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COMPUTATIONAL SIMULATION OF INSTITUTIONAL-INVESTMENT DYNAMICS USING PANEL VECTOR AUTOREGRESSION

Abstract. This study develops a computational framework for simulating dynamic interactions between institutional quality indicators and foreign direct investment using a panel Vector Autoregression model applied to a multi-country dataset. The work emphasizes the algorithmic structure of the modeling pipeline, including preprocessing of heterogeneous panel time series, numerical stationarity diagnostics and cointegration testing. Impulse-response simulations are used to examine system behavior following institutional shocks, illustrating the dynamic propagation of disturbances in a high-dimensional environment. Although the empirical application concerns institutional governance, the contribution of this study lies primarily in its computational workflow design, numerical diagnostics, and reproducible implementation of a panel VAR simulation environment. The presented framework demonstrates how computational finance and applied computer science can integrate econometric modeling to analyze complex, interdependent systems.

Keywords: panel VAR, computational modeling, dynamic systems simulation, impulse response functions, numerical econometrics, data-driven analysis, computational finance.

1. Introduction

The dynamic relationship between institutional quality and foreign direct investment (FDI) remains an important and methodologically challenging topic in computational economics and data-driven modelling. Classical theories of multinational production, most notably the OLI paradigm formulated by Dunning [5], have established institutions as a structural component affecting the locational strategies of global firms. Empirical research reinforces this general conclusion, showing that investment inflows tend to correlate with political stability, regulatory effectiveness, and the rule of law [6], [7]. At the same time, a parallel body of work emphasizes the potential for reverse causality: the arrival of foreign investors can itself transform domestic governance structures by introducing regulatory pressures, informational spillovers, or new administrative standards [8], [10].

Panel VAR (PVAR) methods have become a preferred tool for capturing bidirectional, time-varying interactions across countries because they model the joint dynamics of multiple endogenous variables and allow for impulse–response analysis in a panel setting [2], [12]. Foundational computational implementations and software support for PVAR estimation are provided by Abrigo and Love [1], while comprehensive methodological surveys discuss specification choices, identification strategies, and practical challenges in PVAR applications [3], [16].

Recent advances in computational econometrics address these limitations by employing panel vector autoregression, which provides a flexible architecture for modelling multivariate dynamic systems [2], [12]. They address computational stability and high-dimensionality issues that arise when modelling many institutional indicators and controls jointly. Regularization and penalized estimators adapted to PVAR (panel-LASSO) have been proposed to reduce estimation variance and improve numerical conditioning in large panels [15], while high-dimensional VAR frameworks that accommodate common factors help to manage strong cross-sectional dependence and improve estimator performance [11]. Further work highlights the importance of eigenvalue/stability diagnostics and the potential distortions induced by neglected changes in mean or volatility when estimating VAR systems [4], [13]. Systematic reviews of PVAR practice summaries these developments and emphasize reproducibility and explicit documentation of orthogonalization and identification choices [16].

On the applied side, cross-country PVAR studies document that institutional shocks can have persistent short-run effects on FDI, highlighting the importance of a dynamic, system-based treatment of governance measures [2], [12], [14]. Motivated by this literature, the present study constructs a fully specified computational workflow for modelling institutional–FDI dynamics using panel VAR techniques. The pipeline integrates panel stationarity testing, cointegration verification, forward orthogonal deviations (FOD) transformation, structured Cholesky decomposition (or alternative structural identification), eigenvalue stability checks, and reproducible simulation procedures to produce panel-averaged impulse response functions (IRFs) and forecast error variance decompositions (FEVDs) suitable for cross-country inference [1] – [16].

Despite the growing popularity of PVAR models, many empirical applications remain incomplete from a computational standpoint. Choices regarding orthogonalization, variable ordering, numerical stability of estimated systems, and reproducibility of simulation procedures are often insufficiently documented. Such omissions reduce the transparency of structural inference and weaken the credibility of model-based conclusions. By emphasizing algorithmic clarity, numerical diagnostics, and reproducible simulation design, this study addresses these gaps. The objectives are twofold: to provide empirical insights into the short-term responses of FDI to institutional shocks across a diverse group of economies, and to demonstrate a computationally coherent and transparent methodology aligned with contemporary standards in applied econometrics and computational research.

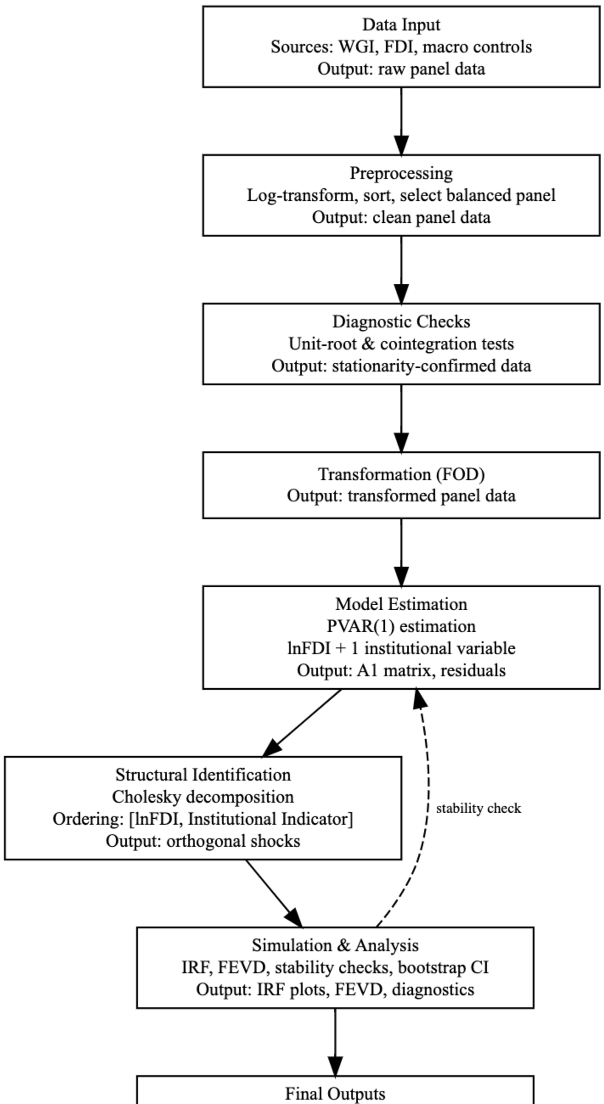

Figure 1 – Overview of the computational workflow

The novelty of the present study should therefore be understood in computational rather than methodological terms. The econometric building blocks employed – panel VAR estimation, unit-root testing, structural identification, and impulse-response analysis – are standard. What distinguishes the approach is the way these components are combined into a reproducible, constraint-based workflow in which diagnostic checks are not merely reported but explicitly govern admissible model configurations and simulations. In this sense, the framework emphasizes disciplined execution, numerical verification, and transparency over the introduction of new estimators or identification schemes. The analysis focuses on short-run dynamic associations rather than causal identification in the structural sense.

2. Materials and Methods

The entire modelling pipeline was implemented as a modularly organized computational workflow, in which logically distinct stages are executed sequentially and validated through intermediate diagnostics: data normalization, differencing, unit-root diagnostics, eigenvalue stability verification, FOD transformation, system estimation, and simulation of shock-driven trajectories. Each module maintains deterministic reproducibility and uses numerically stable matrix operations suitable for high-dimensional panel structures.

2.1. Data Architecture and Preprocessing

The sample consists of 24 countries selected based on data completeness over 2004–2020 and classified by World Bank region and income group (see Table 1). The analysis relies on a balanced panel of twenty-four countries spanning the years 2004 to 2020. The variables include FDI inflows and greenfield FDI, complemented by six World Governance Indicators: control of corruption (COR), government effectiveness (GOV), political stability (POL), rule of law (RUL), regulatory quality (REG), and voice and accountability (VOI) [18]. Standard macroeconomic controls-trade openness, inflation, unemployment, and GDP per capita-were sourced from World Bank Open Data [17] and UNCTAD statistics [19].

Table 1 illustrates the substantial heterogeneity in both FDI inflows and institutional indicators across countries, reinforcing the suitability of a panel-based dynamic framework.

All variables were log-transformed to stabilize variance. The dataset was sorted by country and year, and only units with complete nineteen-year coverage were retained. This ensured numerical consistency of the PVAR estimators and avoided distortions from unbalanced temporal structures, which are known to affect the properties of dynamic panel estimators [2].

All computations were performed in R version 4.4.1 (2024-06-14, “Race for Your Life”) on an x86_64-apple-darwin20 platform. The analysis relied primarily on the *plm*, *panelvar*, *urca*, *vars*, and *tidyverse* packages (versions current as of 2024). Deterministic random seeds were set prior to estimation and bootstrap procedures. To support replication and verification, intermediate artefacts–including transformed datasets, estimated coefficient matrices, residual covariance matrices, and eigenvalue diagnostics–were systematically exported and logged at each major stage of the workflow. Selected impulse-response computations were independently replicated in Stata to verify numerical consistency across software environments. A minimal script outline documenting the execution sequence and diagnostic checks will be made available as supplementary material or upon reasonable request.

2.2. Diagnostic Procedures

The time-series properties of the data were examined using a suite of panel unit-root tests, including Levin–Lin–Chu, Im–Pesaran–Shin, augmented Dickey–Fuller, and Fisher-type tests [2], [12]. All unit-root and cointegration tests were conducted in a pooled panel setting, following standard PVAR practice. Country-level testing was not pursued to preserve statistical power. Variables were treated as integrated of order one when they exhibited non-stationarity in levels and stationarity after differencing.

Table 1 – Countries included in the balanced panel (2004–2022) with region, income group, and summary statistics for key variables: Foreign Direct Investment, Governance Effectiveness, Political Stability and Rule of Law.

country	region	income group	mean FDI	sd FDI	mean GOV	sd GOV	mean POL	sd POL	mean RUL	sd RUL
Albania	Europe	Upper-middle	4982.4073	3043.6103	0.0999268	1.1031541	0.2548025	1.0047710	0.1017663	1.0146840
Angola	Sub-Saharan Africa	Upper-middle	24684.9333	8925.7938	-0.2211279	0.8582962	-0.2208510	1.1153118	-0.1990148	0.8984379
Bhutan	Asia	Lower-middle	346.4255	259.2892	0.1655105	1.0444797	-0.0218899	0.9904666	0.0636915	1.1343357
Chad	Sub-Saharan Africa	Low	4726.6959	1753.6190	-0.1652149	0.9352040	0.0583180	0.7525288	-0.2175765	0.9667489
Chile	Latin America	High	177858.532	64907.7462	-0.0071067	1.1071683	-0.0099975	1.0682045	-0.0676689	1.1071915
Colombia	Latin America	Upper-middle	127532.849	67266.2378	-0.3161419	0.8186278	-0.3818359	0.9876375	-0.3857535	0.8598279
Estonia	Europe	High	20444.2609	7555.9601	0.2528075	1.0952287	0.4911665	0.6689210	0.2147030	1.0853567
Fiji	Oceania	Upper-middle	3531.3399	1577.8022	-0.2422086	0.8616657	-0.0832803	1.1679242	-0.2008122	0.9344640
Germany	Europe	High	928372.517	134007.343	-0.1407846	0.9635251	-0.1188034	0.9751304	-0.2151610	0.9474373
Honduras	Latin America	Lower-middle	10339.9883	5403.8136	0.2505163	1.1465176	0.0379724	1.0098637	0.1835270	1.2131949
Hungary	Europe	High	90646.2653	13184.1782	0.4036586	1.0289071	0.3706888	0.8921296	0.4358061	1.0138094
India	Asia	Lower-middle	261431.186	154089.822	-0.3503703	0.8499743	-0.3636368	0.9638052	-0.2625112	0.9410410
Ireland	Europe	High	661680.820	493395.101	-0.0396834	1.0176809	-0.3025411	0.8756267	-0.0467813	1.0327271
Kazakhstan	Central Asia	Upper-middle	105764.787	48511.7517	-0.3176967	0.8626395	-0.0665632	0.7698897	-0.3928801	0.9452101

Continuation of the table

country	region	income group	mean FDI	sd FDI	mean GOV	sd GOV	mean POL	sd POL	mean RUL	sd RUL
Kenya	Sub-Saharan Africa	Lower-middle	5678.5509	2793.2115	0.0491488	1.0408781	0.0146998	1.1059649	-0.0222785	1.0597301
Kuwait	Middle East	High	11441.2442	6069.6946	-0.4149287	0.7868528	-0.3508415	0.8845619	-0.4416138	0.7978328
Latvia	Europe	High	14180.1272	5514.0176	0.2573243	1.0186930	0.3376108	0.8748282	0.3118882	1.0022222
Mauritius	Sub-Saharan Africa	Upper-middle	3742.9757	1896.5257	0.0951379	1.1663976	0.2411411	0.9476989	0.1480538	1.0253504
Namibia	Sub-Saharan Africa	Upper-middle	4809.1357	1849.6302	-0.0330816	0.9290992	0.0402133	0.9083712	-0.1800200	0.9281190
Norway	Europe	High	145579.503	35486.5752	0.2389848	1.1783227	0.0163374	1.0029353	0.1205695	1.2198415
Pakistan	Asia	Lower-middle	25506.9660	9784.6354	0.3928352	1.0465439	0.4848705	0.7992567	0.4000768	1.0356895
Poland	Europe	High	198154.078	59389.1052	-0.0499497	1.0363820	-0.3103073	0.8504502	-0.0023631	1.0419077
Senegal	Sub-Saharan Africa	Lower-middle	3898.4415	3675.6230	-0.0090956	1.0228359	-0.0338832	1.0616757	-0.0737307	1.0374500
Timor-Leste	Asia	Lower-middle	258.5969	201.7687	-0.3762982	0.8787595	-0.3044273	0.9845603	-0.3612315	0.8448549

Table 2 – Panel unit-root test statistics.

Variable	LLC stat	IPS stat	Fisher stat
lnFDI	−10.5716	−7.4976	228.19
lnGREENFDI	−5.2054	−6.0023	167.40
lnCOR	−10.0471	−11.4101	334.23
lnGOV	−8.1410	−9.4301	259.27
lnPOL	−6.6929	−8.1029	216.01
lnRUL	−10.4982	−11.5921	327.07
lnREG	−8.9451	−9.8530	258.43
lnVOI	−9.2983	−11.2570	298.64
ΔlnFDI	−6.6760	−7.0651	183.99
ΔlnGREENFDI	−13.9215	−17.3808	552.88
ΔlnCOR	−17.9368	−21.0211	734.10
ΔlnGOV	−14.6504	−19.0072	622.62
ΔlnPOL	−11.8233	−16.7560	541.09
ΔlnRUL	−16.3112	−19.3853	639.50
ΔlnREG	−14.4054	−18.1779	578.88
ΔlnVOI	−15.6439	−19.8155	685.33

Panel unit-root tests indicate that all variables are consistent with non-stationarity in levels, with with only limited evidence against the unit-root null in pooled panel tests. In contrast, first-differenced series exhibit strong stationarity, as evidenced by highly negative LLC and IPS statistics and large Fisher test values. This pattern is consistent across all institutional indicators and FDI measures, supporting the treatment of the variables as integrated of order one and justifying the use of a differenced panel VAR specification.

Pairwise Phillips–Ouliaris tests were then used to assess potential cointegration between FDI and each institutional indicator. The absence of significant cointegration relationships justified modelling the system in first differences, ensuring that the dynamic equations were numerically appropriate and free from spurious regressions. The tests provide no evidence of cointegration between FDI and institutional indicators in either direction at the panel level. The absence of long-run equilibrium relationships supports modelling the system in first differences rather than employing a panel VECM framework. This result reinforces the focus on short-run dynamic interactions captured by the panel VAR specification.

Table 3 – Panel Phillips–Ouliaris Cointegration Tests.

Direction	Share cointegrated	Mean test statistic
lnFDI → lnCOR	0.000	0.0645
lnCOR → lnFDI	0.000	13.3359
lnFDI → lnRUL	0.000	0.0571
lnRUL → lnFDI	0.000	12.6975
lnFDI → lnVOI	0.000	0.0381
lnVOI → lnFDI	0.000	12.0910

The stability of the estimated PVAR model was assessed through the eigenvalue modulus test. Figure 2 plots the real and imaginary parts of all eigenvalues associated with the companion matrix. All values lie strictly inside the unit circle, which indicates that the system satisfies the Schur-stability condition. Consequently, the dynamic properties of the model are well defined, and the impulse – response functions can be interpreted in a standard manner. The absence of explosive roots is particularly relevant given the inclusion of institutional indicators and macroeconomic controls, which may induce persistence or near-unit dynamics.

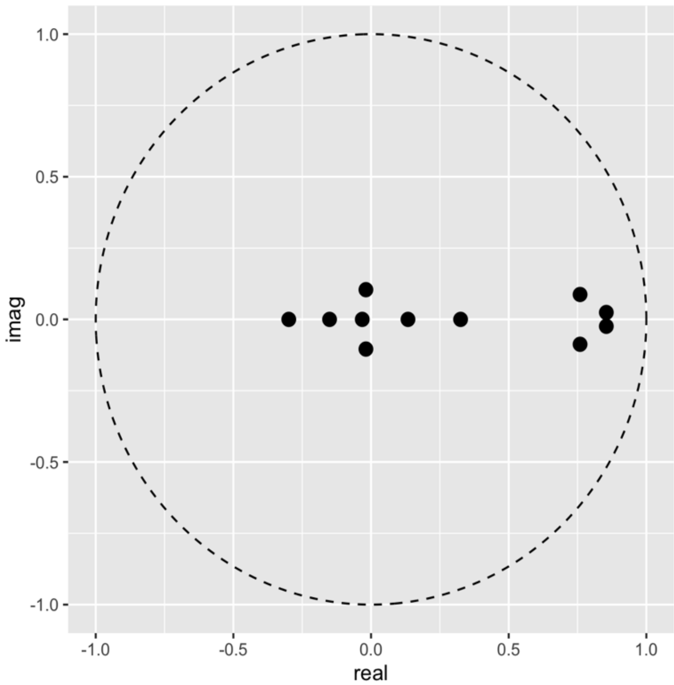

Figure 2 – Eigenvalue stability check

2.3. Model Construction and Structural Identification

The computational model takes the form of a first-order panel vector autoregression. After applying the FOD transformation to eliminate fixed effects without inducing serial correlation, the system can be written as:

$$\Delta y_{i,t} = A_1 \Delta y_{it-1} + u_{i,t}, \qquad (1)$$

where $y_{i,t}$ contains lnFDI and one institutional variable. This specification follows standard practice in simulation-based computational econometrics, in which dynamic responses to shocks are examined by iterating the system forward.

The workflow does not introduce new estimation algorithms, nor does it rely on fully automated model selection; instead, it formalizes best-practice diagnostics and reproducibility safeguards within a transparent execution sequence.

The endogenous vector $y_{i,t}$ consists of the logarithm of FDI inflows and one institutional quality indicator at a time, while macroeconomic controls (trade openness, inflation, unemployment, and GDP per capita) enter the system as exogenous regressors.

$$y_{i,t} = A_1 \Delta y_{it-1} + Bx_{i,t} + \varepsilon_{i,t}, \qquad (2)$$

where:

$t - 1, ..., N -$ indexes countries,

$t - 1, ..., T -$ indexes time,

$y_{i,t}$ – is the vector of endogenous variables,

$x_{i,t}$ – denotes exogenous controls,

$\varepsilon_{i,t}$ – is the reduced-form error vector.

All endogenous variables enter the system in first differences, consistent with the unit-root and cointegration diagnostics reported in Section 2.2. To maintain numerical tractability and avoid overparameterization, the analysis proceeds via a sequence of bivariate panel VAR models rather than a single high-dimensional system. In each specification, the endogenous vector consists of log FDI inflows and one institutional quality indicator.

Macroeconomic controls, including trade openness, inflation, unemployment, and GDP per capita, enter the model as strictly exogenous regressors and are not included in the endogenous VAR vector. The model is estimated using a fixed-effects panel VAR with forward orthogonal deviations, as implemented in the *panelvar* package. This estimator removes fixed effects without relying on internal GMM instruments.

The lag order was set to one based on standard information-criterion considerations, the limited time dimension of the panel (T = 19), and numerical stability requirements of the estimated system. Higher-order specifications were not pursued due to degrees-of-freedom constraints and the risk of overparameterization in a multi-country panel VAR.

2.4. Structural Identification

Structural shocks were extracted using a Cholesky decomposition of the estimated covariance matrix of the residuals. All impulse responses should therefore be interpreted as Cholesky-identified responses under a particular recursive ordering assumption, rather than as fully structural causal effects. The ordering was set as:

$$[\ln FDI, \text{Institutional Indicator}],$$

Under this ordering, institutional variables are allowed to respond contemporaneously to shocks in FDI, whereas FDI responds to institutional innovations only with a lag. This convention is consistent with related research [2], [12], [14], and corresponds to a modelling assumption in which institutional structures respond sluggishly to economic movements, while foreign investors can adjust more rapidly. This identification reflects the assumption that foreign investment decisions can adjust rapidly to economic conditions, while institutional reforms are persistent processes; however, observed institutional indicators may still exhibit contemporaneous responses to investment-related pressures through administrative or political channels.

2.5. Panel-Averaged Impulse Response Functions and Stability Diagnostics

The impulse-response generation procedure can be interpreted as the simulation of a perturbed multivariate dynamical system. The Cholesky-orthogonalized shocks serve as controlled perturbations, while the trajectories approximate the transient dynamics of the system under exogenous disturbances.

Before generating impulse response functions, the numerical stability of the system was verified. The eigenvalues of the autoregressive matrix A_1 were computed, and stability was accepted only if all eigenvalues lay strictly inside the unit circle. This requirement guarantees that the simulated responses decay over time rather than diverging, an essential property for any structural dynamic model. The condition number of the covariance matrix was also monitored to assess the reliability of Cholesky decomposition and mitigate issues arising from near singularity. Bootstrap confidence intervals were computed to detect instability in estimated responses.

To illustrate the computational architecture, Figure 3 shows the integration of stability checks, orthogonal shock decomposition, and profiling of algorithmic complexity within the existing code structure:

3. Results

The results presented in this section summarize the behavior of the simulated institutional–investment system under the estimated panel VAR dynamics. The computational workflow produces several layers of output, including stability verification, system-wide impulse-response trajectories, and variance decompositions based on orthogonal structural shocks. Together, these elements provide a discrete-time characterization of how the model responds to controlled perturbations and how uncertainty propagates through the autoregressive operator. The presentation below focuses first on the empirical properties of the estimated system and then on the simulated responses that reveal its short-term dynamic structure.

3.1. Data properties and preliminary diagnostics

The unit-root tests indicated that *lnFDI* and all six institutional indicators are integrated of order one. Cointegration tests confirmed the absence of robust long-run equilibrium relationships between FDI and any institutional metric, validating the decision to model the system in differences.

3.2. Panel VAR estimation and system-wide impulse responses

The PVAR estimates reveal strong autoregressive behavior in FDI, suggesting high short-term persistence across the countries in the sample. Institutional variables display weaker short-run effects, while trade openness consistently shows a positive association with changes in FDI.

The structural impulse responses showed that an institutional improvement typically induced a short-term decline in FDI inflows. This finding stands in contrast to long-run theoretical expectations but aligns with the hypothesis that institutional reforms may impose temporary adjustment costs or reduce strategic advantages available to investors under less regulated conditions.

The panel-averaged IRF masks considerable heterogeneity. India responded positively to institutional improvements, whereas Brazil, Indonesia, and Kazakhstan exhibited negative reactions. These differences underscore the relevance of country-specific structural conditions and support the use of panel IRFs to derive more generalizable conclusions.

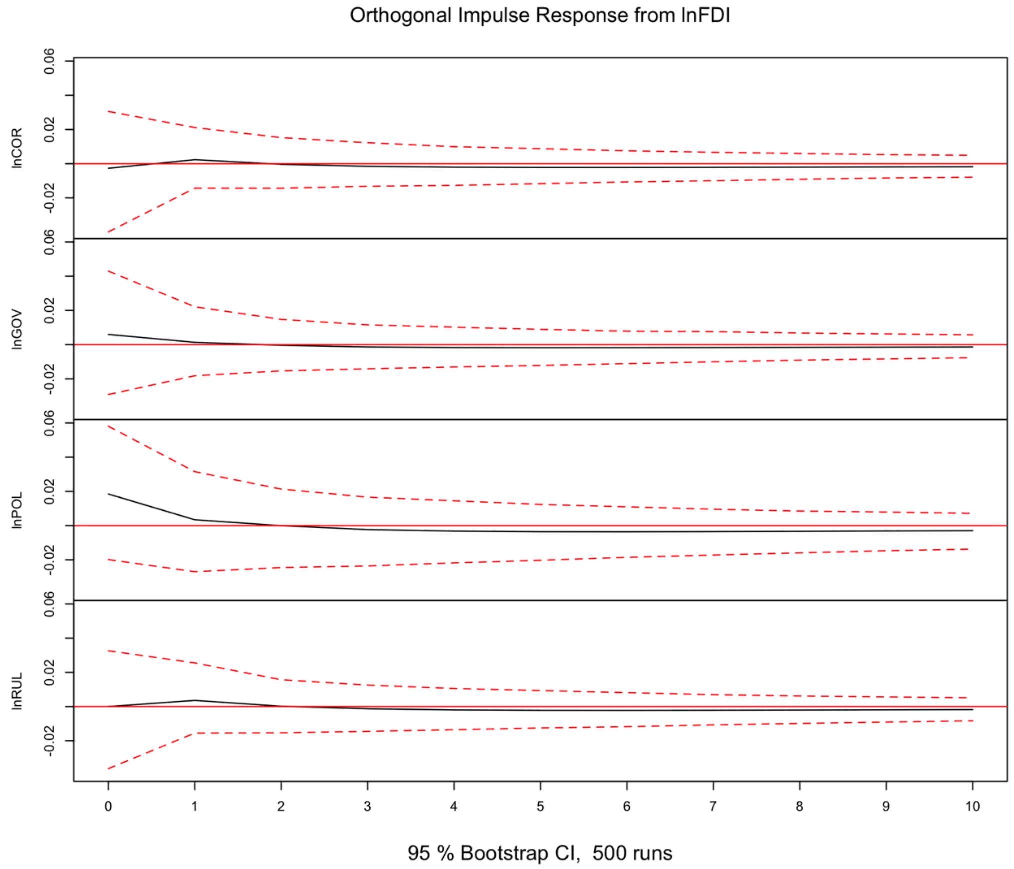

Figure 3 – Panel-averaged IRF

Table 4 – Panel VAR Estimates – *lnFDI* Equation

Predictor	Estimate	Std. Error	p-value
Lagged *lnFDI*	0.8712	0.0155	0.0000
Lagged *lnCOR*	−0.0120	0.0248	0.6289
Lagged *trade*	0.0015	0.0007	0.0457
Lagged *inflation*	−0.0001	0.0030	0.9777
Lagged *unemployment*	0.0008	0.0051	0.8667
Lagged *GDP per capita*	0.0000	0.0000	0.2048

The estimated panel VAR coefficients reveal strong autoregressive persistence in FDI, with the first lag of *lnFDI* exhibiting a large and highly significant coefficient. Lagged institutional quality, proxied by control of corruption, does not exert a statistically significant short-run effect on changes in FDI once dynamics and macroeconomic controls are accounted for. Among the control variables, trade openness shows a weak but statistically significant positive association with FDI dynamics, while inflation, unemployment, and GDP per capita are not significant. These results suggest that short-term movements in FDI are primarily driven by internal dynamics rather than contemporaneous institutional changes.

3.3. Country-level dynamics: the Kazakhstan case

Figure 4. illustrates country-specific IRFs using Kazakhstan as an example. The orthogonalized IRFs are based on a Cholesky decomposition that places institutional variables after FDI in the ordering. Confidence intervals were generated using 500 bootstrap replications.

A one-standard-deviation FDI shock induces a small and short-lived negative response in the control of corruption (*lnCOR*), which dissipates by the third period. Government effectiveness (*lnGOV*) also declines modestly and with slightly greater persistence. These patterns suggest that inward capital flows may temporarily strain administrative capacities rather than improve them.

Political stability (*lnPOL*) shows a more evident negative reaction, indicating that new investment may amplify distributional tensions or expose existing political fragilities. In contrast, the rule of law (*lnRUL*) remains largely unaffected, consistent with its slow-moving institutional character. Overall, these country-specific trajectories indicate that short-term feedback from FDI to institutional quality is weak and, in some dimensions, mildly adverse.

3.4. Shock propagation and variance decomposition

To analyze how shocks propagate through the simulated dynamic system, the computational environment includes a dedicated FEVD module. In addition to its standard econometric interpretation, FEVD is used here as a numerical diagnostic. Using the estimated coefficient matrix A_1, the residual covariance matrix Σ_u, and the Cholesky factor L, the module generates horizon-indexed variance shares that describe how forecast uncertainty is distributed across structural shocks.

For each horizon, the algorithm computes the state-transition operator A_1^h, applies the mapping $A_1^h L$, and aggregates the contribution of each innovation to the forecast variance of every endogenous variable. Numerical reliability is ensured by verifying that the spectral radius of the companion matrix is strictly below unity and by monitoring the conditioning of Σ_u to prevent artefacts caused by near-singular residual structures.

Interpreted as a computational probe, FEVD reveals the internal architecture of the model. It highlights the channels through which innovations propagate, the rate at which dynamics decay, and the extent to which institutional shocks influence the behavior of foreign investment.

The empirical results show a strong dominance of own-variable shocks for all endogenous series. FDI forecast variance is almost entirely driven by its own innovations, with institutional and macroeconomic shocks contributing only marginally across all horizons. Institutional indicators display the same pattern: slow-moving, internally driven dynamics with limited sensitivity to external impulses from FDI. Macroeconomic controls also exhibit minimal cross-variable spillovers.

Taken together, the FEVD evidence indicates a system characterized by high persistence and weak contemporaneous transmission. Institutional shocks exert limited influence on FDI, and FDI shocks have similarly small effects on institutional indicators. These findings align with the IRF results and support the view that, over the short to medium term, institutional quality and foreign investment primarily evolve through gradual internal processes rather than strong dynamic feedback mechanisms.

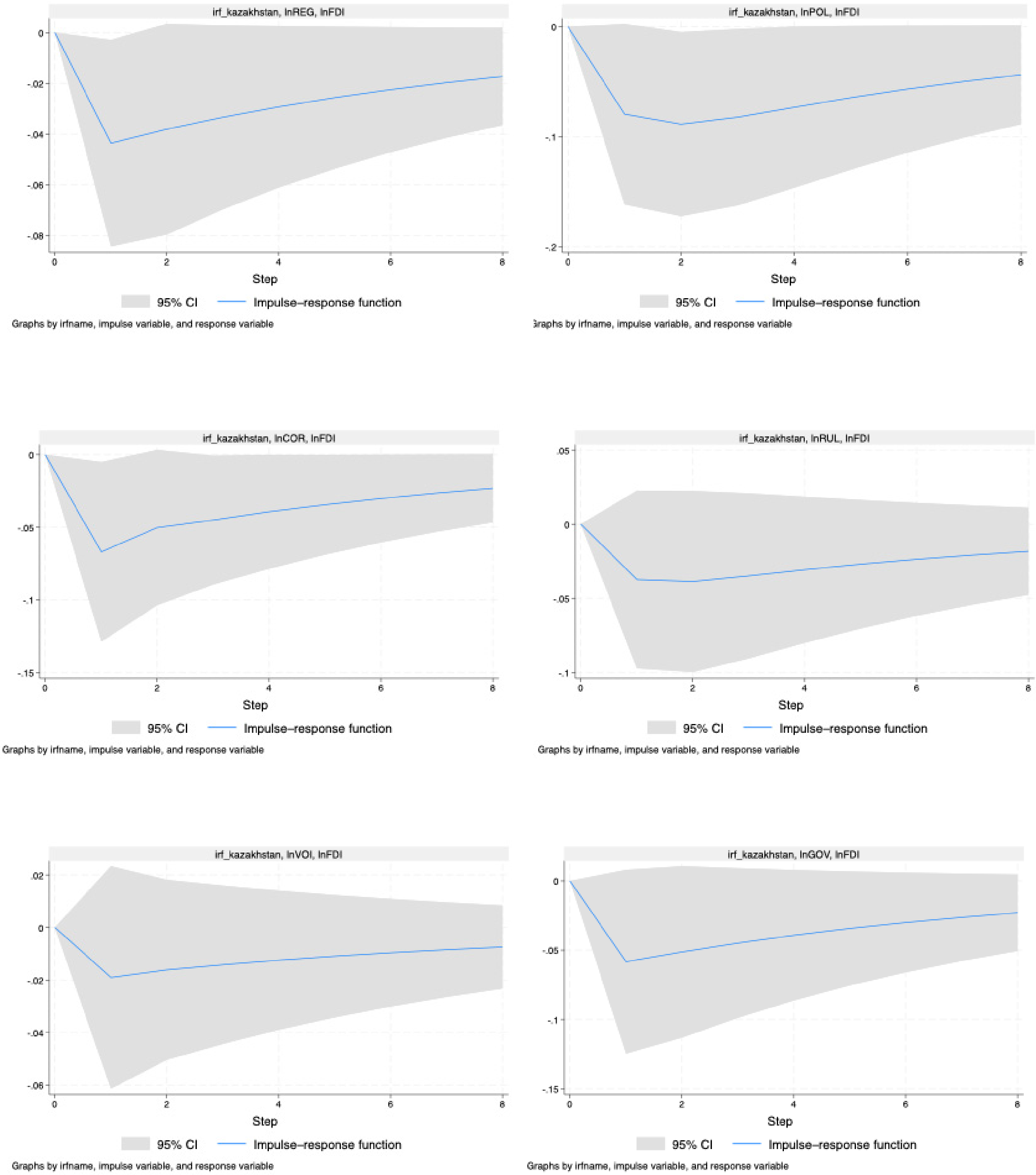

Figure 4 – Country-specific impulse-response functions for Kazakhstan. Each panel shows the response of an institutional indicator to a one-standard-deviation shock in lnFDI over an 8-year horizon. Shaded areas denote 95% bootstrap confidence intervals (500 replications).

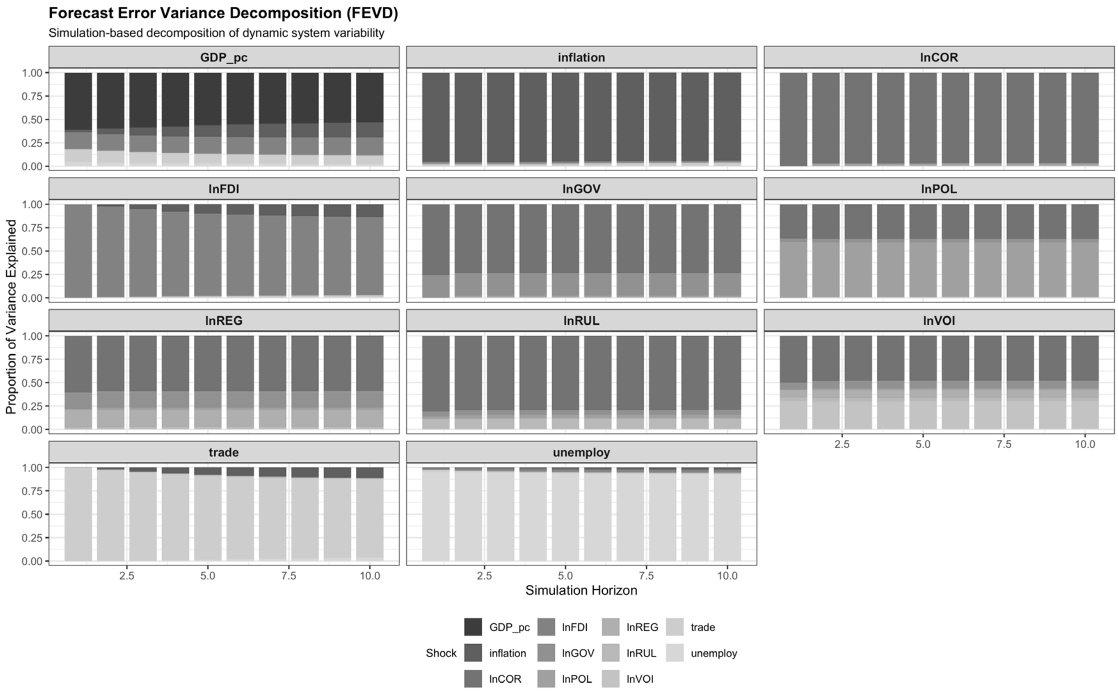

Figure 5 – Forecast Error Variance Decomposition. Proportion of variance in each response variable explained by shocks to all variables over a 10-period horizon in the PVAR model. Panels show how each shock propagates through the system.

4. Discussion

The simulation framework shows that the dynamic behavior of the institutional–investment system is strongly shaped by the structural configuration of the panel VAR model. The orthogonalization scheme, the stability properties of the autoregressive operator, and the numerical conditioning of the system matrices jointly determine how the model reacts to perturbations. The heterogeneous country-level responses, for example, the positive short-run reaction in India contrasted with the negative responses in Brazil, Indonesia, and Kazakhstan, demonstrate how small differences in estimated system parameters produce distinct transient trajectories once the system is shocked. Rather than reflecting only economic mechanisms, these patterns arise from the interaction between empirical estimates, eigenvalue geometry, and the algebraic structure of the transformations applied within the simulation engine.

Interpreting these outcomes is most meaningful when the model is viewed as a discrete-time computational system rather than a purely econometric specification. The impulse-response trajectories represent the evolution of the state-transition operator under controlled perturbations, and their variation across countries reflects differences in the local Jacobians governing each subsystem. This viewpoint aligns the analysis with practices in applied computer science and computational modelling, where system dynamics are often characterized by sensitivity to initial conditions, structural heterogeneity, and path-dependent propagation of shocks across interconnected modules.

The computational diagnostics embedded into the workflow were essential for validating the simulation environment. The stability check ensured that all eigenvalues lay strictly within the unit circle, allowing the system to be treated as a stable dynamical process suitable for forward simulation. From a computational perspective, the ordering defines a specific shock-propagation topology within the simulated system. Conditioning checks on the covariance matrix and its Cholesky factor prevented numerical artefacts that could distort the shape or magnitude of impulse-response paths. These controls made it possible to attribute the observed patterns to the underlying system dynamics rather than to numerical instability. Reproducibility safeguards, including fixed seeds and standardized matrix operations, further strengthened the reliability of the simulation results.

The findings also highlight the value of integrating simulation-based reasoning with economic interpretation. The short-run decline in FDI following improvements in institutional quality, observed in several countries, may reflect transitional frictions, regulatory tightening, or the removal of informal mechanisms previously relied upon by investors. India's positive response illustrates that institutional strengthening can enhance credibility and reduce uncertainty, producing favorable investment dynamics. The computational analysis does not replace these interpretations but clarifies how theoretical mechanisms interact with the system's numerical architecture, shaping the resulting dynamic profiles.

Overall, the study demonstrates that modelling socio-economic systems with panel VARs benefits from a dual perspective: economic theory provides directional hypotheses, while algorithmic analysis reveals how those hypotheses materialize once embedded in a high-dimensional, numerically constrained simulation environment. The results show that dynamic interactions between institutions and FDI are weakly coupled and sensitive to structural and numerical considerations, reinforcing the need for careful system design when applying computational models to complex socio-economic processes.

It should be emphasized that the observed short-term decline in FDI following improvements in institutional quality is hypothetical and transient. This effect likely reflects temporary adjustment costs, regulatory tightening, or strategic responses by investors, rather than a permanent consequence of institutional reforms. Therefore, these results should not be interpreted as evidence of long-term causal effects, which may vary across countries and macroeconomic contexts.

5. Conclusions

The study introduces a computational framework for simulating short-term interactions between institutional quality and foreign direct investment within a panel VAR setting. The workflow integrates the preprocessing of heterogeneous panel data, stability verification, orthogonal shock construction, and dynamic simulation through impulse-response analysis and variance decomposition. By prioritizing algorithmic clarity, numerical conditioning, and reproducibility, the framework reflects contemporary standards in computer science research on dynamic system modelling.

The results show that the system operates as a stable, high-dimensional autoregressive process characterized by strong own-variable persistence and limited cross-variable spillovers. Institutional improvements frequently trigger temporary reductions in investment inflows, while shocks to FDI exhibit similarly short-lived effects on governance indicators. These patterns should be interpreted not only in economic terms but also as emergent properties of a simulated dynamical system whose behavior is shaped by the spectral structure of the autoregressive operator and the conditioning of the transformation matrices.

Beyond the empirical findings, the modelling environment developed here offers a reusable simulation architecture. It can be extended in several computational directions, including alternative orthogonalization schemes, machine-learning-assisted parameter tuning, hybrid integration with agent-based subsystems, or GPU-accelerated evaluation of high-dimensional model variants. The framework therefore contributes both substantive insights into institutional–investment dynamics and a flexible platform for future experimentation in multi-country, data-driven system simulation.

Conflicts of Interest

The author declares no conflict of interest.

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