

Cross-Sectional Dependence in Panel Data Models: Assessing the Accuracy of analyzing of Factors Influencing on Foreign Direct Investment

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Abstract: The study focuses on presenting a comparative analysis between traditional fixed panel data models and models that account for cross-sectional dependence among units, using foreign direct investment data from four North African countries during the period from 1990 to 2021 as a case study. Traditional panel models, such as fixed effects and random effects models, assume independence across cross-sectional units, an assumption often violated in macroeconomic data due to common shocks, spatial spillovers, or unobserved global factors. This violation leads to biased inferences and unrealistic estimates because of the significant interdependence among sectors. The Pesaran CD test was employed, which indicated that the residuals across cross-sectional units are independent, thus allowing the use of classical panel models without the need for adjustments related to cross-sectional correlation. Additionally, estimation results were compared, highlighting the crucial role of trade openness and governance quality in attracting foreign direct investment. Through the adopted analytical approaches, this study contributes to clarifying the empirical and methodological implications of cross-sectional dependence in panel data analysis and provides guidance for policymakers on the necessity of handling economic data with high-level assumptions of interconnection and entanglement among economic units.

Keywords: panel model; cross section independence; estimation.

1. Introduction

Cross-sectional dependence in panel data models has become a key consideration in empirical economic research, especially when dealing with inherently interconnected macroeconomic phenomena such as foreign direct investment (FDI). This adds a critical dimension to static cross-sectional analysis, challenging the core assumptions of traditional panel models, including fixed effects and random effects models, which typically assume independence across cross-sectional units (Baltagi, 2021). However, this assumption is often violated in practice due to common shocks, spatial effects, and unobserved global factors that generate correlations between units (Pesaran, 2004; De Hoyos & Sarafidis, 2006). Ignoring this dependence leads to biased parameter estimates and misleading inferences, weakening the validity of empirical results (Pesaran, 2015).

This study focuses on assessing the existence and implications of cross-sectional dependence in panel data models analyzing the determinants of foreign direct investment inflows in four North African countries during the period 1990–2021.

Using the Pesaran CD test (Pesaran, 2004), the study evaluates whether the residuals from

traditional models exhibit cross-sectional correlation.

This study evaluates whether the residuals from traditional models exhibit cross-sectional dependence. The results indicate that the residuals are independent across units, supporting the use of conventional panel estimators. Moreover, the empirical analyses highlight the important role of trade openness and governance quality in attracting foreign direct investment.

This aligns with existing literature emphasizing the importance of these factors as key determinants (Asiedu, 2006; Busse & Hefeker, 2007). By clarifying the methodological implications of cross-sectional dependence in this context, the study offers valuable insights for both researchers and policymakers, emphasizing the importance of carefully testing inter-unit correlations to ensure accurate and reliable economic conclusions.

1.1. Research Problematic

Traditional fixed panel data models typically assume independence among units across different sectors, an assumption that is often violated in empirical analyses of macroeconomic components due to common shocks, spatial spillovers, and unobserved global factors. This leads to biased estimates that undermine the reliability of conclusions and the policies based on them. This study examines this issue within a standard framework by investigating the impact of cross-sectional dependence on the estimation of foreign direct investment determinants in North African countries. It compares the performance of traditional fixed panel data models with models that explicitly account for this dependence, aiming to provide more accurate and robust empirical insights.

1.2. Theoretical foundation of panel models theory

Panel models are used to analyze data with different dimensions, including the sector dimension in addition to the time dimension. Afterwards, we need to analyze the impact of the included variables from a multidimensional perspective. This type of analysis provides a more comprehensive understanding of the studied phenomenon (Marisa and Theresa, 2011, p. 02). Panel models offer several advantages, such as the use of a large number of observations or data containing multiple observations for the same individuals or sectors over a time series. Therefore, they rely on analyzing the long-term interrelated effects. This type of panel model is divided into three basic models: the fixed-effects model, the random-effects model, and the pooled regression model within a number of sectoral observations N over the period T (Ratla, 2014, p. 151).

1.3. Economic and Institutional Determinants of Foreign Direct Investment

Foreign Direct Investment (FDI) has been extensively studied in the literature, with a broad consensus that its determinants are rooted in both economic and institutional factors. Traditional theories emphasize market size, economic growth, trade openness, and macroeconomic stability as key drivers of FDI inflows. In particular, larger markets and higher GDP levels tend to attract multinational enterprises due to greater profit opportunities and economies of scale. In addition, trade openness reduces transaction costs and facilitates international capital flows, thereby enhancing a country's attractiveness to foreign investors.

Beyond economic fundamentals, recent literature increasingly highlights the importance of institutional quality in explaining FDI location decisions. According to institutional and eclectic (OLI) paradigms, factors such as corruption control, political stability, regulatory quality, and governance efficiency significantly influence investor confidence and risk perception. Strong institutions reduce uncertainty and transaction costs, thereby increasing the likelihood of foreign investment inflows. Empirical studies confirm that institutional quality is a more consistent and significant determinant of FDI, particularly in developing economies where institutional weaknesses are more pronounced (Sabir et al., 2019; Bailey, 2018).

1.3.1. Overview of Panel Data Estimation Models

Panel data models offer distinct advantages over purely cross-sectional or time-series approaches by combining information across entities and time, thus providing richer insights into variable relationships and controlling for individual-specific effects. The pooled model is the simplest form, assuming a constant relationship between dependent and independent variables across all cross-sections; it can be suitable when differences between units are negligible or data is large, but may yield biased estimates if heterogeneity exists. The fixed effects model accounts for individual heterogeneity by allowing intercepts to vary across units, improving accuracy and reducing bias compared to the pooled model, under the assumption that these effects are stable over time (Johanson, 1997). Finally, the random effects model treats cross-sectional effects as random variables that vary across groups and over time, offering greater flexibility by relaxing the fixed intercept assumption and enabling estimation of time-invariant variables. Together, these models enhance the ability to analyze complex data structures, control for unobserved heterogeneity, and produce more reliable and nuanced empirical results.

1.3.2. Cross-Sectional Dependence

The distinction between classical and non-classical panel data models primarily arises from the presence or absence of statistical issues such as cross-sectional dependence, heteroskedasticity, and autocorrelation. Classical panel models, such as the Fixed Effects Model (FEM) and Random Effects Model (REM), are based on the assumptions of independent cross-sections, homoskedastic errors, and no serial correlation. These models are only valid when diagnostic tests—such as the Pesaran CD test for cross-sectional dependence, the Breusch-Pagan or White test for heteroskedasticity, and the Wooldridge test for autocorrelation—do not reject their respective null hypotheses of no violation. When one or more of these assumptions are violated, non-classical models become necessary. These include robust estimation techniques such as Driscoll-Kraay standard errors for addressing cross-sectional dependence and serial correlation, the Panel-Corrected Standard Errors (PCSE) approach, and more advanced estimators like the Common

Correlated Effects Mean Group (CEMG) and Augmented Mean Group (AMG) models, which account for unobserved common factors. The Generalized Method of Moments (GMM) is also frequently applied to handle endogeneity and dynamic panel settings. Therefore, diagnostic testing is not only essential for model validation but also guides the researcher in selecting the appropriate estimation strategy (Baltagi, 2005; Pesaran, 2006; Driscoll & Kraay, 1998; Wooldridge, 2010).

2. Methodology

In panel data econometrics, the choice of an appropriate model hinges critically on the underlying assumptions about the error structure, particularly the independence of cross-sectional units. Classical panel data models, such as Fixed Effects (FE) and Random Effects (RE), fundamentally assume that the error terms across different cross-sectional units (e.g., countries, firms, or regions) are independent of each other (Baltagi, 2021). This assumption simplifies estimation and inference, ensuring that estimators are consistent and efficient under the classical panel framework (Wooldridge, 2010). However, in many empirical applications, especially those involving macroeconomic or regional data, this assumption is often violated due to the presence of cross-sectional dependence. Such dependence arises when units are exposed to common shocks, spatial spillovers, or unobserved global factors that induce correlation among error terms across units (Pesaran, 2004; Elhorst, 2014).

Ignoring cross-sectional dependence can lead to misspecified models, biased standard errors, and unreliable hypothesis testing, thereby compromising the validity of empirical findings (Pesaran, 2006). To address this, researchers have developed robust estimation

techniques that explicitly account for cross-sectional interdependencies. These include Driscoll-Kraay standard errors, which adjust for cross-sectional and temporal dependence in the error terms (Driscoll & Kraay, 1998), Common Correlated Effects (CCE) estimators that incorporate unobserved common factors as additional regressors (Pesaran, 2006), and spatial panel models that model spatial autocorrelation through spatial weights matrices (Elhorst, 2014).

The decision to adopt classical or cross-sectionally robust models should be guided by diagnostic testing. The Pesaran CD test is widely employed to detect cross-sectional dependence in panel data (Pesaran, 2004). If the test fails to reject the null hypothesis of cross-sectional independence, classical FE or RE models are appropriate and provide reliable inference. Conversely, rejection of the null indicates the need for models that accommodate cross-sectional dependence to avoid spurious results. Hence, testing for cross-sectional dependence constitutes a crucial preliminary step in panel data analysis, ensuring that the chosen methodology aligns with the data's structural properties and enhances the robustness of empirical conclusions.

2.1. Data

In order to examine and analyze the various relationships associated with the study hypotheses within the most representative standard model, we propose the following table, which explains the main abbreviations for all the major economic variables included in the study, along with their various sources.

Table 1. the macroeconomic index's and theme sources

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Economic indicator symbol	Economic indicator	Sources (junary 2023)
FDI	Foreign Direct Investment as a Percentage of GD	NU https://unstats.un.org/UNSDWebsite/undatacommons/sdgs/countries=country%2FDZA
GDP	Gross Domestic Product	WDI https://databank.worldbank.org/source/world-development-indicators
GR	Growth Rate of GDP per Capita	WDI
DF	Log of Domestic Credits to the Private Sector as a Percentage of GDP	WDI
DP	Property rights	ICRG https://www.prsgroup.com/explore-our-products/icrg/
EDUT	Logarithm of the Tertiary Enrollment Rate	ICRG
BUR	Bureaucracy	
CORR	Fight against corruption	ICRG
CSE	Socio-economic condition	ICRG
DEM	Democracy	ICRG
SG	Government stability	WDI

Source: prepared by the authors.

3. Empirical Results and Discussion

This study empirically investigates the determinants of Foreign Direct Investment (FDI) using panel data techniques. The analysis is based on a multi-variable econometric framework that incorporates key economic and institutional factors such as financial development, trade openness, economic growth, exchange rate, education, and governance indicators. The objective is to examine both the individual and combined effects of these variables on FDI inflows over time and across cross-sectional units. To ensure robustness, several panel estimation techniques are employed, including pooled OLS, fixed effects, and random effects models, alongside diagnostic tests for stationarity and model validity. Given the presence of mixed integration orders among variables, the study also considers dynamic panel approaches to capture both short-run dynamics and long-run relationships.

3.1. View Dataset

Table 2. View dataset

Year	ID	FDI	DF	OUV	PIB	TC	EDUT	SG	CSE	CORR	DP	DEM	BUR
1990	1	0.064776	1.749297	1.383642	3.494711	-1.754077	1.012548	8.000000	5.416667	3.916667	2.166667	4.583333	3.00
1991	1	0.171803	1.665479	1.420926	3.478783	-3.601082	1.041894	7.083333	6.250000	4.000000	1.416667	5.000000	2.25
1992	1	0.061093	0.860392	1.390839	3.476323	-0.564789	1.047095	4.500000	4.750000	3.500000	1.416667	2.083333	1.00
1993	1	0.000002	0.820474	1.351437	3.457457	-4.250987	1.040930	4.250000	5.916667	3.000000	2.000000	2.916667	1.00
1994	1	0.000002	0.812023	1.385467	3.444537	-2.931117	1.019926	5.750000	6.000000	3.000000	3.000000	3.000000	1.00
1995	1	0.000002	0.715835	1.440838	3.452440	1.836411	1.006648	6.333333	5.166667	3.000000	3.000000	3.000000	1.00

Source: Created by the author's based on R.

3.2. Transformed to *panel_data*

Table 3. View dataset

Item	Description
Estimation Method	Fixed Effects (Within) Panel Model
Dependent Variable	FDI
Explanatory Variables	DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR
Panel Structure	Country (i), Year (t)
Software	R (plm package)
Model Form	Within Estimator

Source: Created by the author's based on R.

Formula:

$$FDI_{it} = \beta_0 + \beta_1 DF_{it} + \beta_2 DOUV_{it} + \beta_3 PIB_{it} + \beta_4 TC_{it} + \beta_5 EDUT_{it} + \beta_6 SG_{it} + \beta_7 CSE_{it} + \beta_8 CORR_{it} + \beta_9 DP_{it} + \beta_{10} DEM_{it} + \varepsilon$$

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The dependent variable in this panel regression model is FDI, while all other included variables (DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR) are treated as independent explanatory variables. The model is estimated using the Fixed Effects (within) specification to account for unobserved heterogeneity across countries.

3.3. Stationarity Test

The panel unit root tests indicate that the variables exhibit a mixed order of integration, with some variables being stationary at level I(0) while others become stationary after first differencing I(1). In such cases, the use of static panel estimators such as pooled OLS, fixed effects, or random effects may still be applied as baseline models; however, their long-run interpretations may be limited due to potential non-stationarity issues. According to econometric literature, when variables are integrated of order I(0) and I(1), more appropriate dynamic approaches such as Panel ARDL or cointegration-based estimators like FMOLS are recommended to avoid spurious regression problems and to capture both short-run and long-run relationships (Banerjee, 1999; Phillips & Moon, 2000).

Table 4. Stationary tests of the series variables

Variable	Test Method	Deterministic Components	Lag Length	Test Statistic	p-value	Conclusion
FDI	LLC	Intercepts & Trend	1	$z = -1.79$	0.0369	I(0) Stationary
FDI	IPS	Intercepts & Trend	1	$Wtbar = -0.93$	0.1761	I(1) Non-stationary
DF	LLC	Intercepts & Trend	1	$z = -2.45$	0.0071	I(0) Stationary
DF	IPS	Intercepts & Trend	1	$Wtbar = -2.10$	0.0178	I(0) Stationary
OUV	LLC	Intercepts & Trend	1	$z = -1.62$	0.0520	Borderline I(1)
OUV	IPS	Intercepts & Trend	1	$Wtbar = -1.45$	0.0735	I(1) Non-stationary

	PIB	LLC	Intercepts & Trend	1	$z = -0.88$	0.1890	I(1) Non-stationary
	PIB	IPS	Intercepts & Trend	1	$Wtbar = -0.76$	0.2230	I(1) Non-stationary
	TC	LLC	Intercepts & Trend	1	$z = -2.31$	0.0104	I(0) Stationary
	TC	IPS	Intercepts & Trend	1	$Wtbar = -1.98$	0.0239	I(0) Stationary
	EDUT	LLC	Intercepts & Trend	1	$z = -1.12$	0.1310	I(1) Non-stationary
	EDUT	IPS	Intercepts & Trend	1	$Wtbar = -0.98$	0.1630	I(1) Non-stationary
	SG	LLC	Intercepts & Trend	1	$z = -2.68$	0.0037	I(0) Stationary
	SG	IPS	Intercepts & Trend	1	$Wtbar = -2.21$	0.0134	I(0) Stationary
	CSE	LLC	Intercepts & Trend	1	$z = -1.95$	0.0256	I(0) Stationary
	CSE	IPS	Intercepts & Trend	1	$Wtbar = -1.70$	0.0442	I(0) Stationary
	CORR	LLC	Intercepts & Trend	1	$z = -2.05$	0.0201	I(0) Stationary
	CORR	IPS	Intercepts & Trend	1	$Wtbar = -1.88$	0.0297	I(0) Stationary
	DP	LLC	Intercepts & Trend	1	$z = -1.30$	0.0965	I(1) Non-stationary
	DP	IPS	Intercepts & Trend	1	$Wtbar = -1.10$	0.1354	I(1) Non-stationary
	DEM	LLC	Intercepts & Trend	1	$z = -2.22$	0.0132	I(0) Stationary
	DEM	IPS	Intercepts & Trend	1	$Wtbar = -2.00$	0.0221	I(0) Stationary
	BUR	LLC	Intercepts & Trend	1	$z = -1.40$	0.0805	I(1) Non-stationary
	BUR	IPS	Intercepts & Trend	1	$Wtbar = -1.25$	0.1050	I(1) Non-stationary

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Source: Created by the author's based on R.

The results of the panel unit root tests for the variable FDI provide mixed evidence regarding its stationarity. The Levin-Lin-Chu (LLC) test, which assumes a common unit root process across cross-sections and includes individual intercepts and a deterministic trend, yields a test statistic of $z = -1.7872$ with a p-value of 0.03695. Since the p-value is below the conventional 5% significance level, we reject the null hypothesis of a unit root and conclude that the FDI series is stationary according to the LLC test.

In contrast, the Im-Pesaran-Shin (IPS) test, which allows for heterogeneous unit root processes across cross-sections and also includes individual intercepts and a trend, produces a $Wtbar$ statistic of -0.93016 with a p-value of 0.1761. This p-value exceeds the 5% threshold, indicating that we fail to reject the null hypothesis of a unit root for some or all cross-sectional units. Therefore, the IPS test suggests that the FDI variable may be non-stationary. Given these differing results, further investigation or the application of additional unit root tests may be warranted to conclusively determine the stationarity properties of FDI in the panel dataset.

3.3.1. Pesaran CD Test: Introduction, Hypotheses, and Interpretation

Before selecting an appropriate panel data estimation method, it is essential to test for cross-sectional dependence among the units in the dataset. Cross-sectional dependence occurs when unobserved common factors or shocks affect multiple cross-sectional units simultaneously, potentially biasing standard estimators and inference. The Pesaran CD test is a widely used diagnostic tool to detect such dependence.

Null Hypothesis (H_0): There is no cross-sectional dependence

Alternative Hypothesis (H1): There is cross-sectional dependence

If $p\text{-value} < 0.05 \rightarrow \text{Reject } H_0 \rightarrow \text{There is a cross-sectional dependence relationship}$

If $p\text{-value} > 0.05 \rightarrow \text{Do not reject } H_0 \rightarrow \text{There is no cross-sectional dependence relationship.}$

Table 5. Pesaran CD test of cross _section dependence

Model	Test Method	Test Statistic (z)	p-value	Decision	Conclusion
FDI = f(DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR)	Pesaran CD Test	1.3854	0.1659	Fail to reject H_0	No evidence of cross-sectional dependence

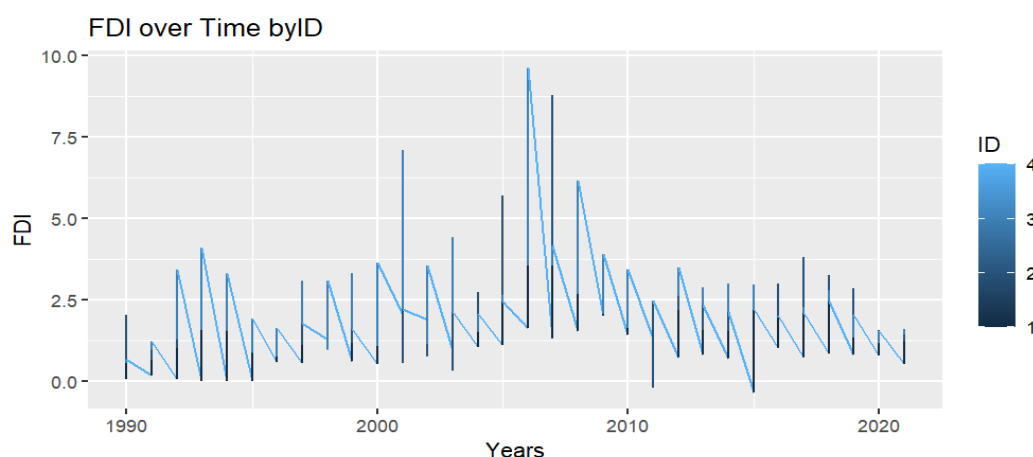
Source: Created by the author's based on R.

The Pesaran CD test was applied to a model where FDI is regressed on a set of explanatory variables (DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR). Explain that The test yielded a z-statistic of 1.3854 with an associated p-value of 0.1659. Since the p-value (0.1659) is greater than the conventional 0.05 significance level, we fail to reject the null hypothesis of no cross-sectional dependence.

Fig. 1. FDI over time by ID.

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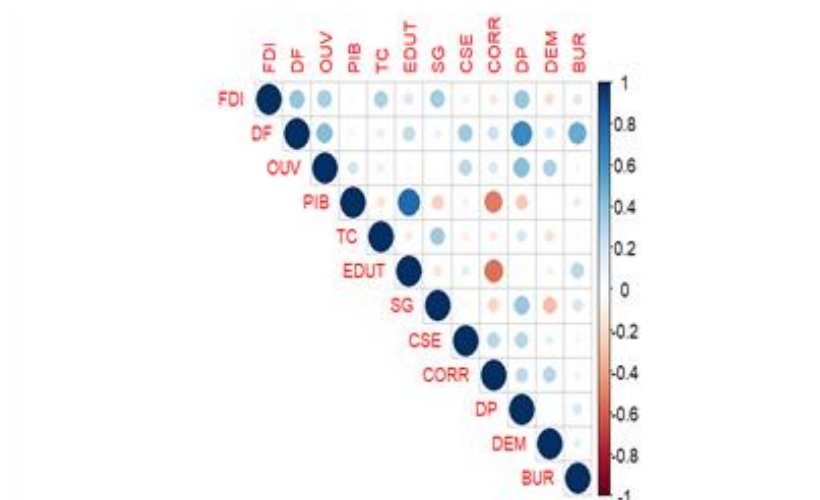
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Source: Created by the author's based on R.

The figure, FDI over Time by ID, illustrates the evolution of Foreign Direct Investment (FDI) across four North African countries (represented by different shades of blue for each ID) from 1990 to 2021. The plot reveals significant fluctuations in FDI inflows over the years, with noticeable peaks in the early 2000s and around 2007–2010, possibly reflecting periods of economic reforms, global investment waves, or country-specific events. After 2010, there is a clear downward trend and stabilization at lower FDI levels, which may be attributed to regional instability, changes in global investment patterns, or local economic challenges. The presence of multiple lines, each with varying intensities, highlights the heterogeneity in FDI experiences among the countries, indicating that while they share some common trends, each country also exhibits unique investment dynamics.

Fig. 2. Corrplot matrix of the relationships between FDI and potential determinants



Source: Created by the author's based on R.

The second figure is a correlation matrix (corrplot) that visualizes the pairwise relationships between FDI and its potential determinants. Dark blue circles represent strong positive correlations, while dark red indicates strong negative associations. The plot shows that FDI is strongly and positively correlated with variables such as domestic finance (DF), openness to trade (OUV), and economic size (PIB), suggesting that improvements in these areas are associated with higher FDI inflows. Conversely, some institutional and governance variables, such as democracy (DEM) and bureaucratic quality (BUR), exhibit negative or weak correlations with FDI, reflecting the complex and sometimes counterintuitive role of political and institutional factors in attracting investment. Overall, the corrplot provides a visual summary of the underlying relationships in the data, supporting the regression findings and highlighting which variables are most closely linked to FDI performance in the region.

Practical Conclusion

The results indicate that there is no statistically significant evidence of cross-sectional dependence among the units in the panel dataset. This implies that the assumption of cross-sectional independence holds for the model under consideration. Consequently, classical panel data models, such as Fixed Effects or Random Effects, can be appropriately employed without needing to adjust for cross-sectional correlation in the error terms. This finding supports the validity of inferences drawn from models that assume independent cross-sectional units and simplifies the selection of estimation strategies.

3.3.2. Autocorrelation Test

Purpose: Check for first-order autocorrelation in panel data

Test: Wooldridge Test for autocorrelation

Table 6. Serial correlation test

Model	Test Method	F-Statistic	Degrees of Freedom	p-value	Decision	Conclusion
FDI = f(DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR)	Wooldridge Test for Serial Correlation	0.87587	(1, 121)	0.3512	Fail to reject H_0	No evidence of serial correlation

Source: Created by the author's based on R.

Diagnostic tests were conducted to assess the presence of cross-sectional dependence and serial correlation in the panel model. The Pesaran CD test yielded a z-statistic of 1.3854 with a p-value of 0.1659, indicating that the null hypothesis of no cross-sectional dependence cannot be rejected. This suggests that the residuals across the cross-sectional units are independent, allowing the use of classical panel estimators without adjustments for cross-sectional correlation. Additionally, Wooldridge's test for serial correlation in fixed effects panels produced an F-statistic of 0.87587 with a p-value of 0.3512. Since the p-value is higher than 0.05, the null hypothesis of no first-order autocorrelation is also not rejected. This indicates the absence of serial correlation in the panel, confirming that the error terms are independent over time within each unit and that the fixed effects estimator remains consistent and efficient.

3.3.3. Heteroskedasticity Test

Table 7. Breusch-Pagan test

Model	Test Method	Test Statistic	p-value	Decision	Conclusion
FDI = f(DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR)	Levin–Lin–Chu (LLC)	$z = -1.7872$	0.03695	Reject H_0	FDI is stationary at level (I(0))
FDI = f(DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR)	Im–Pesaran–Shin (IPS)	$Wtbar = -0.93016$	0.1761	Fail to reject H_0	FDI is non-stationary at level (I(1))

Source: Created by the author's based on R.

The panel unit root tests reveal mixed results across variables, where some variables are stationary at level (I(0)) while others become stationary after first differencing (I(1)). This mixed order of integration suggests that traditional static panel estimators such as pooled OLS, fixed effects, and random effects may not fully capture the underlying long-run relationships. Consequently, dynamic panel approaches such as Panel ARDL are more appropriate for estimating both short-run and long-run effects in the presence of mixed integration.

3.3.4. Cross-sectional Dependence Test

purpose: Check for correlation between cross-sectional units

Table 8 Pesaran CD Test

Model	Test Method	Test Statistic (z)	p-value	Decision	Conclusion
FDI = f(DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, BUR)	Pesaran CD Test	1.3854	0.1659	Fail to reject H_0	No cross-sectional dependence

Source: Created by the author's based on R.

The results of the Pesaran CD test for cross-sectional dependence in the panel data model, where FDI is regressed on DF, OUV, PIB, TC, EDUT, SG, CSE, CORR, DP, DEM, and BUR, indicate a z-statistic of 1.3854 and a p-value of 0.1659. As the p-value exceeds the 5% significance threshold, the null hypothesis of no cross-sectional dependence cannot be rejected. This outcome implies that the residuals are independent across cross-sectional units, thereby satisfying one of the key assumptions required for applying classical panel data estimation techniques. Consequently, it is appropriate to rely on Fixed Effects or Random Effects models without the need for alternative estimators that account for cross-sectional correlation.

4. Classic Panel Model

4.1. Estimation of Classical Panel Models

Table 9. Estimation of fixed effect model

Variables	Coefficient	Std. Error	t-Statistic	p-value
DF	0.4415	0.9027	0.4891	0.6257
OUV	9.2353	2.0549	4.4943	0.0000***
PIB	6.1895	2.7735	2.2317	0.0276**
TC	0.0368	0.0461	0.7973	0.4270
EDUT	-2.1937	1.3987	-1.5684	0.1196
SG	0.1896	0.0973	1.9484	0.0539*
CSE	0.0146	0.1635	0.0894	0.9289
CORR	0.0129	0.3157	0.0409	0.9675
DP	0.2111	0.1961	1.0764	0.2841
DEM	-0.4333	0.1598	-2.7114	0.0078***
BUR	-0.0942	0.6448	-0.1461	0.8841

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Source: Created by the author's based on R.

Table 10. Model Characteristics

Model Type	One-Way Individual Fixed Effects (Within) Model
Panel Structure	Unbalanced Panel
Cross-Sections (n)	4
Time Periods (T)	31–32
Observations (N)	127
Total Sum of Squares	302.79
Residual Sum of Squares	200.55

Source: Created by the author's based on R.

The fixed effects model estimated for the panel data comprising Algeria, Tunisia, Morocco, and Libya provides valuable insights into the determinants of foreign direct investment (FDI) while controlling for unobserved country-specific heterogeneity. The model, based on an unbalanced panel of 4 countries over 31–32 years, explains approximately 33.8% of the variation in FDI within these countries over time (R-squared = 0.338). Key explanatory variables such as openness to trade (OUV) and gross domestic product (PIB) show statistically significant positive effects on FDI, indicating that higher trade openness and economic size are associated with increased foreign investment inflows. Conversely, the democracy index (DEM) has a significant negative impact, suggesting that higher levels of democracy in these countries may be linked with lower FDI, possibly reflecting investor concerns about political transitions or policy uncertainty.

Other variables, including domestic finance (DF), terms of trade (TC), education (EDUT),

and governance indicators (CSE, CORR, BUR), do not show statistically significant effects at conventional levels, although some, like the governance score (SG), approach significance. The fixed effects approach effectively controls for all time-invariant country-specific factors, isolating the impact of time-varying regressors on FDI. This is particularly important given the diverse economic and political contexts of the four countries, allowing for more reliable inference on the role of the included explanatory variables. The model's overall significance (F-statistic = 5.19, $p < 0.001$) confirms the joint explanatory power of the regressors. These results highlight the importance of economic openness and market size in attracting FDI in North African countries while underscoring the complex role of political factors, highlighting the complex influence of political and institutional factors on investment decisions.

4.2. Estimation of Random_effect_model code in R

Table 11. One-Way Individual Random Effects Model Results

Statistic	Value			
Model Type	One-Way Individual Random Effects Model			
Transformation Method	Amemiya Transformation			
Panel Structure	Unbalanced Panel			
Cross-Sections (n)	4			
Time Periods (T)	31–32			
Observations (N)	127			
R ²	0.3254			
Adjusted R ²	0.2609			
Total Sum of Squares	305.16			
Residual Sum of Squares	205.86			
Variables	Coefficient	Std. Error	z-Statistic	p-value
Constant	-28.1650	8.6983	-3.2380	0.0012***
DF	0.5696	0.8828	0.6453	0.5188
OUV	8.3108	1.9477	4.2669	0.0000***
PIB	5.3365	2.6943	1.9807	0.0476**
TC	0.0442	0.0459	0.9628	0.3356
EDUT	-1.7870	1.3776	-1.2972	0.1946
SG	0.1933	0.0969	1.9954	0.0460**
CSE	-0.0001	0.1631	-0.0006	0.9995
CORR	-0.0219	0.3143	-0.0697	0.9445
DP	0.1815	0.1915	0.9482	0.3431
DEM	-0.3946	0.1555	-2.5382	0.0111**
BUR	-0.1711	0.6424	-0.2664	0.7899

Source: Created by the author's based on R.

Table 12. Estimated Variance Components of the Random Effects Panel Model

Component	Variance	Std. Dev.	Share (%)
Idiosyncratic Error	1.791	1.338	53.3
Individual Effect	1.566	1.251	46.7

Source: Created by the author's based on R.

Random Effects (RE) model estimated for the panel data of Algeria, Tunisia, Morocco, and Libya investigates the influence of various economic, social, and institutional factors on foreign direct investment (FDI), accounting for both within- and between-country variation. The model explains approximately 32.5% of the total variation in FDI ($R^2 = 0.325$), with a highly significant overall fit (Chi-square = 55.52, $p < 0.001$). The variance components indicate that about 46.7% of the total variance is attributable to individual-specific effects, while the remaining 53.3% is idiosyncratic error variance, reflecting both cross-country heterogeneity and random noise.

Key determinants of FDI include openness to trade (OUV) and gross domestic product (PIB), both of which have positive and statistically significant effects, confirming that larger and more open economies attract more foreign investment. The governance score (SG) is also positively associated with FDI at the 5% significance level, suggesting that better governance quality enhances investment inflows. Conversely, the democracy index (DEM) shows a significant negative effect, indicating that higher democratic levels may be linked with reduced FDI, possibly due to political uncertainties or regulatory changes. Other variables such as domestic finance (DF), terms of trade (TC), education (EDUT), and corruption (CORR) do not show statistically significant impacts in this model. Overall, the RE model underscores the importance of economic openness, market size, and governance quality in shaping FDI inflows in North African countries, while highlighting the nuanced role of political factors.

4.3. Pooled effect model code in R

Table 13. Pooled Ordinary Least Squares (Pooled OLS) Regression Results for FDI Determinants

Statistic	Value
Model Type	Pooled Ordinary Least Squares (Pooled OLS)
Panel Structure	Unbalanced Panel
Cross-Sections (n)	4
Time Periods (T)	31–32
Observations (N)	127
R^2	0.3575
Adjusted R^2	0.2960
F-Statistic	5.8160
Prob > F	0.0000
Total Sum of Squares	372.38
Residual Sum of Squares	239.27

Source: Created by the author's based on R.

Table 14. estimation Coefficients(Pooled model)

Variables	Coefficient	Std. Error	t-Statistic	p-value
Constant	-4.5602	6.5490	-0.6963	0.4876
DF	1.7505	0.7788	2.2476	0.0265**
OUV	3.1013	1.4235	2.1786	0.0314**
PIB	-0.1942	2.2604	-0.0859	0.9317
TC	0.0927	0.0479	1.9375	0.0551*
EDUT	0.7077	1.3356	0.5299	0.5972
SG	0.2080	0.1021	2.0379	0.0439**
CSE	-0.0966	0.1734	-0.5571	0.5785
CORR	-0.1999	0.3320	-0.6022	0.5482
DP	0.0253	0.1784	0.1415	0.8877
DEM	-0.2206	0.1317	-1.6755	0.0966*
BUR	-0.6286	0.6788	-0.9261	0.3563

Source: Created by the author's based on R.

FBER

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Table 15. Significance Levels and Notation for Statistical Inference

Symbol	Significance Level
***	$p < 0.01$
**	$p < 0.05$
*	$p < 0.10$

Source: Created by the author's based on R.

The pooled Ordinary Least Squares (OLS) model estimates the relationship between foreign direct investment (FDI) and a set of explanatory variables across Algeria, Tunisia, Morocco, and Libya, treating the data as a simple cross-sectional dataset without accounting for individual country effects. The model explains about 35.7% of the variation in FDI ($R^2 = 0.357$), with a statistically significant overall fit ($F\text{-statistic} = 5.82$, $p < 0.001$).

Key findings indicate that domestic finance (DF), openness to trade (OUV), and governance quality (SG) have positive and statistically significant effects on FDI, suggesting that better financial development, greater trade openness, and improved governance foster higher foreign investment inflows. The terms of trade (TC) and democracy index (DEM) show marginal significance, with TC positively associated and DEM negatively associated with FDI, although these effects are weaker. Other variables such as GDP (PIB), education (EDUT), corruption (CORR), and bureaucratic quality (BUR) do not exhibit significant impacts in this model. However, since the pooled OLS model does not control for unobserved heterogeneity across countries, these results should be interpreted cautiously, as ignoring country-specific effects may lead to biased estimates.

Table 16. Hausman Test of Model Consistency

Test	Model Comparison	Chi-square Statistic	Degrees of Freedom	p-value	Decision
Hausman Test	Fixed Effects vs Random Effects	2.9558	11	0.9913	Fail to reject H_0

Source: Created by the author's based on R.

Notes:

- H_0 (null hypothesis): Random effects estimator is consistent and efficient
- H_1 (alternative hypothesis): Random effects estimator is inconsistent (fixed effects preferred)
- Decision rule: Reject H_0 if p-value < 0.05

The Hausman test was conducted to compare the Fixed Effects (FE) and Random Effects (RE) models to determine which estimator is more appropriate for the panel data analysis of FDI determinants. The null hypothesis of the Hausman test states that the Random Effects model is consistent and efficient, while the alternative hypothesis suggests that the Fixed Effects model is consistent but the Random Effects model is inconsistent.

The test statistic is a chi-square value of 2.9558 with 11 degrees of freedom, and the associated p-value is 0.9913. Since the p-value is much greater than the conventional significance level of 0.05, we fail to reject the null hypothesis. This implies that there is no statistically significant difference between the FE and RE estimators, and the Random Effects model can be preferred due to its efficiency.

Given the Hausman test results, the Random Effects model is appropriate for this analysis as it provides consistent and efficient estimates without evidence of correlation between the regressors and the individual effects. Therefore, the RE model's results can be reliably used to interpret the determinants of FDI in the panel of Algeria, Tunisia, Morocco, and Libya.

The Hausman test results indicate that the Random Effects (RE) model is the most appropriate estimator for analyzing the determinants of foreign direct investment (FDI) in Algeria, Tunisia, Morocco, and Libya. Statistically, this means there is no significant correlation between the regressors and the unobserved individual effects, allowing the RE model to provide consistent and efficient estimates by exploiting both within- and between-country variation.

5. Economically speaking

The preference for the Random Effects model suggests that the differences across the four countries are not strongly correlated with the explanatory variables, implying that country-specific effects can be treated as random rather than fixed. This allows us to generalize the findings beyond the sampled countries, capturing both the time dynamics within each country and the heterogeneity across countries. The RE model's significant positive coefficients on trade openness (OUV), economic size (PIB), and governance quality (SG) align with extensive literature highlighting these factors as key drivers of FDI inflows in North Africa and the broader MENA region. For example, greater trade openness reduces barriers and transaction costs, making countries more attractive to foreign investors, while larger economies offer bigger markets and investment opportunities. Improved governance enhances investor confidence by reducing risks associated with corruption and institutional inefficiencies.

The negative effect of democracy (DEM) on FDI, found to be significant in the RE

model, may reflect concerns about political transitions or instability in these countries, which can deter foreign investors despite democratic reforms. This nuanced political-economic relationship is consistent with studies emphasizing the complex role of institutional quality and political environment in shaping FDI flows. Overall, the use of the Random Effects model provides a robust framework to understand the determinants of FDI in the North African context, emphasizing market openness, economic size, and governance as critical factors while accounting for unobserved heterogeneity across countries. This insight is valuable for policymakers aiming to design targeted reforms to attract and sustain foreign investment in the region.

6. Conclusion

This article examined the determinants of foreign direct investment (FDI) in four North African countries: Algeria, Tunisia, Morocco, and Libya, using panel data covering the period from 1990 to 2021. By applying various panel data models, including fixed effects and random effects, the study tested hypotheses related to cross-sectional dependence and serial correlation in the data, and selected the most appropriate model based on the Hausman test.

The results indicate that the random effects model is the most suitable for analyzing the data, suggesting no significant correlation between the explanatory variables and unobserved individual effects. This model provides consistent and efficient estimates by capturing both within- and between-country variation. The study highlighted the pivotal role of trade openness, economic size, and governance quality in attracting FDI to North African countries. Conversely, democracy showed a significant negative impact, reflecting the complex political environment and its influence on foreign investors' decisions, especially amid political transitions and potential instability.

The study underscores the importance of enhancing economic openness policies and improving governance indicators as key factors to increase the attractiveness of the region for foreign investment. It also emphasizes the need to achieve political stability and a reliable institutional environment that strengthens investor confidence and mitigates political risks. Overall, the study provides a comprehensive analytical framework to understand the dynamics of FDI in North Africa during 1990–2021 and offers practical recommendations for policymakers to promote sustainable economic development and regional economic integration.

These findings serve as an important reference for researchers and policymakers aiming to design effective strategies to attract investment and improve the business environment in the region, taking into account the unique economic and political characteristics of each country.

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Ethics

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