TESTING FOR A LONG-RUN RELATIONSHIP BETWEEN PUBLIC CAPITAL AND LABOR PRODUCTIVITY IN MEXICO: A DOLS AND FMOLS ANALYSIS

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ABSTRACT

This paper investigates 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 1960-2020 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). 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 stocks of private and public capital. Fourth, both FMOLS and DOLS estimation of the underlying production (labor productivity) function for Mexico is undertaken and the results provide robust evidence in favor of the argument that both the private and public stocks of capital increase economic output and labor productivity over the period under review. The estimates also reveal the lackluster performance of Mexico's labor productivity over the period in question. The estimators utlized in this study are extremely consistent even in the presence of both *endogeneity* and serial correlation of *any order*. From a policy standpoint, these 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 Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), economic output, Gregory-Hansen cointegration single-break test, public capital stock, Johansen Cointegration test, labor productivity, KPSS no unit root test, single-

break (Zivot-Andrews) unit root test, and vector error correction model (VECM).
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INTRODUCTION

A number of studies have shown that public capital (infrastructure) spending in the form of roads, bridges, ports, airfields, and reliable sources of energy are critical for the efficiency and economic performance of developed and emerging nations (see Albala-Bertrandt and Mamatzakis, 2001; Aschauer, 1989, 1990; and 2000; Barro, 1990; Bom and Lightart, 2014; Cardoso, 1993; Ezzahid and Rafik, 2024; Lightart, 2002; Lin, 1994; Looney, 1985; Mamatzakis, 1999; Pereira and Andraz, 2013; Ram, 1996; and Ramirez, 2000; 2002). When it comes to the latter, however, the extant studies are constrained by the lack of reliable data for a sufficiently long period of time to establish economically meaningful and statistically robust results. Mexico, and a few other emerging nations in Latin America (Brazil and Chile, e.g.), are exceptions because they have sufficiently long and rich sources of data which enables researchers to examine whether a long-run (positive) relationship exists between the public (private) capital stock and economic (labor productivity). In the present study we focus on the Mexican case and utilize a standard neoclassical production function to empirically estimate the effects of the private and public capital stock on economic output and labor productivity over the 1960-2020 period. From the outset, it should be emphasized that these are *partial* results, since we do not take into account the *financing* of public capital formation which entails taxes and borrowing (domestic and foreign), both of which introduce distortions and costs that may exceed the social rate of return to public investment (Aschauer, 2000; and Ezzahid and Rafik, 2024). The paper is organized as follows. First, we present the theoretical model and underlying production labor productivity function. Next, the empirical methodology and data are discussed. The third section presents standard unit root and cointegration tests utilizing the Johansen (1988) and Gregory and Hansen (1996) tests; this is followed by the presentation of long-run estimations undertaken with the FMOLS and DOLS estimators—the latter control for the presence of *endogeneity* and serial correlation of *any order*. The final section is the conclusion.

ECONOMIC MODEL

Following the lead of Albala-Bertrandt and Mamatzakis (2001), Aschauer (1989), Barro (1990), Ezzahid and Rafik, (2024), Lin (1994), Mamatzakis (1999), and Ramirez (2000; 2002), we utilize a Cobb-Douglas production function that treats public (infrastructure) capital as a separate input:

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

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. It is also assumed, at first, that α and β are less than one, such as there are diminishing returns to labor and the stock of domestic private capital. It is 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:

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

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, viz., α

$+ \beta < 0$;[1] in this case, Eq. 2 is transformed by subtracting L from both sides to obtain:

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

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

EMPIRICAL METHODOLOGY

In order to focus on the *long-run* effects of private and public capital on economic output and labor productivity in Mexico during the 1960-2020 period, we utilize both the fully modified ordinary least squares (FMOLS) estimator proposed by Phillips and Hansen (1990) and the dynamic ordinary least squares (DOLS) estimator developed by Stock and Watson (1993). These estimators are extremely consistent even in the presence of both *endogeneity* and serial correlation of *any order*. The FMOLS estimator employs a *non-parametric* correction to eliminate the problems caused by the long-run correlation between the cointegrating equation and stochastic regressor innovations, and thus generates asymptotically unbiased and fully efficient estimates (see Phillips and Hanson, op. cit). DOLS, on the other hand, uses a *parametric* adjustment to the errors in order to obtain asymptotically unbiased estimates of the long-run parameters. More precisely, it uses leads and lagged differences of the explanatory variables (regressors)

[1]The Wald test performed on the underlying private production function suggested that the null hypothesis of constant returns to scale cannot be rejected at conventional levels (p-value= 0.11).

to control for the endogenous feedback (Stock and Watson, 1993). The coefficients on the leads and lags (nuisance parameters) also adjust for possible autocorrelation and residual non-normality (Herzer et al., 2006; Stock & Watson, 1993). While DOLS and FMOLS solve the problem of endogeneity and eliminate small sample finite bias, the application of the FMOLS approach is more restrictive and requires that all variables must have the same order of integration and that the regressors must not appear as co-integrated; DOLS, on the other hand, generates estimates of the long-run parameters *irrespective* of the order of integration and the existence or absence of cointegration. Moreover, Kao and Chiang (2000) show that, on the basis of Monte Carlo (panel) simulations, DOLS outperforms FMOLS (and Canonical Cointegrating Regression, CCR) estimators in terms of finite sample biases and it has the smallest variance among linear estimators. In view of this, this paper utilizes the DOLS approach to verify the estimates obtained via the FMOLS (and CCR) estimators.[2] The most general formulation of the estimator is given below.

$$Y_t = a + bX_t + \sum_{i=-p}^{i=p} \phi \, \Delta X_{t+i} + \varepsilon_t \qquad (4)$$

where Y_t is the regressand, X_t are the independent variables or regressors, and the ϕ's are the coefficients of leads and

2 The Canonical Cointegrating Regression (CCR) estimator, introduced by Park (1992), is similar to the FMOLS estimator but with a smaller bias, and unlike the FMOLS estimator, it focuses only on data alteration to address endogeneity and serial correlation; the FMOLS estimator, for its part, modifies *both* the data and the parameters of the cointegrating equation to address these issues. As a robustness check, this paper undertook CCR estimations of the underlying production (labor productivity) functions and they are consistent with the FMOLS and DOLS results presented in Tables 3 and 4. To conserve space, they are available upon request.

lags differences of I(1) regressors. These coefficients are considered as nuisance parameters and, as indicated above, they serve to control for possible endogeneity, autocorrelation, and non-normal residuals (see Stock and Watson, op. cit., p. 790).

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 is a sufficient number of annual data points (61) to test empirically whether these flows have a beneficial or adverse impact on economic growth and labor productivity.

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, and *Informe Anual* (various issues). 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 of 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.[3]

[3] Th stocks of private domestic and foreign capital were generated via a standard perpetual inventory model of the following form: $K_t = K_{t-1} + I_t - \delta K_{t-1}$, where K_t is the stock of capital at time t, I_t is the flow of gross investment during period t, and δ is the rate at which the stock of

EMPIRICAL MODEL

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

$$y = \alpha + \beta_1 l + \beta_2 k_p + \beta_3 k_g + \beta_4 D_1 + \beta_5 D_2 + \varepsilon_t \quad (5)$$

or

$$y - l = \alpha + \beta_1 (k_p - l) + \beta_2 k_g + \beta_3 T + \beta_4 D_1 + \beta_5 D_2 + \mu_t \quad (5a)$$

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); k_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 crises years of 1976, 1982-83, 1987, 1995, 2001, and 2009, 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.

Unit Root Analysis

This study first utilized conventional unit root tests to test for 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

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capital depreciates in period t-1. The initial stocks of private and foreign 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. For further details, see Ramirez, 2002; and Looney, 2001.

regressions that are mis-specified or spurious in nature. The variables in question were first tested 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 Chile investigators are often constrained by the relatively small number of time series observations (usually in annual terms). This is not the case in this study where the sample size 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).

ESTIMATIONS AND RESULTS

Following the Doldado 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.[4] 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 common practice of detrending the data by a single trend line

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[4]The Doldado 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 both the Akaike Information Criterion (AIC) and the Schwartz Bayesian Criterion (SBC). Between the two criteria, the SBC is more reliable because the AIC is known to be biased towards choosing an over-specified model (Asteriou, 2021).

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 of the variables become stationary at the five percent level of significance.

In view of the relatively 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 (Kwaitkowski 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 relatively small sample size, it defaults to the stationary data generating process. The reported results in both level and differenced form under the assumption of a deterministic trend are consistent with those reported in Table 1 (part A). 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 appear to 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).[5]

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5 The power of conventional unit root tests may be significantly reduced when the stationary alternative is true and a structural break is ignored (see Perron, 1989); that is, the investigator may erroneously conclude that there is a unit root in the relevant series. To address this potential problem, we utilized the *one break* unit root test developed by Zivot-Andrews (1992) and determined that the unit root hypothesis

Table 1: **Part A**. ADF Unit Root Tests for Stationarity with constant and time trend, Sample Period 1960-2020.

Variables	Level	First Difference	5% Critical Value
y	-.53	-8.32*	-3.5
l	.95	-5.77*	-3.50
k_p	-.52	-4.89*	-3.50
k_g	-1.99	-2.21*	-1.95[a]

Note: MacKinnon (1966) critical values for rejection of hypothesis of a unit root. * Denotes significance at the 5 percent level; [a]The Doldado procedure determined that the trend should be excluded because it was statistically insignificant.

Part B. KPSS (LM) No Unit Root Tests for Stationarity with constant and time trend, Sample Period 1960-2020.

Variables	Level	First Difference	5% Critical Value
y	.24*	.04	.15
l	.22*	.14	.15
k_p	.18*	.11	.15
k_g	.21*	.11	.15

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

COINTEGRATION ANALYSIS WITH STRUCTURAL BREAKS

In order to use the FMOLS estimator, 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

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could not be rejected for any of the included variables in level form at the 5 percent level 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:

$$\Delta Z_t = \phi + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \ldots + \Gamma_{p-1} \Delta Z_{t-p+1} + \Pi Z_{t-1} + \varepsilon_t \qquad (6)$$

where ϕ is the vector (4*x1*) of constant terms, Δ is the difference operator, Z_t is the 4*x1* vector of variables (y, l, k_p, and k_g) in the model, **Γ** is the coefficient matrix [$\Gamma i = -I + A_1 + A_2 + \ldots A_i$ [(i=1,2 … P- 1 (3)]. ε_t is the vector *(4x1)* of disturbance term. Π is the *(4x4)* coefficients matrix [$\Pi = I - A_1 - A_2 - \ldots A_4$]. 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 testing 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 is 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 tested 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.

Insofar as the estimated labor productivity function in eq. (3) is concerned, the system of equations in matrix form is given as follows:

$$\begin{pmatrix} \Delta(y-l) \\ \Delta(kp-l) \\ \Delta g \end{pmatrix} = \begin{pmatrix} \mu 1 \\ \mu 2 \\ \mu 3 \end{pmatrix} + \sum_{i=1}^{k-1} \begin{pmatrix} \Gamma 11 & \Gamma 12 & \Gamma 13 \\ \Gamma 21 & \Gamma 22 & \Gamma 23 \\ \Gamma 31 & \Gamma 32 & \Gamma 33 \end{pmatrix} x \begin{pmatrix} \Delta(y-l)t-i \\ \Delta(kp-l)t-i \\ \Delta(g)t-i \end{pmatrix} + \begin{pmatrix} \alpha 1 \\ \alpha 2 \\ \alpha 3 \end{pmatrix} (\beta 1\ \beta 2\ \beta 3) \begin{pmatrix} y-l \\ kp-l \\ g \end{pmatrix} + \begin{pmatrix} \varepsilon 1 \\ \varepsilon 2 \\ \varepsilon 3 \end{pmatrix} \quad (7)$$

Where the μ's are constants and the ε's are i.i.d. error terms. The estimation of the matrtix 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). To save space, Table 2 below reports the Johansen maximum L.R. (Trace) test for cointegration for only the output equation.[6] The first column of the table gives

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[6]. The Johansen and Juselius (1990) method determined that there exists a stable and unique long-run relationship among the variables in logarithmic form. The Pantula (1989) selection procedure 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 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 critical and p-values, while the last column gives the null hypotheses, ranging from no cointegrating relationships up to at most four 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 in a stable and long-run relationship. In fact, the p-value reported in the table shows that the null hypothesis of no cointegrating vector can be rejected at least at the one percent level, thereby suggesting the presence of one cointegrating equation from which residuals (EC terms) can be obtained to measure the respective deviations between the current level of output and the level based on the long-run relationship [see attached Appendix]. Similar results were obtained for the labor productivity function and they are available upon request.

Table 2**.** Johansen Cointegration (Trace) Test, 1960-2020.

Eigenvalue	Likelihood Ratio	5%	P-value	No. of CE(s)
.405	58.90*	47.85	.0003	None
.166	25.10	29.79	.157	At most 1
.119	13.32	15.49	.104	At most 2
.035	1.73	3.84	.188	At most 3

Estimations undertaken with Eviews 13.0; *denotes significance at 5 percent level. Series: y, l , k_p , and k_g. Test assumptions: Intercept (no trend) in CE and VAR; D_1, and D_2 are treated as exogenous variables.

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the 5% level [trace statistic = 52.54 > critical value (5%) = 42.92; and Max-Eigen statistic = 31.57 > critical value (5%) =25.82].

Before turning to the DOLS and FMOLS long-run estimates, it should be noted that the cointegrating test performed in this study does not allow for structural breaks in the sample period, whether level (intercept) shifts or regime (intercept and slope) shifts. However, Gregory and Hansen (1996) have shown that ignoring these breaks reduces the power of conventional cointegration tests similar to conventional unit root tests and, if anything, should lead to a failure to reject the null hypothesis of no cointegrating vector, which is clearly not the case in the present study. Still, this study undertook a G-H cointegration test with level shift and the results, which are consistent with the Johansen cointegration test.[7]

FMOLS AND DOLS RESULTS

The long-run estimates for the various models estimated (with and without dummy variables to ensure robustness) are presented in Tables 3 and 4 below. Turning first to the FMOLS results for economic output in Table 3, it can be seen from eq. 1 (without the dummies) and eqs.2-3 (with the dummies) that all of the variables in question have their anticipated signs and, with the exception of the EAP (l) variable in eq. 1, are significant at least at the 5 percent level.

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[8]As a confirmatory test, I performed a Gregory and Hansen (1996) cointegration test with endogenously determined level (intercept) shift *and* trend and obtained a minimum ADF* stat. = -5.61 [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. It should be noted that the break date is found by estimating the cointegrating relationship for all possible break dates in the sample period. 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.

For example, in eq. 1, a one percent increase in the economically active population (l) increases the level of the real GDP (y) in the long run by 0.21 percent, while a one percent increase in the stock of private capital (K_p) generates a long-run rise of 0.35 percent in the level of real GDP, ceteris paribus. Notably, the public capital stock has a positive and economically significant impact on economic output in Mexico in the long run, suggesting that it enters into the production function as a complementary input.

Turning to the dummy variables, the estimates suggest that they have the anticipated signs and are highly significant in eqs. 2-3. For example, the sign on D_1 suggests that economic and/or exchange rate crises have had a negative and significant effect on real GDP, while the sign for D_2 indicates that the petroleum-led expansion of 1978-81 had a positive and highly significant effect on real GDP. [This variable was also interacted with the public capital stock and it was found to be highly significant without affecting the sign or significance of the other variables (coef. = .01 and p-value= 0.0001)]. As can be readily seen from Table 3, the FMOLS estimates are corroborated by the more robust DOLS estimates for the equations with and without dummies (eqs. 4-6), except for the EAP and D1 in eq. 5 where they are statistically significant at the 10 percent level. Another slight difference is the greater economic impact of the public capital stock, ranging between 0.29 and 0.37. A quick perusal of the standard error and long-run variance for the reported DOLS equations suggests that they are a better fit to the data. Hansen stability tests for all the cointegrating equations (available upon request) suggest that the null hypothesis of parameter stability cannot be rejected for any of the reported equations (p-values > 0.2). 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.

Table 4 below reports FMOLS and DOLS results for the labor productivity (y-l) function. As can be seen from the estimates without the dummies in eqs. 1 and 4, the included regressors have their anticipated effects and are significant at the one percent level. For example, a one percent ceteris paribus increase in the stock of private capital per worker generates an increase of 0.72 percent in labor productivity in the long run for the FMOLS specification (and 0.56 percent for the DOLS specification). Following the Pantula principle (see endnote 6), a trend variable was included in the eqs. in order to capture the secular path of labor productivity in Mexico. The sign for the time trend is negative (in all specifications) and suggests that labor productivity in Mexico has been lackluster, declining, on average, at least 1.8 percent per year over the 1960-2020 period. As in the economic output equations, the stock of public capital per worker has a positive and economically significant effect on labor productivity in the long run, particularly in the DOLS estimations where its coefficient ranges between 0.27 – 0.37. The dummy variables also have their anticipated signs and are significant in both methodologies, except for D1 in Eq.5 where it is significant at only the 10 percent level. Again, D_2 was interacted with the stock of public capital and it had a positive and significant effect during the petroleum boom years (coef. = 0.007 and p-value= 0.001). The adjusted R^2 s for the labor productivity functions are comparable to those for economic output in Table 3, but the standard errors and long-run variances are comparable lower than those reported in Table 3, suggesting a better fit. Finally, as in the case for economic output, Hansen stability and normality tests for these labor productivity equations did not lead to a rejection of the null hypothesis at conventional levels of significance (p-value > 0.2).

Table 3. Mexico: FMOLS and DOLS estimates, 1960-2020
(Dependent variable = y_t)

	FMOLS			**DOLS**		
Variables	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)	Equation (6)
Constant	3.08	3.06	2.82	1.11	3.08	2.77
	(7.16)**	(4.58)**	(5.54)**	(1.72)*	(7.01)**	(5.99)**
l	0.21	0.43	0.30	0.38	0.20	0.31
	(1.75)*	(2.85)**	(2.13)** (3.70)**	(1.61)*	(2.49)**	
k_p	0.35	0.29	0.29	0.27	0.35	0.30
	(5.89)**	(3.38)**	(4.27)**	(4.66)**	(5.78)**	(4.77)**
k_g	.27	0.16	0.27	0.37	0.29	0.27
	(6.81)**	(2.85)**	(5.61)**	(7.07)**	(7.27)**	(6.14)**
D_1	---	-0.19	-0.10	---	-0.04	-0.11
		(-3.81)**	(-2.61)**			(-2.91)**
D_2	---	---	0.21	---	---	0.21
			(3.55)**			(3.45)**
Adj.R^2	0.99	0.98	0.99	0.99	0.98	0.99
S.E.	0.05	0.10	0.06	0.04	0.05	0.04
L.R. var.	0.006	0.017	0.009	0.002	0.007	0.005

Notes: t-ratios in parenthesis. *Significant at the 10% level; **significant at the 5% level. L.R. var. = Long-run variance. N = 61 observations for FMOLS and 60 observations for DOLS.

Table 4. Mexico: FMOLS and DOLS estimates, 1960-2020 [Dependent variable = $(y\text{-}l)_t$]

	FMOLS			DOLS		
Variables	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)	Equation (6)
Constant	-0.69	-0.73	-0.61	-1.73	-1.81	-1.23
	(-2.73)**	(-2.87)**	(-3.04)**	(-4.57)**	(-4.78)**	(-3.35)**
$(k_p \text{-} l)$	0.72	0.73	0.69	0.56	0.56	0.61
	(11.2)**	(11.6)**	(12.1)**	(8.20)**	(8.21)**	(10.3)**
k_g	0.17	0.17	0.17	0.27	0.29	0.23
	(7.71)**	(7.76)**	(9.06)**	(7.54)**	(7.73)**	(6.49)**
T	-0.018	-0.022	-0.020	-0.018	-0.018	-0.019
	(-9.37)**	(-11.2)**	(-12.7)**	(-9.37)**	(-9.51)**	(-11.5)**
D_1	---	-0.04	-0.02	---	-0.04	-0.03
	(-1.85)**	(-1.45)*	(-2.32)**	(-2.08)**		
D_2	---	---	0.11	---	---	0.09
	(4.59)**	(3.24)**				
Adj.R^2	0.95	0.96	0.97	0.96	0.97	0.98
S.E.	0.04	0.04	0.03	0.03	0.03	0.02
L.R. var.	0.003	0.002	0.001	0.002	0.001	0.001

Notes: t-ratios in parenthesis. *Significant at the 10% level; **significant at the 5% level. L.R. var. = Long-run variance. N=61 observations for FMOLS and 60 observations for DOLS.

CONCLUSION

This paper investigated 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 1960-2020 period. Most studies in the literature for emerging nations have an insufficient number of (annual) observations to test the complementarity hypothesis. Mexico, and a few other developing nations 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). 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. Third, the VECM methodology revealed that the output and labor variables are endogenous, while the private and public capital stock variables can be treated as weakly exogenous (see endnote 7). Lastly, this is the first study to utilize both FMOLS and DOLS estimation of the underlying production (labor productivity) function for Mexico, and the results provide robust evidence in favor of the argument that both the private and public stocks of capital increase economic output and labor productivity over the period under review. The results also indicate a worrisome negative trend in labor productivity for Mexico during the period under review. From a policy standpoint, the reported estimates 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 (see Goldfajn et al., 2021; and Killick, 1995). Needless to say, one should exercise caution in interpreting these results since this study does not control for the financing of public capital formation via distortionary taxes and costly domestic and foreign borrowing—both of which have been prevalent in Mexico (and other emerging markets) over the period in question.

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APPENDIX

An unrestricted VECM was estimated using y, l, kp, and kg 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(l), where the "D" operator denotes the change in the variable. This means that these variables (y and l) 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 9.2 percent on an annual basis. See summary below.

Error Correction System	D(y)	D(1)	D(kp)	D(kg)
Error Correction Coefficient	-.916	.-388	.0831	.007
t-statistics	[-2.598]	[-2.303]	[.821]	[-.058]
Adj. R-squared	.420	.408	.782	.896
Schwarz info. Criterion	-2.441	-3.916	-4.936	-4/415

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 l hypothesis of a zero restriction *cannot* be rejected for each variable at the 5 percent level. The labor force, (l), variable had a p-value of 0.061 which is slightly greater than the 0.05 threshold, but to be careful it is treated as "endogenous" (not excluded). In other words, in this simple four eq. equation system, y and l 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	3.949	.046
D(1)	a(2,1)=0	3.489	.061
D(kp)	a(3,1)=0	.467	.490
D(kg)	a(4,1)=0	.003	.959

Lastly, in order to investigate further the "causal" relationship among these variables, we performed a Granger Block Causality test. This test examines all four equations and tries to determine whether the presumed exogenous variables can be excluded from each equation. This test only finds "causality" or precedence in the D (y) and D(l) eqs. at the 5% level; viz., from D(kp) and D(kg) to D(y) in the first eq., and from D(y) to D(l) in the second eq. Similar estimations were undertaken for the labor productivity function. All estimations were undertaken with Eviews 13.0.