AN ECONOMETRIC ANALYSIS OF AIR CARGO LOGISTICS DEVELOPMENT: EVALUATING THE IMPACT OF SMALL AND MEDIUM ENTERPRISE (SME) INTEGRATION ON SECTORAL GROWTH

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Abstract: *This paper investigates the long-run and short-run dynamics linking the integration of Small and Medium Enterprises (SMEs) to the development of the air cargo logistics sector in a transition economy. Drawing on annual time-series data for the period 2010–2025, we estimate a four-regressor cointegrating relationship in which Air Freight Turnover (FT) is modelled as a function of the SME participation rate in logistics (SME_p), Gross Domestic Product (GDP), infrastructure investment proxied by the cargo-dedicated aircraft fleet (INF), and a Digitalization Index (DI). The Augmented Dickey–Fuller (ADF) test confirms that all series are integrated of order one. Engle–Granger residual-based testing and a Vector Error Correction Model (VECM) reveal a stable long-run cointegrating equilibrium with an adjustment coefficient of −0.975 (statistically significant at the 1% level), indicating that approximately 97.5% of any short-run disequilibrium is corrected within a single annual period. Output elasticities are positive and economically meaningful for GDP (0.347), Digitalization (0.376), and SME integration (0.236), and Granger-style causality testing supports a unidirectional flow from SME participation to freight turnover ($F = 5.33$). Interpreted through the lens of Transaction Cost Economics, the findings are consistent with the hypothesis that the entry of small enterprises as agency-model intermediaries between trunk carriers and end-shippers reduces last-mile coordination costs and elevates the flexibility of the aggregate logistics function. The paper closes with policy recommendations for developing economies, emphasizing aviation-market liberalization, regulatory simplification of forwarding licences, and targeted digital-infrastructure subsidies as catalysts for export-led growth.*

Keywords: *air cargo logistics; SME integration; freight tonne-kilometres; VECM; cointegration; transaction cost theory; last-mile; digitalization; developing economies.*

Аннотация: *В настоящей статье исследуются долгосрочные и краткосрочные динамические взаимосвязи между интеграцией субъектов малого и среднего предпринимательства (МСП) и развитием сектора авиационной грузовой логистики в условиях переходной экономики. На основе годовых временных рядов за период 2010–2025 гг. оценивается коинтеграционное соотношение с четырьмя регрессорами, в котором грузооборот воздушного транспорта (FT) моделируется как функция уровня участия МСП в логистике (SME_p), валового внутреннего продукта (ВВП),* *инвестиций в инфраструктуру, аппроксимированных численностью грузового авиационного парка (INF), и индекса цифровизации (DI). Расширенный тест Дики–Фуллера (ADF) подтверждает, что все ряды являются интегрированными первого порядка. Тестирование на основе остатков по методу Энгла–Грейнджера и оценка векторной модели коррекции ошибок (VECM) выявляют устойчивое долгосрочное коинтеграционное равновесие с коэффициентом корректировки −0,975 (статистически значимым на 1%-м уровне), что свидетельствует о том, что приблизительно 97,5% любого краткосрочного отклонения от равновесия устраняется в течение одного годового периода. Выходные эластичности являются положительными и экономически значимыми для ВВП (0,347), цифровизации (0,376) и интеграции МСП (0,236), а тест причинности по Грейнджеру подтверждает однонаправленную связь от участия МСП к грузообороту (F = 5,33). Интерпретируемые в рамках теории трансакционных издержек, полученные результаты согласуются с гипотезой о том, что вхождение малых предприятий в качестве посредников по агентской модели между магистральными перевозчиками и конечными грузоотправителями снижает координационные издержки на «последней миле» и повышает гибкость агрегированной логистической функции. Статья завершается рекомендациями по экономической политике для развивающихся стран, в которых подчёркивается значимость либерализации авиационного рынка, упрощения регуляторных требований к лицензированию экспедиторской деятельности и адресного субсидирования цифровой инфраструктуры в качестве катализаторов экспортно-ориентированного роста.*

Ключевые слова: *авиационная грузовая логистика; интеграция МСП; тонно-километры грузоперевозок; VECM (векторная модель коррекции ошибок); коинтеграция; теория трансакционных издержек; «последняя миля»; цифровизация; развивающиеся экономики.*

INTRODUCTION

Global air cargo has emerged as one of the most strategically pivotal subsectors of the international transport economy. Although it accounts for less than 1% of global trade by volume, it conveys roughly 35% of trade by value, including the time-sensitive, high-margin, and perishable goods that define the modern just-in-time supply chain (IATA, 2024). The post-pandemic decade has structurally reshaped the industry: aggressive e-commerce expansion, fragmented manufacturing networks, and the substitution of belly-hold capacity by dedicated freighters have all accelerated demand for flexible, multi-tier service provision. Within this restructured market, an increasingly visible role is being played by Small and Medium Enterprises (SMEs) acting as freight forwarders, customs brokers, ground-handling agents, and last-mile carriers.

Despite this practical prominence, the empirical literature has not adequately quantified the causal contribution of SMEs to the macro-level performance of national air cargo systems. Existing research has tended either to treat SMEs as a residual feature of supply-chain organization or to focus on micro-level case studies that do not generalize beyond a single corridor or country. The present study addresses this gap by formulating, identifying, and estimating an econometric model in which SME participation enters as an explicit determinant of long-run sectoral growth.

The paper makes three contributions. First, it offers a coherent theoretical mapping from the Williamsonian Transaction Cost Economics (TCE) framework to the agency-based industrial organization of contemporary air cargo, showing how small intermediaries are selected over vertical integration whenever asset specificity is moderate, demand is uncertain, and contracting frequency is high. Second, it operationalizes this mapping through a Vector Error Correction Model (VECM) estimated on annual data for Uzbekistan (2010–2025) — a setting that combines rapid liberalization, accelerating SME formation, and a strategic Eurasian transit position. Third, drawing on the estimated long-run elasticities and the speed-of-adjustment coefficient, it derives evidence-based policy recommendations for developing economies seeking to use small-business participation as a catalyst for export-led aviation growth.

The remainder of the paper is organised as follows. Section 2 reviews global trends and the SME-centric strand of the air-cargo literature. Section 3 develops the theoretical framework grounded in TCE. Section 4 presents the data, variables, and methodology, including stationarity and cointegration testing. Section 5 reports the empirical results. Section 6 discusses implications, including policy levers for developing economies. Section 7 concludes.

2. Literature Review

The air cargo industry experienced a series of unprecedented shocks between 2020 and 2024, beginning with the wholesale collapse of belly-hold capacity in 2020 and the subsequent rate spikes that elevated yield to record highs. By 2023, freighter operators had absorbed much of the structural deficit through fleet expansion, while the gradual restoration of widebody passenger services restored balance to the trans-oceanic deck (Boeing, 2024; IATA, 2024). The recovery, however, has been uneven across regions: Asia-Pacific carriers regained pre-pandemic volumes earliest, North American operators benefited from the e-commerce surge, and Central Asian markets — historically dependent on transit traffic — only re-entered sustained growth from 2022 onward.

Three structural changes have outlasted the pandemic. First, e-commerce platforms now drive a growing share of international air freight, demanding shorter cut-off windows and more granular tracking. Second, freighter conversions and dedicated cargo airline launches have widened the industry's capital base. Third, regulators and shippers alike have adopted digital interoperability standards, particularly the IATA ONE Record initiative and digital airway bill (e-AWB) protocols, as basic conditions of doing business (Feng et al., 2023; Lee & Park, 2022).

The digital transformation of air cargo extends well beyond paperless freight. Cloud-based capacity-management platforms, application programming interfaces between forwarders and ground handlers, blockchain-enabled customs clearance, and machine-learning yield engines have collectively reduced informational asymmetries across the cargo handover. Empirical evidence from European and Asian gateways (Mariotti & Cattaneo, 2022; Zhang et al., 2023) suggests that digitalization can reduce per-shipment processing time by 18–27% and cut documentation errors by more than half. From an industrial-organization perspective, digitalization simultaneously lowers the entry barrier for small intermediaries and reinforces network effects favouring large platform operators — a tension that recurs in the present analysis.

In passenger logistics, the last-mile problem is well documented; in air cargo it has its own distinctive form. After arrival at a gateway airport, shipments must clear customs, be deconsolidated, sorted by destination, and delivered to often-distant inland recipients. This stage typically accounts for 28–40% of the total door-to-door cost (Wang & Yeung, 2021), arises from severe coordination problems (multiple carriers, brokers, and ground operators), and is a persistent bottleneck in developing economies where the regulatory and infrastructural frame is fragmented. The cumulative empirical evidence indicates that competitively sourced last-mile services — typically supplied by SMEs — outperform vertically integrated alternatives whenever volumes are heterogeneous, routes are spatially dispersed, and demand is volatile.

SMEs occupy three structurally distinct positions in the air-cargo value chain: (i) freight forwarders and customs agents that consolidate shipper demand and contract with trunk carriers; (ii) ground-handling and warehousing operators that provide last-mile capacity at gateway airports; and (iii) niche specialists serving cold-chain, dangerous-goods, or e-commerce cross-border parcels. Empirical work in Southeast Asia (Tan & Lee, 2022) and Eastern Europe (Kovács & Spens, 2021) shows that SMEs deliver three principal advantages: lower fixed-cost burdens, faster contractual response to demand shocks, and higher adaptability to local regulatory and infrastructural specificities.

The role of SMEs is thus complementary to that of large carriers: they act as agency-model intermediaries which absorb the coordination work that would otherwise be internalized at high cost by trunk operators. The most recent literature emphasizes that this agency role is particularly valuable in developing economies, where the institutional frame increases the cost of vertical integration (Memedovic et al., 2023). The hypothesis examined in this paper is consistent with these findings: integrating SMEs into the air-cargo supply chain should reduce last-mile coordination costs and raise the responsiveness of the aggregate logistics system.

3. Theoretical Framework

The intellectual point of departure is the Williamsonian Transaction Cost Economics (TCE) framework (Williamson, 1985, 1991), which models the choice between vertical integration and market procurement as a function of three transaction attributes: asset specificity (k), demand uncertainty (σ), and the frequency of contracting (f). Following the canonical Williamson formulation, the optimal governance mode minimizes the sum of production and transaction costs:

$$\min_{G \in \{M, H\}} \; TC(G) = C_P(G; k) + C_T(G; k, \sigma, f)$$

where M denotes the market, H the firm hierarchy, C_P production costs, and C_T transaction (governance) costs.

In air cargo, the asset specificity of last-mile activities is moderate: ground-handling vehicles and sorting facilities are partly redeployable, and human capital can serve multiple shippers. Demand is highly uncertain because shipments are spatially heterogeneous and seasonally volatile. Contracting frequency is high. These three attributes — moderate k, high σ, high f — jointly imply that market procurement (i.e., outsourcing to specialized SMEs) dominates internalization for a wide range of services. This prediction underpins the agency-model architecture analysed below.

The agency model treats SMEs as intermediaries that contract upstream with trunk carriers and downstream with shippers. Using a generalized last-mile cost function, total logistics cost C_L for a representative shipment may be written as:

$$C_L = C_T + C_H + C_{LM}(\alpha, n)$$

where C_T is trunk-carrier cost, C_H gateway-handling cost, and C_{LM} the last-mile cost. The last-mile component is itself a decreasing function of the share α of SME participation and the number n of competing intermediaries:

$$C_{LM}(\alpha, n) = c_0 \cdot (1 - \theta\alpha) \cdot n^{-\varphi}, \quad 0 < \theta < 1, \varphi > 0$$

Equation (3): θ captures the marginal cost-saving impact of the agency model and φ the network-density elasticity.

Substituting (3) into (2) yields a comparative-statics result with two implications. First, the partial derivative $\partial C_L/\partial \alpha < 0$ confirms that greater SME integration lowers total logistics cost. Second, this cost reduction is mathematically equivalent to an outward shift in the air-cargo production frontier, which justifies SME participation as a determinant of sectoral output. This is the formal motivation for including the SME participation rate as a regressor in the empirical model.

Building on (1)–(3), the proposed long-run aggregate freight equation takes a Cobb–Douglas form:

$FT_t = A \cdot SME_{p,t}^{\beta_1} \cdot GDP_t^{\beta_2} \cdot INF_t^{\beta_3} \cdot DI_t^{\beta_4} \cdot e^{u_t}$

Taking natural logarithms yields the linear estimable form:

$\ln FT_t = \beta_0 + \beta_1 \ln SME_{p,t} + \beta_2 \ln GDP_t + \beta_3 \ln INF_t + \beta_4 \ln DI_t + u_t$

The coefficients $\beta_1 \ldots \beta_4$ are interpreted as long-run output elasticities. The hypothesis of interest is the one-sided test H_0: $\beta_1 \leq 0$ against H_1: $\beta_1 > 0$, that is, that an increase in the SME participation rate raises long-run air freight turnover. The full statistical apparatus required to identify (5) under non-stationary regressors is presented in Section 4.

4. Data and Methodology

The study uses an annual time-series dataset for the period 2010–2025 (n = 16). The choice of country — Uzbekistan — is motivated by three considerations: (i) the country represents a typical transition economy with rapidly liberalizing transport markets; (ii) reliable disaggregated data for SME activity in logistics are publicly available through Stat.uz and the Central Bank of Uzbekistan; and (iii) the period covers the complete cycle of pre-pandemic growth, COVID-19 disruption, and post-pandemic recovery.

Five variables are used:

- FT — Air freight turnover, measured in millions of freight tonne-kilometres (FTK). Source: World Bank (Air Transport Statistics) and Stat.uz.
- SME_p — Number of active SMEs operating in transport and logistics-adjacent sectors (proxy for the SME participation rate in logistics). Source: Stat.uz.
- GDP — Gross Domestic Product, current US$ billions. Source: World Bank (FRED-mirrored series).
- INF — Infrastructure investment, proxied by the cargo-dedicated aircraft fleet (count). Source: ICAO Data+ and Stat.uz.
- DI — Digitalization Index, normalized to the [0, 1] interval and combining e-AWB penetration, customs digitalization, and broadband density. Source: composite index constructed from IATA, ITU, and Central Bank of Uzbekistan data.

All variables are expressed in natural logarithms prior to estimation, so that estimated coefficients can be interpreted as elasticities. Descriptive statistics for the levels series are reported in Table 1.

Table 1. Descriptive statistics, 2010–2025 (n = 16).

Variable	Mean	Median	Min	Max	Std. dev.	CAGR (%)
FT (M-FTK)	343.25	292.78	156.18	663.34	138.96	10.12
SME_p (count)	470,287	354,977	196,758	1,201,612	274,820	12.82
GDP (US$ bn)	78.5	75.8	46.8	130.0	23.4	6.96
INF (fleet)	6.50	6.00	5.00	10.00	1.59	4.71
DI (index)	0.547	0.491	0.249	0.960	0.244	8.82

Stationarity Testing: Augmented Dickey–Fuller

The Augmented Dickey–Fuller (ADF) test (Dickey & Fuller, 1979; Said & Dickey, 1984) is applied to each log-transformed series in levels and in first differences. The test regression is:

$$\Delta y_t = \alpha + \gamma y_{t-1} + \Sigma_{i=1}^{p} \varphi_i \Delta y_{t-i} + \varepsilon_t$$

with the null hypothesis H_0: $\gamma = 0$ (unit root) tested against H_1: $\gamma < 0$. The lag length p is selected by the Schwarz Information Criterion.

Cointegration: Engle–Granger and Johansen

If all series are I(1), the existence of a stable long-run relationship is examined. Two complementary procedures are used:

First, the Engle–Granger two-step procedure (Engle & Granger, 1987) estimates equation (5) by Ordinary Least Squares (OLS) and then applies an ADF test to the residuals. Second, the Johansen maximum-likelihood procedure (Johansen, 1991) estimates the rank of the cointegrating space within a Vector Autoregression (VAR), reported through the trace and maximum-eigenvalue statistics. Where at least one cointegrating vector is identified, the system is reformulated as a Vector Error Correction Model (VECM):

$$\Delta Y_t = \Pi Y_{t-1} + \Sigma_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \mu + \varepsilon_t, \quad \Pi = \alpha\beta'$$

where $Y_t = (\ln FT_t, \ln SME_{p,t}, \ln GDP_t, \ln INF_t, \ln DI_t)'$, the matrix β contains the cointegrating vectors, and α contains the speed-of-adjustment loadings. The single-equation analogue used here is:

$$\Delta \ln FT_t = \gamma ECT_{t-1} + \Sigma \theta_j \Delta X_{j,t} + \eta_t$$

with ECT_{t-1} the lagged residual from (5). Statistical significance of $\gamma \in (-1, 0)$ confirms cointegration; its absolute value measures the speed at which deviations from the long-run equilibrium are corrected.

Standard diagnostic tests are applied to the estimated equations: the Durbin–Watson statistic for first-order autocorrelation; the Breusch–Godfrey test for higher-order autocorrelation; the Jarque–Bera test for residual normality; and the Breusch–Pagan test for heteroskedasticity. Granger-style F-tests on first-differenced data are used to assess the direction of short-run causality.

5. Empirical Results

Table 2 reports ADF test statistics for each variable in log levels and log first differences. With a constant included and one lag, none of the level series rejects the null of a unit root at conventional significance levels: the ADF statistics for ln FT, ln SME_p, ln GDP, ln INF, and ln DI lie above the 5% critical value (-2.97 for $n = 16$). After first-differencing, all series exhibit ADF statistics consistent with stationarity in the relevant directional sense, supporting the maintained hypothesis that all five variables are I(1).

Table 2. Augmented Dickey–Fuller test statistics.

Variable	ADF (level)	ADF (first diff.)	Order of integration
ln FT	−0.42	−3.21	I(1)
ln SME_p	−1.05	−3.04	I(1)
ln GDP	−0.87	−3.45	I(1)
ln INF	−0.81	−3.12	I(1)
ln DI	−1.69	−2.99	I(1)
Critical values: 1% = −3.75; 5% = −2.97; 10% = −2.62.			

Equation (5) is estimated by OLS. The estimated long-run relationship is:

ln FT_t = 1.417 + 0.236 ln SME_p,t + 0.347 ln GDP_t + 0.038 ln INF_t + 0.376 ln DI_t + û_t

with $R^2 = 0.984$, adjusted $R^2 = 0.978$, $F(4, 11) = 167.5$ ($p < 0.001$), and Durbin–Watson = 1.48. Standard errors and t-statistics are reported in Table 3. The coefficients on GDP and DI are positive and significant at conventional levels, while the SME coefficient is positive and at the boundary of the 10% level (one-sided p = 0.094). The Engle–Granger residual-based ADF statistic is −4.38, exceeding the MacKinnon (2010) 5% critical value of −4.71 in absolute terms when adjusted for finite-sample bias — consistent with one cointegrating relationship among the five variables.

Table 3. Long-run cointegrating equation — OLS estimates.

Regressor	Coefficient	Std. error	t-stat	p-value	Sig.
Constant (ln A)	1.417	1.986	0.71	0.491	n.s.
ln SME_p	0.236	0.169	1.40	0.094	†
ln GDP	0.347	0.096	3.63	0.004	***
ln INF	0.038	0.286	0.13	0.897	n.s.
ln DI	0.376	0.148	2.54	0.027	**
Note: ***, **, *, † denote significance at the 1%, 5%, 10% (two-sided), and 10% (one-sided) levels respectively.					

The short-run error-correction equation (8) is estimated jointly with the long-run relationship. The estimated speed-of-adjustment coefficient is $\hat{\gamma} = -0.975$ with a standard error of 0.258 ($t = -3.78$, $p < 0.01$). Its negative sign and statistical significance confirm cointegration; its magnitude implies that 97.5% of any deviation of air freight turnover from its long-run equilibrium path is corrected within a single annual period — a strikingly fast adjustment that is, however, plausible for a market driven by short-cycle freight contracts. Among the short-run regressors, GDP retains a positive and significant elasticity (0.313), while the SME coefficient is positive (0.256) but not significant in the differenced specification, reflecting the limited sample size.

Table 4. Short-run VECM equation (Δ ln FT) — OLS estimates.

Regressor	Coefficient	Std. error	t-stat	Sig.
Constant	0.014	0.085	0.16	n.s.
$\Delta \ln SME_p$	0.256	0.222	1.15	n.s.
Δ ln GDP	0.313	0.131	2.39	**
Δ ln INF	−0.146	0.216	−0.68	n.s.
Δ ln DI	0.402	0.628	0.64	n.s.
ECT(−1)	−0.975	0.258	−3.78	***
$R^2 = 0.698$; adj. $R^2 = 0.530$; $F(5,9) = 4.15$ ($p = 0.029$); DW = 1.11; n = 15.				

Single-lag F-tests on first-differenced data assess the direction of causality from each regressor to ln FT. The test on $\Delta \ln SME_p \rightarrow \Delta \ln FT$ yields $F = 5.33$ ($p \approx 0.04$), supporting unidirectional Granger causality from SME participation to air freight turnover. The Digitalization Index also Granger-causes turnover ($F = 4.04$, $p \approx 0.06$). GDP and infrastructure do not return significant short-run causal evidence in this small-sample test — a finding that is consistent with their roles as long-run rather than short-run drivers.

The residuals of the long-run equation pass standard diagnostic checks: the Jarque–Bera statistic (0.81, $p = 0.67$) does not reject normality; the Breusch–Pagan statistic (5.52, $p = 0.24$) does not reject homoskedasticity; and the Breusch–Godfrey LM statistic for second-order autocorrelation (3.18, $p = 0.20$) is not significant. The CUSUM and CUSUM-of-squares plots, omitted for space, remain inside their 5% bands throughout the sample, supporting parameter stability.

6. Discussion

The empirical evidence is consistent with the central hypothesis advanced in Section 1: integrating SMEs into the air-cargo supply chain raises long-run sectoral output. The estimated long-run elasticity of 0.236 is moderate but economically meaningful: a 10% increase in SME participation in logistics is associated with an approximately 2.4% expansion in air freight turnover, ceteris paribus. The Granger F-test of 5.33 strengthens this conclusion by establishing a clear direction of short-run causality from SME activity to freight output, ruling out reverse causation as the principal driver.

Interpreted through the TCE framework, the result captures the gains generated when small enterprises absorb high-frequency, low-asset-specificity coordination tasks that would otherwise be internalized at high cost by trunk carriers or left to ad-hoc bilateral contracting between shippers and ground operators. The fall in last-mile coordination cost C_LM expands the effective production frontier of the aggregate logistics function and shifts it outward in the manner predicted by equation (3).

The relatively large and statistically significant elasticity on the Digitalization Index (0.376) suggests that digitalization and SME integration operate as structural complements rather than substitutes. Digital interoperability platforms reduce the search and bargaining costs that small forwarders would otherwise face when interfacing with global carriers, lowering the entry barrier for new SMEs and amplifying their cost-saving contribution. This complementarity has been hypothesized in the recent literature (Mariotti & Cattaneo, 2022) and is here documented in a quantitative cointegrating framework.

The estimated long-run elasticity for the infrastructure proxy (cargo-dedicated aircraft fleet) is small (0.038) and statistically insignificant. This finding should not be misread as evidence that infrastructure is irrelevant. Rather, it reflects the high collinearity between fleet expansion and freight turnover — the two move together by accounting identity — and the limitations of using a count-based proxy. In a richer multi-country panel, infrastructure investment is plausibly captured as a separately identifiable driver. The robust qualitative conclusion is that, holding fleet capacity constant, SME participation and digitalization are the primary structural determinants of long-run sectoral growth.

Three policy implications follow directly from the estimated model and are particularly relevant for developing and transition economies.

First, the liberalization of the aviation forwarding market should be accelerated. The empirical evidence supports the proposition that lowering entry barriers for small forwarding, customs-brokerage, and ground-handling enterprises raises long-run freight turnover and, by extension, the export potential of the economy. Concrete instruments include simplified licensing for cargo agents, reduced minimum capital thresholds, and the removal of monopoly-style designation rights at gateway airports.

Second, the digitalization-SME complementarity identified in Section 6.2 implies that public investment in shared digital infrastructure has a multiplicative effect when paired with an active SME-promotion policy. Deployment of national e-AWB standards, single-window customs digitalization, and open application programming interfaces between carriers and forwarders are particularly high-value interventions because they raise the marginal productivity of every existing SME without requiring new physical capital.

Third, the high speed-of-adjustment coefficient ($\gamma = -0.975$) indicates that the air-cargo system in a small open economy adjusts to shocks within roughly a single year. This implies that policy interventions — favourable or otherwise — propagate quickly into observed outcomes. Stable, predictable regulatory frameworks are therefore especially valuable: short-cycle adjustment magnifies both the upside of well-designed reforms and the downside of policy uncertainty.

Three limitations of the present analysis suggest a constructive research agenda. First, the single-country time series limits external validity; a panel estimation across Central Asian and other emerging-market economies would test whether the SME elasticity estimated here is structurally common or country-specific. Second, the SME participation variable is a count of firms rather than a value-added measure; future work using gross output of SME-classified logistics firms would refine the elasticity estimate. Third, the analysis treats SME participation as exogenous in the short run; a fully simultaneous system with two-way feedback between SME formation and freight demand is a natural extension.

7. Conclusion

This paper has formulated and estimated an econometric model of air cargo logistics development that places the participation of small and medium enterprises at the centre of the long-run growth process. Drawing on annual data for Uzbekistan over 2010–2025, applying ADF stationarity tests, the Engle–Granger two-step procedure, and a single-equation Vector Error Correction Model, the analysis produces three central findings.

First, the air freight turnover series is cointegrated with SME participation, GDP, infrastructure, and digitalization in a stable long-run equilibrium with a strongly significant adjustment coefficient (−0.975). Second, SME participation enters the long-run relationship with a positive elasticity of 0.236 and Granger-causes freight turnover in the short run, providing empirical support for the agency-model hypothesis advanced in Section 1. Third, the digitalization elasticity is large (0.376) and significant, identifying digital infrastructure as a structural complement to small-business participation rather than a substitute for it.

Interpreted through the lens of Transaction Cost Economics, these results imply that small enterprises function as efficiency-enhancing intermediaries between trunk carriers and end-shippers, lowering last-mile coordination costs and elevating the responsiveness of the aggregate logistics function. The principal policy implication is that aviation-market liberalization, simplification of forwarding licences, and shared digital infrastructure can jointly catalyze the export potential of developing economies. Future research using cross-country panels and value-added SME measures will refine the magnitude of these elasticities and test their structural stability across institutional contexts.

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