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# Technological Modernization as a First-Order Driver of Competitiveness in Transition Economy Electrotechnical Industries: Panel Evidence from Uzbekistan

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**Abstract:** This study examines the mechanisms through which technological modernization and innovation capacity influence the competitiveness of electrotechnical industry enterprises in Uzbekistan, a lower-middle-income transition economy. Drawing on panel data from 150 enterprises over the period 2018–2023, the study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) and Levinsohn-Petrin total factor productivity (TFP) estimation to test a sequencing hypothesis: that in below-threshold transition economies, technological modernization constitutes the dominant first-order predictor of firm-level competitiveness, whereas innovation capacity becomes statistically significant only after a baseline modernization threshold has been crossed. Results confirm that technological modernization ( $\beta = 0.487$ ,  $p < 0.001$ ) exerts the strongest direct effect on the competitiveness composite, while innovation capacity fails to reach conventional significance ( $\beta = 0.139$ ,  $p = 0.062$ ) for the full sample. Subgroup analysis reveals that innovation capacity becomes a significant predictor ( $\beta = 0.312$ ,  $p = 0.004$ ) exclusively among firms that have surpassed the modernization threshold. Human capital partially mediates the modernization–competitiveness path, and institutional support moderates this relationship. The findings carry implications for industrial policy sequencing in post-Soviet manufacturing economies and contribute to the evolutionary economics literature on technological catch-up.

**Keywords:** Competitiveness, technological modernization, electrotechnical industry, PLS-SEM, total factor productivity, Uzbekistan, transition economy.

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## 1. Introduction

The electrotechnical industry occupies a pivotal position within the industrial architecture of Uzbekistan, supplying essential inputs—transformers, cables, switchgear, electric motors—to the energy, construction, and mining sectors that constitute the backbone of the national economy. Despite its strategic importance, the sector has experienced significant competitive pressures since independence in 1991, as legacy Soviet-era production systems have struggled to meet the quality, cost, and technological standards demanded by increasingly open regional and global markets [1]. Understanding the mechanisms through which competitiveness can be enhanced in this context is therefore a matter of both scholarly and practical urgency.

A substantial body of literature links competitiveness to innovation, yet the applicability of innovation-centric frameworks to below-threshold transition economies remain contested [2]. Fagerberg and Srholec demonstrate that the relative weight of

innovation versus technological capability varies systematically with development level, while Castellacci identifies a technology-gap dynamic in which catch-up economies benefit disproportionately from absorbing existing technologies rather than generating novel ones. This study builds on these insights to advance a sequencing hypothesis: in economies where the majority of manufacturing enterprises operate below a critical modernization threshold, technological modernization—defined as the adoption, adaptation, and integration of existing but previously unutilized technologies—serves as the dominant first-order driver of competitiveness. Innovation capacity, while valuable, becomes a statistically meaningful predictor only after this threshold has been crossed [3].

The empirical setting of Uzbekistan provides a compelling natural laboratory for testing this hypothesis. The country has pursued an ambitious industrial modernization agenda since 2017, with targeted programs for the electrotechnical subsector, including the localization decree framework and free economic zone incentives [4]. Yet the heterogeneity of firm-level responses to these policies remains poorly understood. By combining structural equation modeling with production function estimation on a comprehensive panel dataset, this study offers both a theoretical contribution to the evolutionary economics literature on catch-up and practical guidance for industrial policy design [5].

The remainder of the article is structured as follows. Section 2 reviews the theoretical foundations and develops the research hypotheses. Section 3 describes the data, variables, and analytical methods. Section 4 presents the empirical results. Section 5 discusses the findings in the context of the existing literature and draws policy implications. Section 6 concludes [6].

## **2. Literature Review and Hypothesis Development**

### **2.1 Competitiveness in Manufacturing: Conceptual Foundations**

The concept of competitiveness, despite its ubiquity in economic discourse, remains multidimensional and contested. At the firm level, competitiveness may be understood as the sustained ability to profitably produce goods and services that meet the quality and price requirements of domestic and international markets [7].

This definition foregrounds both cost efficiency and qualitative dimensions—product reliability, technological sophistication, and responsiveness to demand—that are particularly relevant for electrotechnical manufacturers, whose outputs must satisfy stringent technical standards [8].

Porter's Diamond Model situates firm competitiveness within a system of factor conditions, demand conditions, related industries, and strategy structures, all shaped by the roles of government and chance. While influential, the Diamond framework was developed primarily from evidence in advanced industrial economies and may understate the specific constraints facing firms in transition economies, where factor markets are thin, demand is captive or state-directed, and institutional uncertainty is endemic [9].

### **2.2 Technological Modernization versus Innovation: A Sequencing Perspective**

The distinction between technological modernization and innovation is analytically crucial for transition economy analysis. Following Bell and Pavitt, we define technological modernization as the acquisition and effective deployment of production capabilities embodied in equipment, processes, and organizational routines that are new to the firm but not necessarily new to the world [10]. Innovation, by contrast, involves the generation of novel products, processes, or business models that extend the technological frontier. While these two dimensions are complementary in the long run, the evolutionary economics tradition emphasizes that they follow a developmental sequence: firms must first accumulate a threshold stock of production capability before they can invest productively in innovation [11].

This sequencing logic yields a testable implication. In a transition economy sample where most firms are below the modernization threshold, technological modernization

should exhibit a stronger association with competitiveness than innovation capacity. Only in the subsample of already-modernized firms should innovation emerge as a statistically significant predictor. Empirical support for this pattern would carry significant policy implications, suggesting that premature emphasis on innovation promotion—at the expense of foundational modernization investments—may misallocate scarce public resources [12].

### 2.3 Human Capital as a Mediating Channel

The effectiveness of technological modernization depends critically on the availability of human capital capable of operating, maintaining, and adapting new equipment and processes. Skilled engineers and technicians serve as the transmission mechanism through which embodied technology translates into realized productivity gains. In the Uzbek electrotechnical sector, Soviet-era training institutions bequeathed a substantial human capital stock, but its relevance has eroded as technology has advanced [13]. We therefore hypothesize a partial mediation effect: technological modernization enhances competitiveness partly through its stimulus to workforce upgrading.

### 2.4 Institutional Support as a Moderating Factor

The government of Uzbekistan has deployed a suite of institutional instruments—tax exemptions, customs duty reductions, localization incentives, and free economic zone benefits—to accelerate industrial modernization [14]. These instruments are expected to amplify the competitiveness returns to technological modernization by reducing the cost of technology adoption and lowering the risk premium for capital-intensive investments. We therefore hypothesize a positive moderation effect of institutional support on the modernization–competitiveness relationship [15].

### 2.5 Research Hypotheses

Based on the foregoing discussion, the study tests the following hypotheses:

**H1:** Technological modernization has a positive and statistically significant direct effect on enterprise competitiveness.

**H2:** Innovation capacity does not have a statistically significant effect on competitiveness for the full sample of below-threshold transition economy firms.

**H3:** Innovation capacity has a positive and statistically significant effect on competitiveness in the subsample of firms above the modernization threshold.

**H4:** Human capital partially mediates the relationship between technological modernization and competitiveness.

**H5:** Institutional support positively moderates the relationship between technological modernization and competitiveness.

## 3. Data and Methodology

### 3.1 Data Sources and Sample

The study draws on an original panel dataset covering 150 electrotechnical enterprises in Uzbekistan over six years (2018–2023). Data were obtained from three sources: (1) the State Committee of the Republic of Uzbekistan on Statistics ([stat.uz](http://stat.uz)), which provides establishment-level production, employment, and investment figures; (2) enterprise-level surveys administered in collaboration with the Association of Electrotechnical Enterprises of Uzbekistan; and (3) customs and trade data from the State Customs Committee. The sample encompasses the major subsectors of the electrotechnical industry—transformer manufacturing, cable production, switchgear and circuit breaker production, electric motor assembly, and lighting equipment—and includes enterprises ranging from large state-owned complexes such as Toshkent transformator zavodi and O'zelektroapparat to smaller private and joint-venture firms [16].

### 3.2 Variables and Measurement

Table 1 summarizes the key variables and their operationalization.

**Table 1.** Variable Definitions and Roles in the Structural Model

Variable	Definition and Indicators	Role in Model
COMP	Composite competitiveness index (export intensity, unit costs, capacity utilization)	Endogenous
TMOD	Technological modernization (equipment vintage, automation rate, ISO adoption)	Exogenous
INNO	Innovation capacity (R&D expenditure ratio, patent filings, new-product share)	Exogenous
HUMCAP	Human capital (share of engineers, training expenditure per employee)	Mediator
INST	Institutional support (tax incentives utilized, free-zone membership, subsidy receipt)	Moderator
SIZE	Firm size (natural log of total employees)	Control
AGE	Firm age (years since establishment)	Control

### 3.3 Analytical Strategy

The empirical analysis proceeds in two stages. First, a PLS-SEM model is estimated using SmartPLS 4 to test the hypothesized structural relationships. PLS-SEM is preferred over covariance-based SEM (CB-SEM) for several reasons: the research objective is predictive rather than purely confirmatory; the model includes both reflective and formative constructs; and the sample size, while adequate for PLS, would be marginal for CB-SEM given model complexity. Path significance is evaluated using bootstrapping with 5,000 subsamples [17].

Second, Levinsohn-Petrin (LP) TFP estimates are computed for each enterprise-year observation to provide an independent measure of productive efficiency that addresses the endogeneity of input choices in standard OLS production function estimation [18]. The LP method uses intermediate inputs (materials and energy) as a proxy for unobserved productivity shocks. TFP estimates are then regressed on the modernization threshold indicator to validate the PLS-SEM findings [19].

For the threshold analysis (H2 and H3), the sample is split at the median of the TMOD composite. Firms above the median are classified as "above threshold," and the PLS-SEM model is re-estimated for each subgroup to examine whether the path coefficient from INNO to COMP achieves significance only in the above-threshold subsample [20].

## 4. Results

### 4.1 Measurement Model Assessment

Convergent validity is confirmed by average variance extracted (AVE) values exceeding 0.50 for all reflective constructs, with composite reliability (CR) values above 0.80. Discriminant validity is established through the Heterotrait-Monotrait (HTMT) ratio, with all pairwise values below the conservative threshold of 0.85. The formative construct (COMP) is evaluated using variance inflation factor (VIF) diagnostics; all indicator VIFs are below 3.0, indicating no problematic multicollinearity among formative indicators.

### 4.2 Structural Model and Hypothesis Testing

Table 2 presents the structural model results for the full sample.

**Table 2.** PLS-SEM Structural Model Results (Full Sample, N = 150)

Path	$\beta$	t-value	p-value	Decision
TMOD → COMP	0.487	8.341	< 0.001	Supported***
INNO → COMP	0.139	1.874	0.062	Not supported

HUMCAP → COMP	0.218	3.462	0.001	Supported**
TMOD → HUMCAP → COMP	0.112	2.781	0.006	Mediation supported**
INST × TMOD → COMP	0.094	2.115	0.035	Moderation supported*
SIZE → COMP	0.071	1.203	0.230	Not significant
AGE → COMP	-0.043	0.812	0.417	Not significant

Note: \*\*\*  $p < 0.001$ ; \*\*  $p < 0.01$ ; \*  $p < 0.05$ . Bootstrap with 5,000 subsamples.

The results provide strong support for H1: technological modernization exerts the largest and most significant direct effect on competitiveness ( $\beta = 0.487$ ,  $t = 8.341$ ,  $p < 0.001$ ). This finding is consistent with the sequencing perspective, which predicts that in a below-threshold transition economy, foundational technology adoption dominates. H2 is also supported: innovation capacity does not achieve conventional significance for the full sample ( $\beta = 0.139$ ,  $t = 1.874$ ,  $p = 0.062$ ), though the marginal p-value suggests a latent effect that emerges under specific conditions—a pattern further explored in the subgroup analysis.

Human capital is a significant predictor of competitiveness ( $\beta = 0.218$ ,  $t = 3.462$ ,  $p = 0.001$ ), and the indirect effect through the TMOD → HUMCAP → COMP mediation path is significant ( $\beta = 0.112$ ,  $t = 2.781$ ,  $p = 0.006$ ), supporting H4. The moderation effect of institutional support on the TMOD → COMP path is positive and significant ( $\beta = 0.094$ ,  $t = 2.115$ ,  $p = 0.035$ ), providing support for H5. The control variables—firm size and age—do not reach significance, suggesting that the modernization and human capital constructs absorb the variance that firm demographics might otherwise explain.

#### 4.3 Subgroup Analysis: The Modernization Threshold

When the sample is split at the TMOD median, the subgroup of 72 above-threshold firms yields a significant path from INNO to COMP ( $\beta = 0.312$ ,  $t = 3.014$ ,  $p = 0.004$ ), supporting H3. In contrast, the below-threshold subsample of 78 firms produces an insignificant innovation path ( $\beta = 0.048$ ,  $t = 0.631$ ,  $p = 0.528$ ). This pattern robustly confirms the sequencing hypothesis: innovation capacity contributes meaningfully to competitiveness only after a baseline of technological modernization has been established [21].

#### 4.4 Levinsohn-Petrin TFP Estimates

Table 3 presents summary statistics for LP TFP estimates by modernization group.

**Table 3.** Levinsohn-Petrin TFP Estimates by Modernization Group

Enterprise Group	Mean TFP	Std. Dev.	Growth Rate (% p.a.)	N
High modernization	1.247	0.183	4.8	47
Medium modernization	0.983	0.214	2.1	62
Low modernization	0.741	0.267	-0.3	41
Full sample	0.987	0.289	2.3	150

Note: TFP is index-normalized with the full-sample mean set to 1.0 for the base year (2018).

The high-modernization group exhibits a mean TFP 26% above the full-sample average and a robust annual growth rate of 4.8%, while the low-modernization group shows a TFP 25% below average with negative growth. An OLS regression of TFP on the above-threshold dummy (controlling for subsector, size, and year fixed effects) yields a coefficient of 0.391 (robust SE = 0.087,  $p < 0.001$ ), reinforcing the structural model's finding that

technological modernization is the dominant predictor of productive efficiency in the sample [22].

## 5. Discussion

### 5.1 Theoretical Implications

The findings contribute to the evolutionary economics literature by providing micro-level empirical evidence for the sequencing hypothesis in a transition economy manufacturing sector. While the general principle that technological capability precedes innovation capability has been established conceptually, this study offers quantitative evidence from a contemporary post-Soviet context, extending the geographical and temporal scope of the catch-up literature. The results suggest that the Schumpeterian framework—which privileges innovation as the primary engine of competitiveness—requires qualification in settings where the majority of enterprises have not yet attained a foundational level of production capability [23].

The partial mediation by human capital aligns with the capabilities perspective, underscoring that technology is not self-executing; its competitiveness effects are realized through complementary investments in workforce skills. This finding is particularly salient in the Uzbek context, where a mismatch between legacy Soviet-era training and the requirements of modern electrotechnical production has been documented [24].

### 5.2 Policy Implications

The results carry actionable implications for industrial policy in Uzbekistan and comparable transition economies. First, policy resources directed at competitiveness enhancement should prioritize technological modernization—equipment renewal, adoption of international process standards, and automation—particularly for the large share of enterprises that remain below the modernization threshold [25]. Second, innovation promotion (R&D subsidies, technology park development, patenting incentives) should be sequenced to follow, rather than precede or accompany, foundational modernization investments. This does not mean innovation policy is unimportant—the subgroup analysis clearly demonstrates its significance for already-modernized firms—but rather that its timing matters.

Third, human capital development should be tightly integrated with modernization programs, given its mediating role. Enterprise-level training programs tied to equipment upgrades are likely to yield higher returns than standalone educational investments. Fourth, the positive moderation effect of institutional support validates the government's suite of incentives but also implies that these instruments' effectiveness is contingent on enterprises' willingness and capacity to invest in modernization—a condition that may not be uniformly met and that warrants targeted diagnostic assessment.

### 5.3 Limitations and Future Research

Several limitations should be noted. First, the sample is restricted to a single country and industry, limiting generalizability. Cross-country and cross-sector extensions would strengthen the external validity of the sequencing hypothesis.

Second, the six-year panel, while sufficient for the statistical methods employed, is relatively short; longer time series would permit more robust dynamic analysis of threshold-crossing behavior.

Third, the modernization threshold is operationalized using a sample-median split, which, while common in the PLS-SEM literature, introduces some arbitrariness. Future research might employ continuous threshold regression techniques to endogenously identify the critical modernization level. Fourth, while the LP TFP estimator addresses input endogeneity, it does not fully resolve potential selection effects; instrumental variable approaches or matched difference-in-difference designs could further bolster causal identification.

## 6. Conclusion

This study has investigated the mechanisms through which technological modernization, innovation capacity, human capital, and institutional support shape the competitiveness of electrotechnical enterprises in Uzbekistan. The central finding—that technological modernization is the dominant first-order driver of competitiveness and that innovation capacity becomes significant only above a modernization threshold—advances the evolutionary economics literature on catch-up dynamics and carries direct implications for industrial policy sequencing in transition economies. The results suggest that the pathway to competitive electrotechnical industries in below-threshold economies runs through systematic modernization of production capabilities, complemented by workforce development and calibrated institutional support, with innovation promotion phased in as firms cross the modernization threshold. Policymakers in Uzbekistan and similarly situated economies would be well advised to resist the temptation to leapfrog directly to innovation-led strategies and instead invest first in the foundational capabilities that make innovation productive.

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