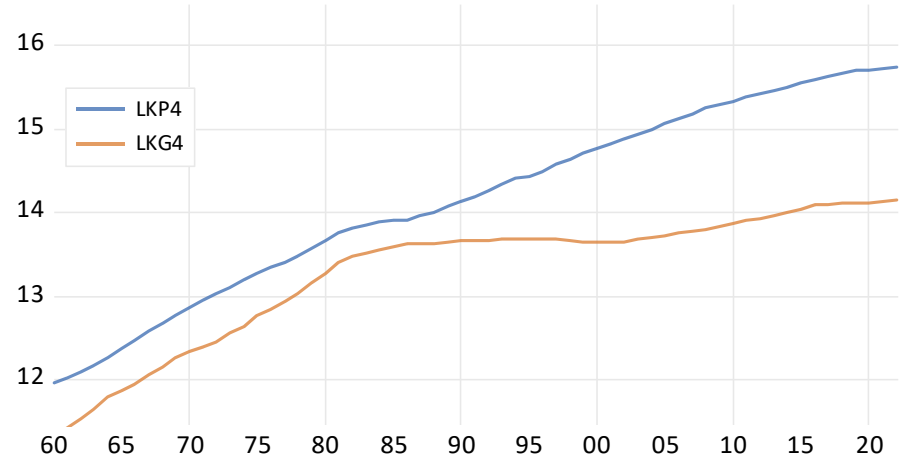


Figure A2. Logs of the Stocks of Domestic Private Capital (LKP4) and Public Capital (LKG4), 1960-2022

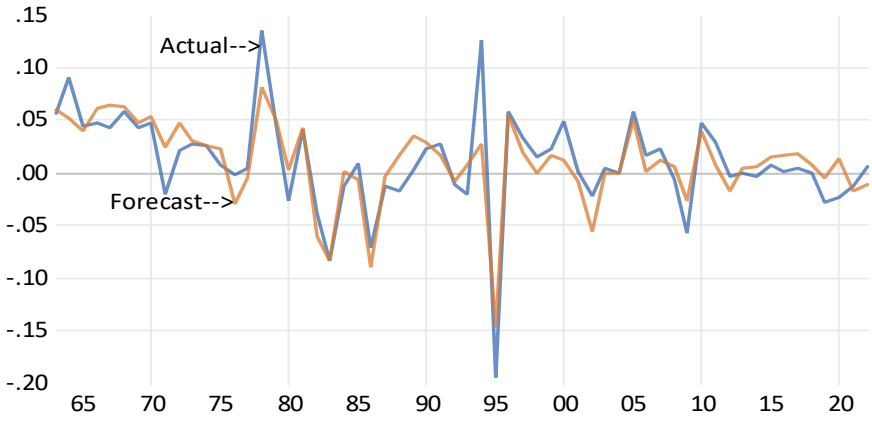


Figure A3. Actual and In-Sample Forecast of the Growth Rate in Labor Productivity for Mexico, 1963-2022

Table A1. VEC Granger Causality/Block Tests

VEC Granger Causality/Block Exogeneity Wald Tests
Date: 05/13/26 Time: 10:52
Sample: 1960 2022
Included observations: 63

Dependent variable: D(LRGDP1)

Excluded	Chi-sq	df	Prob.
D(LEAP1)	15.94567	3	0.0012
D(LKP4)	11.60431	3	0.0089
D(LKG4)	9.503157	3	0.0233
All	46.49212	9	0.0000

Dependent variable: D(LEAP1)

Excluded	Chi-sq	df	Prob.
D(LRGDP1)	0.763863	3	0.8581
D(LKP4)	0.915062	3	0.8218
D(LKG4)	1.039212	3	0.7918
All	4.490780	9	0.8763

Dependent variable: D(LKP4)

Excluded	Chi-sq	df	Prob.
D(LRGDP1)	20.83631	3	0.0001
D(LEAP1)	25.34897	3	0.0000
D(LKG4)	7.807607	3	0.0502
All	39.74705	9	0.0000

Dependent variable: D(LKG4)

Excluded	Chi-sq	df	Prob.
D(LRGDP1)	2.825013	3	0.4194
D(LEAP1)	8.189267	3	0.0423
D(LKP4)	8.774316	3	0.0324
All	18.03370	9	0.0348

Table A2. Variance Decompositions (VDCs)

Accumulated Response of LRGDP1:

Period	LRGDP1	LEAP1	LKP4	LKG4
1	0.033297	0.009235	0.012250	0.015661
2	0.056486	0.018851	0.026579	0.036081
3	0.084799	0.036108	0.044756	0.060189
4	0.112092	0.055178	0.064681	0.086455
5	0.140103	0.076979	0.086046	0.114077
6	0.167906	0.100341	0.108205	0.142452
7	0.195626	0.125094	0.130850	0.171188
8	0.223088	0.150864	0.153715	0.200010
9	0.250280	0.177455	0.176636	0.228740
10	0.277166	0.204689	0.199499	0.257263

Accumulated Response of LEAP1:

Period	LRGDP1	LEAP1	LKP4	LKG4
1	0.006764	0.024388	0.003663	-3.97E-05
2	0.013372	0.046126	0.009103	0.002749
3	0.021435	0.069149	0.016224	0.007450
4	0.030137	0.092464	0.024555	0.013686
5	0.039532	0.116157	0.033867	0.021133
6	0.049423	0.140063	0.043943	0.029541
7	0.059740	0.164132	0.054627	0.038717
8	0.070398	0.188303	0.065797	0.048511
9	0.081339	0.212541	0.077357	0.058806
10	0.092515	0.236820	0.089234	0.069509

Accumulated Response of LKP4:

Period	LRGDP1	LEAP1	LKP4	LKG4
1	0.004050	0.001653	0.011008	0.003193
2	0.011125	0.005243	0.029748	0.012509
3	0.019738	0.013369	0.053748	0.026677
4	0.029297	0.025789	0.081331	0.044311
5	0.039217	0.041740	0.111258	0.064199
6	0.049167	0.060519	0.142663	0.085419
7	0.058907	0.081514	0.174927	0.107309
8	0.068293	0.104253	0.207620	0.129406
9	0.077240	0.128362	0.240447	0.151401
10	0.085706	0.153555	0.273209	0.173092

Accumulated Response of LKG4:

Period	LRGDP1	LEAP1	LKP4	LKG4
1	0.006783	-2.35E-05	0.004183	0.014422
2	0.018345	8.75E-05	0.012452	0.037238
3	0.035103	-0.002390	0.024942	0.067075
4	0.056324	-0.007883	0.041432	0.103102
5	0.081708	-0.016056	0.061711	0.144756
6	0.110815	-0.026584	0.085504	0.191543
7	0.143286	-0.039110	0.112527	0.242996
8	0.178766	-0.053341	0.142495	0.298674
9	0.216937	-0.069025	0.175132	0.358159
10	0.257506	-0.085951	0.210175	0.421063

Generalized One S.D. Innovations

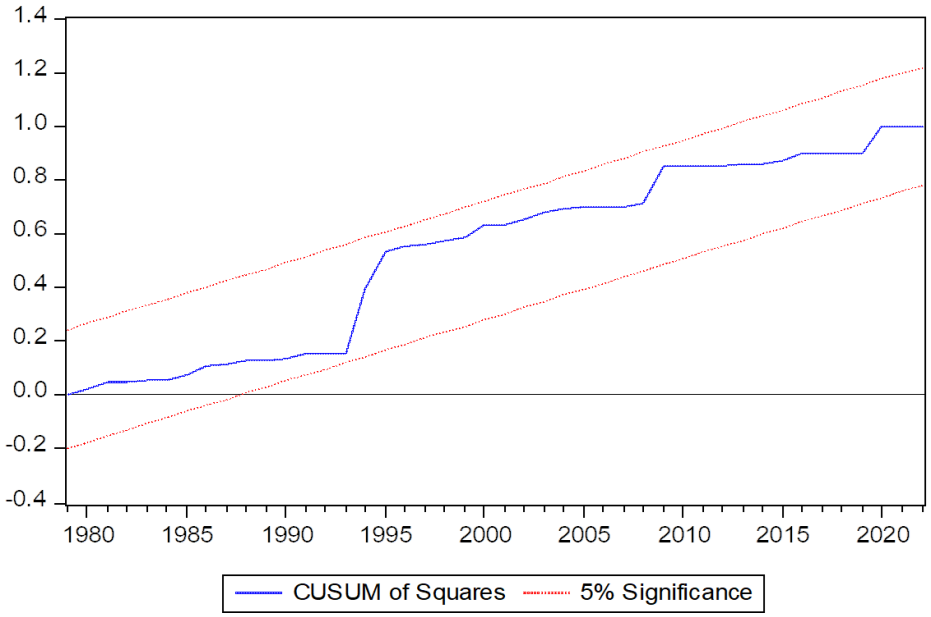


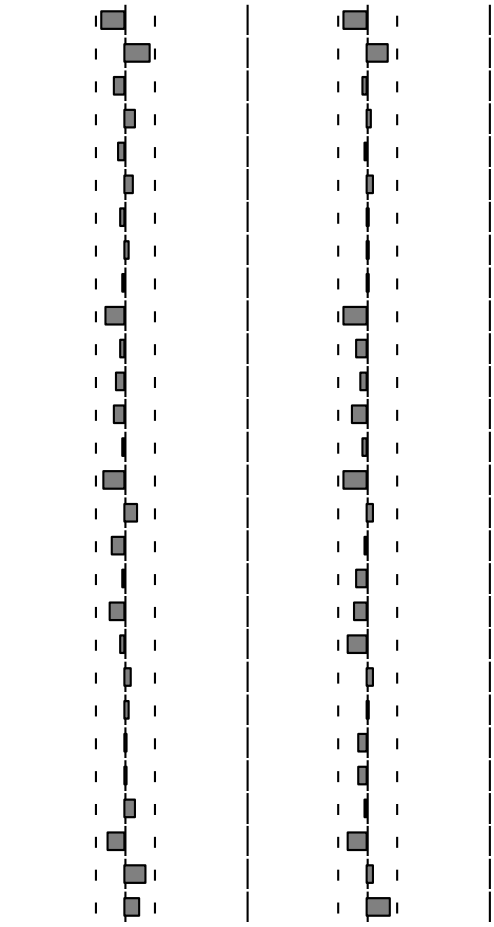
Figure A4. Stability Diagnostics: Cumulative Sum of Squares (CUSUMSQ) Test

Table A3. Residual Diagnostic Results

Breusch-Godfrey Serial Correlation LM Test: Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	0.939915	Prob. F(2,53)	0.3971
Obs*R-squared	2.157975	Prob. Chi-Square(2)	0.3399

Heteroskedasticity Test: Breusch-Pagan-Godfrey Null hypothesis: Homoskedasticity			
F-statistic	1.656956	Prob. F(7,55)	0.1391
Obs*R-squared	10.97195	Prob. Chi-Square(7)	0.1398
Scaled explained SS	16.24630	Prob. Chi-Square(7)	0.0230

Date: 06/23/26 Time: 11:57
Sample: 1960 2022
Q-statistic probabilities adjusted for 1 dynamic regressor



	AC	PAC	Q-Stat	Prob*
1	-0.202	-0.202	2.7052	0.100
2	0.209	0.175	5.6291	0.060
3	-0.097	-0.029	6.2746	0.099
4	0.092	0.038	6.8626	0.143
5	-0.054	-0.012	7.0722	0.215
6	0.078	0.046	7.5110	0.276
7	-0.043	-0.008	7.6474	0.365
8	0.030	-0.005	7.7128	0.462
9	-0.021	-0.001	7.7467	0.560
10	-0.167	-0.197	9.8921	0.450
11	-0.039	-0.097	10.013	0.529
12	-0.080	-0.051	10.521	0.570
13	-0.089	-0.116	11.168	0.597
14	-0.022	-0.030	11.207	0.670
15	-0.188	-0.195	14.218	0.509
16	0.103	0.064	15.137	0.515
17	-0.103	-0.019	16.080	0.518
18	-0.016	-0.088	16.103	0.585
19	-0.127	-0.114	17.592	0.550
20	-0.046	-0.166	17.790	0.601
21	0.046	0.050	17.993	0.649
22	0.029	0.001	18.075	0.702
23	-0.005	-0.070	18.078	0.753
24	0.001	-0.068	18.078	0.799
25	0.087	-0.009	18.903	0.802
26	-0.150	-0.161	21.392	0.721
27	0.185	0.060	25.270	0.559
28	0.122	0.198	27.014	0.518

*Probabilities may not be valid for this equation specification.

Figure A5. Correlogram for Residuals