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The Impact of Energy Intensity, Investment, and Price Shocks on the Manufacturing Sector: ARDL-ECM Evidence from Azerbaijan

Mayis Gulaliyev[1,2,3]*, Shafa Aliyev[4,5], Flora Kashiyeva[5], Mehriban Zeynalova[5], Elchin Elibeyli[6]

[1]Ganja State University, Ganja, Azerbaijan, [2]Azerbaijan Technological University, Ganja, Azerbaijan, [3]Baku Eurasian University, Baku, Azerbaijan, [4]Sumgait State University, Sumgait, Azerbaijan, [5]Azerbaijan State University of Economics, Baku, Azerbaijan, [6]Nakhchivan State University, Nakhchivan, Azerbaijan. *Email: mayis.gulaliyev@gmail.com

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ABSTRACT

This article evaluates the relationship between energy intensity (EI), investment in fixed capital (INVEST), employment (EMP), producer price index (PPI), and real output in Azerbaijan's manufacturing industry over the period 2007-2024 within the ARDL-ECM framework. Since the ADF tests indicate that the variables have mixed orders of integration, I(0) and I(1), the Bounds test is applied to check for the presence of a long-run relationship, which is confirmed. In the ECM model, the negative and statistically significant error-correction coefficient shows that deviations from equilibrium are corrected rapidly. The results reveal that an increase in EI leads to a decline in real output, while efficiency improvements reduce EI and raise production volume. Growth in EMP positively affects output. INVEST in the manufacturing sector exerts a negative short-run effect due to "installation delays," but a positive effect with a 1-year lag. PPI shocks, especially with lags, have a negative impact. Inference is conducted using HAC/Newey-West robust standard errors. The LM, BPG, RESET, Jarque-Bera, and CUSUM/CUSUMSQ diagnostics confirm that the model's functional form and stability are satisfactory.

Keywords: ARDL-ECM, Energy Intensity, Investment, Producer Price Index, Manufacturing Industry, Error-Correction Model, Bounds Test, HAC/Newey-West

JEL Classifications: Q56, Q53, C32, F31, L67, O14

1. INTRODUCTION

One of the key conditions for competitiveness in global value chains is the efficient use of resources. Shock fluctuations in energy prices, pressures on water resources, and the decarbonization agenda make the dissemination of resource-efficient technologies (RET) a priority, especially in labor-intensive sectors such as light industry. Azerbaijan's foreign trade is of great importance for the country's economic growth (Gulaliyev et al. 2021). The textile, clothing, and leather and footwear sub-sectors of the country's economy have a leading potential for diversifying non-oil exports. Despite the country's economy's gradual transformation towards digitalization (Mayis et al., 2023), maintaining competitive advantage is directly related to reducing material (MI), energy (EI), and water (WI) intensity.

Azerbaijan's manufacturing industry - particularly the light industry sectors, including textiles, apparel, and leather products - faces a dual challenge. First, producers operate under cost pressure due to volatile raw material and energy prices that are passed through to producer prices. Second, they must accelerate the adoption of resource-efficient technologies to enhance productivity and competitiveness. In this context, we examine the joint impact of energy intensity, investment in fixed capital, and producer price shocks (PPI) on real manufacturing output (OUTPUT) over the period 2007-2024. The results hold direct implications for policy design and firm-level strategy.

The analysis in this study is structured around three intuitive transmission channels. First is the efficiency channel: Lower energy intensity (EI) reflects improvements in technology and process management. This reduces unit costs and, other conditions being equal, increases production output. Second is the capital channel: Investment in fixed assets may dampen production in the short run due to installation and adjustment costs, but over time it enhances capacity and productivity. Third is the price shock channel: an increase in the producer price index (PPI) - especially under conditions of price-sensitive demand and "rigid" contracts - compresses profit margins and, often with a lag, leads to a decline in production.

Based on the above transmission channels, we formulate three testable hypotheses:

- H_1: An increase in energy intensity - i.e., a decline in efficiency - reduces the volume of real manufacturing output
- H_2: Investment creates an "installation hurdle" in the short run but exerts a positive effect with a lag
- H_3: PPI shocks reduce manufacturing output, and their lagged effects are stronger than their contemporaneous impacts.

It should be noted that no similar study addressing this issue has been conducted for Azerbaijan in the existing economic literature. This research partially fills that gap. Existing studies tend to focus either on sectoral trends or on individual determinants in isolation. To date, there has been no macro or meso-level study that simultaneously integrates long and short-run elasticities within the ARDL-ECM framework to examine the relationship between EI, investment, and PPI with real manufacturing output while employing modern diagnostic tests.

The main findings of the study highlight several policy implications. Measures that enhance efficiency - including concessional financing for best available technologies that reduce EI, energy audits, and targeted guarantees - tend to increase production output in both the short and long run. The impact profile of investment underscores the need for sequential implementation of instruments that bridge the installation phase, such as grace periods. Finally, transparent and phased tariff or indexation rules can mitigate the pass-through of fluctuations in raw material and energy prices to the PPI, thereby reducing delayed losses in production volume.

The second section of the paper outlines the main contribution of the research, while the third section reviews the related literature. The fourth section describes the methodology, variable structure, and econometric strategy employed in the study, including the ARDL-ECM models, as well as diagnostic and robustness tests. The fifth section presents the baseline and robustness results, including long and short-run elasticities and the speed of adjustment. The sixth section discusses the comparison of the findings with those of similar studies, as well as policy simulations and implications. The seventh section provides the study's main conclusions and suggests directions for future research, particularly expanding the analysis to panel data across manufacturing subsectors and employing richer proxies for resource-efficiency technologies.

The main contribution of the study is threefold. First, by using official data - including that from the State Statistical Committee of the Republic of Azerbaijan (SSCRA, 2025) - we construct time series for the period 2007-2024 covering manufacturing output, energy intensity, investment volume, employment level, and the producer price index (PPI), and identify a stable long-run equilibrium relationship among them. Second, using the ARDL-ECM strategy, we estimate both the long-run parameters and the error-correction (speed of adjustment) term. Inference is conducted with HAC/Newey-West robust standard errors and a full diagnostic package, including the Bounds cointegration test, normality, heteroskedasticity, RESET, and CUSUM/CUSUMSQ stability tests. Third, we derive policy-relevant semi-derivatives that allow for "back-of-the-envelope" calculations of how, for example, a 5-10% improvement in efficiency or a tariff-induced PPI shock would affect manufacturing output.

2. LITERATURE REVIEW

Although Azerbaijan is rich in oil and gas resources, the country's energy security and diversification of its energy balance are of great importance in the long term (Bayramov et al., 2021). Energy security requires its efficient use in all sectors of the economy. Therefore, energy efficiency, along with resource efficiency, is one of the main challenges of the modern era.

The classical approach to energy and resource efficiency is grounded in the concepts of the "efficiency gap" and the "paradox." The slow diffusion of technologies with even net positive value is often linked to informational, financial, and agency barriers (Jaffe and Stavins, 1994a; 1994b; Allcott and Greenstone, 2012). Systematic mapping of policy, market, and behavioral determinants underscores the multilayered nature of these barriers (Gillingham et al., 2009). Although the dynamics of technology adoption vary across sectors and countries, the Bass (1969) model is widely used to parameterize diffusion through the innovator–imitator mechanism. Such an approach provides a practical basis for sector-level calibration.

Learning curves (learning-by-doing) represent the key mechanism explaining how technology adoption affects unit costs (Nemet, 2006). At the same time, rebound effects-where part of the efficiency gains is offset through additional production and demand channels-have been examined at both micro and macro levels (Sorrell and Dimitropoulos, 2008; Brockway et al., 2021). The likelihood of large-scale rebound effects at the macro level calls for caution in sectoral regulation and in assessing the real magnitude of efficiency improvements (Greening et al., 2000; Saunders, 2000).

Empirical evidence on firm-level adoption determinants highlights the decisive role of the payback criterion, financial constraints, and policy signals (Abadie et al., 2012; García-Quevedo and Jové-Llopis, 2021). In particular, for light industry sectors-including textiles, apparel, and leather manufacturing-technology catalogues for energy and water efficiency and their typical payback periods are well documented (Hasanbeigi and Price, 2012). Recent studies on quantifying water and chemical footprints refine the identification of critical stages in the process chain and provide a basis for targeted interventions (Uddin et al., 2023). From an economic perspective, approaches based on the "material footprint" have become the standard method for tracking production-consumption linkages in measuring resource intensity, especially material intensity (Wiedmann et al., 2015).

In the manufacturing industry-including the light industry sector-the existing literature on the effects of energy intensity on production output can, in line with the objectives of this study, be classified into four groups. The first group concerns the methodological foundation. Most similar studies apply the ARDL-Bounds approach along with robust inference methods. The ARDL-Bounds test has become a standard tool in industrial and energy economics because it allows for testing long-run relationships in small samples with mixed integration orders, I(0) and I(1). The approach was formally established by Pesaran et al. (2001). Moreover, the authors' pooled mean group (PMG) estimator enables the pooling of long-run coefficients in a panel context. Considering that economic and political shocks may lead to heteroskedastic and autocorrelated errors, the Newey and West (1987) HAC covariance matrix enhances the reliability of inference.

Another group of studies focuses on energy intensity and the efficiency channel. Stern (2012), for instance, presents long-term results for 85 countries using the energy distance function approach to analyze macro trends and the measurement of energy efficiency. The adoption of conservation technologies that reduce energy intensity (EI) is closely linked to economic performance. Sorrell (2009), examining the rebound effect, systematizes the mechanism through which part of the energy savings at the micro level is offset by additional consumption - an aspect that must be taken into account in policy design. Evidence from China, the E7, and other economies using ARDL-type models confirms the long-run nature of the energy-growth relationship.

The third group of studies examines industrial output, electricity/energy use, and investment. Research by Sankaran et al. (2019), which evaluates the long-run relationship between manufacturing output and electricity consumption in a multi-country context using ARDL and Toda-Yamamoto approaches, clearly demonstrates the role of the energy channel in industrial production. Within the manufacturing-energy nexus, the ARDL framework also proves practical for testing the relationship between investment and structural change. Panel and ARDL applications - including PMG and CS-ARDL methods - reveal the influence of industrialization, trade, and financial factors on energy intensity (EI).

The fifth group of studies focuses on price shocks and the PPI channel. In the context of the macroeconomic effects of price shocks, classic works such as Hamilton (1996) and Kilian (2009) demonstrate that fluctuations in energy and raw material prices are transmitted to real sector dynamics through different channels. Torun and Yassa (2023), analyzing cost pass-through from the PPI and the role of sectoral structure for Turkey at the industry level, emphasize the importance of market concentration in D-PPI dynamics. These findings justify the need to model the lagged and asymmetric effects of PPI shocks in the manufacturing sector.

The existing literature has tested the mechanisms of (a) efficiency (EI), (b) capital channel (investment), and (c) price shock (PPI) separately through ARDL/ECM frameworks. However, for Azerbaijan's manufacturing industry, a joint evaluation of these three channels within the same model over the 2007-2024 period remains rare. The results presented here-supported by HAC-robust inference, Bounds cointegration, and stability tests-are specifically aimed at filling this gap.

3. METHODOLOGY

The data used in this study pertain to Azerbaijan's manufacturing industry and cover the period from 2007 to 2024. The main indicator considered is the real manufacturing output (Y). Energy intensity was calculated using the first equation.

$$EI_t = \frac{\text{energy use}_t}{Y_t}\left(\text{toe / real azn}\right) \quad (1)$$

In this study, the real manufacturing output (LOGOUTPUT) is measured at constant prices, i.e., deflated by the producer price index or a broad-based deflator. Energy intensity (LOGEI) represents the amount of energy used per unit of real manufacturing output, expressed in TOE per million real AZN. Investment (LOGINVEST) denotes real expenditures on fixed capital in the manufacturing sector, while employment (LOGEMP) captures the labor input. The producer price index (LOGPPI) is calculated on a 2000 = 100 base.

The study also incorporates two dummy variables representing key events: The 2015 devaluation of the Azerbaijani manat against the U.S. dollar and the COVID-19 pandemic during 2020-2021. The ADF tests will be employed to determine the mixed order of integration among the variables. If some variables are stationary at I(1) and others at I(0), the ARDL model will be applied.

The study uses time series data covering the period 2007-2024. All series are based on data from the State Statistical Committee of the Republic of Azerbaijan (SSCRA, 2025). The dependent variable is real manufacturing output (Y_t), measured in million AZN at constant prices and expressed as ln Y_t ≡ LOGOUTPUT. The independent variables are as follows:

- Energy intensity (EI): EI_t = Energy use in processing (TOE)/actual volume of processed products (mln.AZN); ln EI_t ≡ LOGEI.
- Investment (INVEST): Investments in fixed capital in the processing industry (mln. AZN), expressed in real terms;lnINV_t ≡ LOGINVEST.
- Employment (EMP): Wage earners in the manufacturing industry; ln EMP_t ≡ LOGEMP.
- Price index (PPI): PPI by processing, base 2000 = 100; level is entered as (PPİ-annual$_t$/PPİ$_{2000}$)*100 ≡ PPI_t kimi daxil edilir.
- Event variables: DUMMY2 will be used for the COVID-19 shocks in 2020-2021, and DUMMY3 for the 2015 devaluation shock.

In the model, the lag structure is selected using the AIC, SBIC, and HQ information criteria. To address potential heteroskedasticity and low-order serial correlation, HAC/Newey-West robust standard errors are applied. For annual data, a bandwidth of 1 or 2 is used. This approach does not alter the coefficient estimates but ensures that the standard errors and P-values are reliable.

Model diagnostics and stability are verified through several tests:
- LM (Breusch-Godfrey) test for serial correlation,
- BPG (Breusch-Pagan-Godfrey) test for heteroskedasticity,
- Jarque-Bera test for residual normality,
- Ramsey RESET test for functional form specification,
- CUSUM and CUSUMSQ tests for parameter and variance stability.

For robustness checks, the ARDL model's sensitivity to lag selection is examined, and alternative dummy specifications are used—DUMMY-pulse and DUMMY-step for the 2015 devaluation shock, as well as dummy variables covering 2020-2021 or 2020-2022 for the COVID-19 shock. Bandwidth robustness is also tested by comparing HAC lag = 1 and lag = 2 configurations.

4. RESULTS

To evaluate the impact of resource-efficient technologies - including energy-saving technologies - on production volume in Azerbaijan's manufacturing sector, energy intensity (EI) is adopted as the main proxy. This indicator represents the ratio of total energy consumed in the manufacturing industry to the volume of output. Along with energy intensity, factors such as investment, the number of wage employees, and the producer price index (PPI) may also influence production volume. The dynamics of these indicators, or those related to them, for the period 2007-2024 are presented in Table 1.

Based on these indicators, the main variables to be included in the model are defined as follows:
- LOGOUTPUT (dependent variable) - the logarithm of real manufacturing output (in million AZN, constant prices);
- LOGEI - the logarithm of energy intensity in the manufacturing sector (tons of NET per million AZN of real output);
- LOGEMP - the logarithm of the number of wage employees in the manufacturing sector (persons);
- LOGINVEST - annual investments directed to the manufacturing sector (in million AZN, constant prices);
- PPP_2000 - producer price index in the industrial sector, with the base year 2000 = 100;
- DUMMY2 - reflects the continuing effects of the Azerbaijani manat devaluation of 2015 in subsequent years;
- DUMMY3 - represents the persistence of the COVID-19 pandemic during 2020-2021.

The descriptive statistics of the variables to be included in the model-including real manufacturing output (the dependent

Table 1: The dynamics of the variables included in the model (or related indicators)

Years	Output (real azn)	Energy consumption (min NET)	Investment (real azn)	Waged and salaried employment (thousand people)	PPI- (annual %)
2007	2365209620	1153,7	144195472	110,1	117,7
2008	2220929909	1352	153984474	105,5	123,4
2009	2337869298	825	171227498	95,1	80,6
2010	2124715917	678,4	188996994	84,8	130,5
2011	1773769246	814,8	235276100	93,1	133,5
2012	1867168007	1093,7	228676169	97,6	104,5
2013	2001824015	1097,8	245610204	102,2	96,1
2014	2346900392	1164,1	187679824	102,9	94,9
2015	3306100712	1179,7	202593274	94,4	69,4
2016	2928351730	1371,4	139614545	100,7	127,5
2017	2338805752	937,4	156970703	105,1	136,8
2018	1997822140	858,2	273346601	109,1	126,0
2019	2181599628	1280,5	456231013	121,9	103,2
2020	2914469358	1310,3	642136193	127,1	75,2
2021	2304196429	1375,3	292683854	127,2	169,6
2022	1425686934	1593,5	94608246,3	129,7	184,3
2023	1629730801	1600,8	81065649,5	129,3	89,0
2024	1726517952	1550,2	124622520	136,0	100,0

Source: SSCRA (2025)

Table 2: Descriptive statistics of the variables included in the model

Statistics	Logoutput	Dummy2	Dummy3	Logei	Logemp	Loginvest	PPI	Residuals
Mean	7,6795	0,1111	0,5556	6,2731	11,5951	5,2766	1,4443	0.000
Median	7,6967	0,0000	1,0000	6,1982	11,5646	5,2382	1,3061	-0.0005
Maximum	8,1035	1,0000	1,0000	7,0190	11,8204	6,4648	2,5422	0.0146
Minimum	7,2624	0,0000	0,0000	5,7661	11,3481	4,3953	0,7269	-0.0108
Standard deviation.	0,2129	0,3234	0,5113	0,3469	0,1380	0,5062	0,5689	0.0065
Skewness	0,0878	2,4749	-0,2236	0,7267	0,1400	0,5385	0,7087	0.5660
Kurtosis	2,7344	7,1250	1,0500	2,8385	1,9067	3,3217	2,4496	3.0375
Jarque-Bera	0,0761	31,1367	3,0019	1,6040	0,9553	0,9477	1,7339	0.8551
Probability	0,9627	0,0000	0,2229	0,4484	0,6202	0,6226	0,4202	0.6521
Sum	138,2315	2,0000	10,0000	112,9164	208,7110	94,9784	25,9982	-
Sum Sq. deviation	0,7706	1,7778	4,4444	2,0453	0,3237	4,3559	5,5029	-
Number of observations	18,0000	18,0000	18,0000	18,0000	18,0000	18,0000	18,0000	-

Calculated by authors uusing Eviews-12

variable) and the independent variables that may influence it-are presented in Table 2.

Based on the results of the descriptive statistics, all variables included in the model-except for DUMMY2-follow a normal distribution. Since dummy variables are categorical (binary), Jarque-Bera, skewness, and kurtosis tests are not applied to them; instead, it is sufficient to report their frequency and proportion. The DUMMY3 variable exhibits good variation, while DUMMY2, being sparse, should be interpreted with caution.

Among the continuous variables, PPI (sd = 0.569) and LOGINVEST (sd = 0.506) display the highest volatility, indicating that price and investment shocks are more cyclical compared to other indicators. LOGEI (sd = 0.347) shows moderate variability, whereas LOGOUTPUT (sd = 0.213) and LOGEMP (sd = 0.138) are relatively stable. This suggests that price (PPI) and investment dynamics fluctuate more sharply than production and employment levels.

In terms of distribution shape, LOGEI (+0.73) and PPI (+0.71) exhibit right skewness, indicating a tendency toward higher values. LOGEMP is nearly symmetric (+0.14), while LOGOUTPUT shows a very mild right skew (+0.09). The kurtosis values, ranging between 2 and 3.3, indicate no pronounced deviation from normality.

The Jarque-Bera test results confirm normal distribution for all continuous variables, as the null hypothesis (H_0: residuals are normally distributed) is not rejected at conventional significance levels:

- LOGOUTPUT (P = 0.963)
- LOGEI (P = 0.448)
- LOGEMP (P = 0.620)
- LOGINVEST (P = 0.623)
- PPI (P = 0.420).

Hence, the variables are consistent with the assumption of normality, making them suitable for residual-based diagnostic tests and further econometric modeling within the ARDL-ECM framework.

Thus, these indicators can be used for OLS, ARDL, and other models. In order to choose between the OLS and ARDL models, it is necessary to assess the stationarity of the variables.

The results of the ADF stationarity test for the variables included in the model are presented in Table 3. According to the ADF test results, LOGOUTPUT is marginally stationary at level in the intercept specification at the 10% significance level ($t = -2.9153$), but it is non-stationary in the trend specification. At the first difference, the variable shows strong stationarity in both specifications ($t = -4.3317$; -4.3122). Based on this evaluation, it can be concluded that the variable is practically stationary at order I(1).

LOGEI is non-stationary at level, but becomes stationary at the first difference in both the intercept and trend specifications at the 1-5% significance level ($t \approx -4.29 \ldots -4.42$). Therefore, LOGEI can be confirmed as stationary at order I(1). LOGEMP is not stationary at level (I[0]), but it becomes stationary at the first difference—at the 10% significance level in the intercept specification and at the 5% level in the trend specification ($t = -2.9311$; -4.4802). Hence, this variable is also considered I(1) stationary. The LOGINVEST variable is stationary at level in both the intercept and trend specifications at the 5% significance level ($t = -3.5677$; -4.0105). It also remains stationary at the first difference. Therefore, this variable is accepted as stationary at order I(0). The PPI variable is non-stationary at level but becomes stationary at the first difference in both specifications at the 1–5% significance level ($t \approx -4.18 \ldots -4.24$). Accordingly, PPI is considered I(1) stationary.

Thus, the variables exhibit mixed orders of integration: LOGINVEST is stationary at I(0), while the remaining key indicators are stationary at I(1)—at least under the trend specification. None of the variables are integrated of order I(2). This legitimizes the use of the ARDL-Bounds approach. The choice of deterministic terms (intercept vs. trend) should be confirmed through graphical inspection; including a trend appears justified for LOGOUTPUT and LOGEMP.

Thus, considering the stationarity properties of the variables to be included in the model, the ARDL model will be employed. Among the possible ARDL specifications, the ARDL (2, 1, 1, 0, 0, 1, 1) model is selected because it yields the smallest information criteria values: AIC = −5.6775, BIC = −5.0498, and HQ = −5.6454. The adjusted $R^2 = 0.9959$, indicating an excellent fit. This model achieves a balance between goodness of fit and parsimony, meaning that it combines the lowest information criteria values with the exclusion of unnecessary lags. In this specification, the dependent variable includes two lags, while only essential lags are retained for the independent variables. According to the parsimony principle, when alternative models have similar explanatory power, the model with the lowest AIC/BIC and fewer parameters is preferred. The chosen ARDL (2, 1, 1, 0, 0, 1, 1) model satisfies

Table 3: Stationarity of the variables included in the model

Variables	I (0)				I (1)			
	intercept		Intercept and trend		intercept		Intercept and trend	
	t-statistics	I (0)	t-statistics	I (0)	t-statistics	I (1)	t-statistics	I (1)
LOGOUTPUT	−2.9153*	±	−2.9182	−	−4.3317***	+	−4.3122**	+
LOGEI	−1.4904	−	−2.3557	−	−4.2853***	+	−4.4153**	+
LOGEMP	−0.2073	−	−2.8758	−	−2.9311*	±	−4.4802**	+
LOGINVEST	−3.5677**	+	−4.0105**	+	−4.2909***	+	−4.0012**	+
PPI	−0.5911	−	−2.5301	−	−4.2437***	+	−4.1804**	+

Calculated by authors usuing Eviews-12. *,**,*** are significance in 10%, 5% and 1%, respectively these criteria, providing an optimal balance between efficiency and explanatory strength.

Based on the results of the ARDL (2, 1, 1, 0, 0, 1, 1) model, a decrease in energy intensity (LOGEI)—that is, an improvement in energy efficiency—leads to an increase in manufacturing output both in the short run and the long run. Investment has a negative short-run effect but becomes positive after 1 year, while in the long run, its impact appears neutral. An increase in the number of wage employees in the manufacturing sector positively affects production volume in the short run. In contrast, a rise in the producer price index (PPI) exerts a negative effect on manufacturing output, reflecting the cost pressure transmitted through input prices. The character and magnitude of both short-run and long-run effects are summarized in Table 4.

In the long run, the elasticities of the variables have different signs: logEI (−0.25), loginvest (0.00), logemp (+1.05), logPPI (−0.38).

According to the results of the ARDL long-run relationship test (Bounds test), the F-statistic = 33.83, with k = 6 variables. For a finite sample (n ≈ 30-35), the upper bound I(1) critical values range from 3.96 to 4.15 at the 5% level and 5.33-5.69 at the 1% level. Since the F-statistic in our model greatly exceeds these critical values, the null hypothesis (H_0) of “no level relationship” is rejected, confirming the existence of cointegration among the variables in the model.

According to the results of the ECM (error-correction) model, the coefficient of CointEq(−1) = −1.845 (P < 0.001). This indicates that deviations from the long-run equilibrium are corrected at a rate exceeding 100% per year, meaning that the adjustment occurs within roughly half a year-a very rapid correction speed. In the short run, ΔLOGINVEST = −0.359 (P < 0.001) and ΔLOGPPI = −0.117 (P ≈ 0.006). This implies that an increase in investment generates a “setup delay” effect within the same year, while a producer price shock also exerts a negative short-run impact on manufacturing output. The model exhibits a high goodness of fit, with Adjusted $R^2 \approx 0.999$, indicating excellent explanatory power. The Durbin-Watson statistic (DW ≈ 2.31) suggests the absence of autocorrelation in the residuals. The LM test results also confirm no serial correlation up to two lags when considering the F-statistic version, which is more reliable for small samples: F-stat = 1.888, P = 0.458.

Table 4: Short-run effects (Δ form)

Variable	Ratio	P-value	Comment
ΔlogEI	−0.455	0.006	As energy intensity increases, the volume of manufacturing output decreases in the short run.
Δloginvest	−0.359	0.004	In the same year, a “setup delay” effect is observed: An increase in investment tends to slow down production in the short run.
Δloginvest (−1)	+0.365	0.002	In the following year, investment exerts a positive effect, as the capital becomes operational.
Δlogemp	+1.935	0.019	An increase in employment raises output in the short run.
ΔlogPPI	−0.117	0.154	In the current year, the price shock is weak or statistically insignificant.
ΔlogPPI (−1)	−0.584	0.065	With a 1-year lag, the negative effect becomes marginally significant.

Calculated by authors using Eviews-12

However, when interpreting the asymptotic χ^2 version ($Obs{\cdot}R^2$ = 12.65, P = 0.0018), the null hypothesis (H_0) of no autocorrelation would be rejected, indicating possible autocorrelation. In the test equation, DW ≈ 3.10 is obtained. Nevertheless, given that the sample size in our model is only 18 observations, the F-statistic version of the LM test is considered more appropriate. Therefore, we conclude that no autocorrelation up to two lags is present in the model.

In the long run, the elasticity for logEI is −0.246 (P ≈ 0.006), indicating that as energy efficiency improves (i.e., EI decreases), manufacturing output increases. For logEMP, the elasticity is +1.049 (P ≈ 0.005), meaning that a 1% increase in employment raises manufacturing output by approximately 1.0%, confirming a strong and positive long-run labor effect. The elasticity of loginvest is +0.003 (P = 0.8780), suggesting that the long-run impact of investment is neutral and statistically insignificant. Finally, the elasticity of logPPI is −0.380 (P ≈ 0.004), which implies that an increase in producer prices reduces manufacturing output in the long term, reflecting the persistent cost pressures on the sector.

According to the results of the Breusch-Pagan-Godfrey test, F = 0.612, P = 0.766 and $Obs{\cdot}R^2$ χ^2 = 11.36, P = 0.498. These results confirm that there is no heteroskedasticity in the presented model.

Based on the Ramsey RESET test results (t = −1.557, P = 0.260; F = 2.424, P = 0.260), the functional form of the model is appropriate, indicating that no nonlinear or omitted terms are present.

The results of the CUSUM and CUSUM of Squares (CUSUMSQ) tests are presented in Figures 1 and 2. The findings show that the cumulative sum of residuals remains within the 5% significance bands, indicating no evidence of structural breaks or parameter shifts in the model coefficients during the period covering

Figure 1: Result of CUSUM test of ARDL model

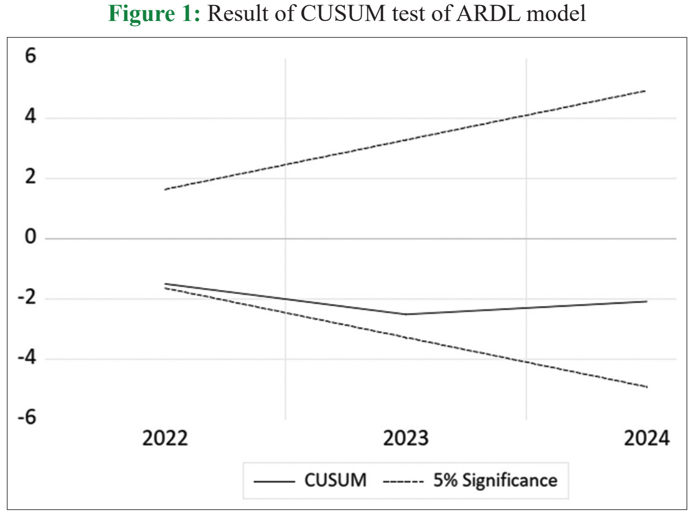
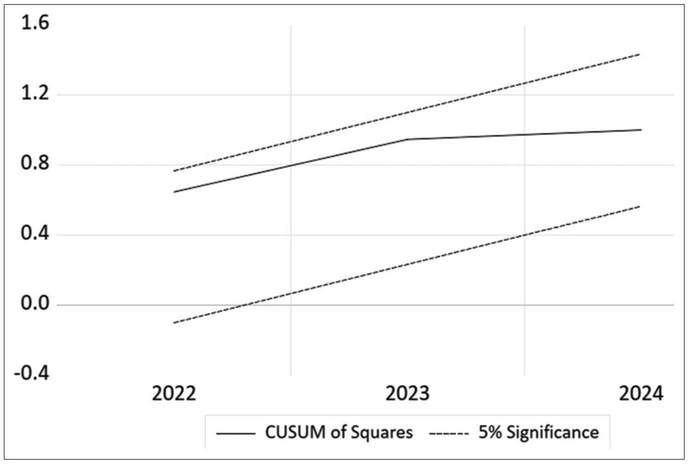


Figure 2: Result of CUSUMSQ test of ARDL model



2022-2024. Similarly, the cumulative sum of squared residuals also stays within the 5% critical bounds, confirming that there are no regime changes or pronounced instabilities in the residual variance.

Thus, the macro/meso-level assessment of the economic effects of energy-saving technologies in Azerbaijan's manufacturing sector for the period 2007-2024 made it possible—within the ARDL (ECM) framework—to estimate the elasticities of the key determinants.

Empirical results show that an increase in energy intensity reduces real manufacturing output (LOGOUTPUT) both in the short run and the long run. This confirms that the adoption of energy-efficient technologies and improvements in efficiency strengthen production performance. The employment elasticity is approximately unity, meaning that a 1% increase in the number of employees leads, on average, to a 1% rise in production volume.

The effect of investment is negative in the short run but positive with a 1-year lag, reflecting a "setup delay" effect. However, its net long-run impact appears close to neutral. Through the producer price channel, an increase in the PPI-especially with a lag-reduces output, indicating the sector's sensitivity to raw material and energy shocks.

The Bounds test fully confirms the existence of cointegration, while the error-correction term in the ECM is negative and significant, demonstrating that deviations from long-run equilibrium are corrected rapidly. The results of the normality, heteroskedasticity, RESET, and CUSUM/CUSUMSQ tests collectively support the soundness of the model specification.

Based on the obtained results, three policy-relevant conclusions stand out for Azerbaijan's manufacturing sector: First, stimulating energy-efficiency-oriented investments-along with concessional financing, guarantee mechanisms, and targeted subsidies-constitutes a key channel for ensuring sustained growth in production. It should be noted that the stable operation of the banking system in Azerbaijan in recent decades has facilitated access to finance (Gulaliyev et al., 2019). Second, the predictable and phased design of price signals, including energy tariff indices, can mitigate the transmission of cost shocks, thereby stabilizing production dynamics. Third, accelerating the diffusion of energy-saving technologies through technological imports and learning mechanisms-such as training programs, energy audits, and catalogues of best available technologies-enhances the competitiveness of the sector. For future research, expanding the analysis to a subsectoral panel and incorporating indicators such as the real effective exchange rate (REER) and export quality indices into the models could provide a deeper understanding of the issue.

5. DISCUSSION

Empirical results show that an increase in energy intensity (EI) weakens real manufacturing output both in the short and long term. Employment (EMP) increases production with "approximately unit" elasticity. Investment (INVEST) has a negative short-term effect due to "installation delays," a positive effect with a 1-year lag, and is nearly neutral in the long term. PPI shocks, especially with a lag, have a negative impact. The Bounds test confirms cointegration, the adjustment speed in the ECM is negative and significant, and inference conducted with HAC/Newey-West standard errors and stability tests (LM/BPG/RESET/JB/CUSUM/CUSUMSQ) supports the soundness of the specification. These findings are consistent with results obtained in existing studies. As efficiency increases (that is, EI decreases), unit costs decline, which in turn raises production volume. The impact of capital shows a negative profile in the short term and a positive one afterward. A delayed negative effect of cost and price shocks (PPI) is observed.

Based on the long-run elasticities, a 10% decrease in EI corresponds to an approximately +2.5% increase in production volume. A +5% rise in EMP results in an approximately +5% increase in output. Conversely, a +10% increase in PPI leads to an approximately −3.8% decline in the long run. These semi-elasticity relationships can be directly applied for policy simulation purposes.

The emergence of such effects can be explained through several transmission channels. The first is the efficiency channel: when EI decreases, the share of energy/raw material costs per unit declines, profit margins improve, and production expands. The second is the capital channel: The short-term negative effect of INVEST reflects installation and adaptation costs, while the delayed positive effect represents increased capacity and productivity. The third is the price shock channel: when PPI rises, especially in sectors with rigid contracts and price-sensitive demand, profit margins are compressed. This effect is often realized with a lag. These mechanisms may strengthen or weaken depending on the sectoral structure, including the share of imported intermediate goods and the substitution between labor and energy.

The model was selected within the ARDL-ECM framework. Since the ADF results indicate a mixture of I(0)/I(1) integration orders, the chosen method is appropriate. After the Bounds test confirms the existence of a level relationship, the ECM form provides clearer interpretability for economic analysis. The use of HAC standard errors ensures more reliable P-values in the presence of a small sample size (T) and potential low-order autocorrelation risks. The results of the LM, BPG, RESET, and JB tests are satisfactory, while the CUSUM and CUSUMSQ tests demonstrate that both the model parameters and variance are stable.

It should be noted that the obtained results may vary across subsectors of the manufacturing industry, such as textiles, apparel, and leather production. In processes with a higher energy share, the EI elasticity may be larger, whereas in segments where labor costs dominate, the EMP elasticity is likely to be higher. Moreover, import dependence and exchange rate volatility can amplify the impact through the PPI channel. Therefore, it is more appropriate to interpret these findings as average effects for the overall manufacturing sector, while in policy design, subsector-specific parameters should be used for more precise targeting.

The obtained results may have policy implications for Azerbaijan's manufacturing sector. Specifically, systematically reducing energy intensity (EI) through energy audits, concessional financing, guarantee mechanisms, and catalogues of best available technologies could increase manufacturing output in both the short and long run. Given the short-term negative and subsequent positive profile of investment effects, introducing grace periods and working capital bridge mechanisms during the installation phase is essential. This would help realize the delayed positive impact of investment (INVEST). Managing PPI pass-through through phased and transparent rules, particularly for energy and intermediate input prices, can reduce delayed output losses. The employment elasticity (EMP) underscores the significant role of workforce quantity and skill enhancement. Efficiency gains can be further strengthened through on-the-job training and technological specialization programs aimed at upgrading skills and improving labor productivity.

6. CONCLUSION

This study evaluates, within the ARDL-ECM framework, the dependence of the real manufacturing output volume in Azerbaijan's manufacturing industry on energy intensity (EI), investment in fixed capital (INVEST), employment level (EMP), and the producer price index (PPI) using annual official data for the period 2007-2024. The ADF results indicate a mixture of I(0) and I(1) variables, while the Bounds test confirms the existence of a long-run relationship. In the ECM, the error-correction coefficient is negative and statistically significant, confirming that deviations from equilibrium are corrected rapidly. The results show that as EI increases, the volume of manufacturing output decreases. EMP has a strong positive effect on output, while PPI shocks have a negative long-term impact. INVEST shows a negative short-term effect due to "installation delays," turns positive after 1 year, and appears nearly neutral in the long run. These findings highlight the delicate balance among the efficiency, capital formation, and cost/price channels.

The policy message is straightforward. A 10% reduction in EI translates, on average, into approximately a 2.5% increase in production potential. Enhancing employment and skills directly strengthens manufacturing output. If price shocks transmitted through the PPI channel are not managed gradually and transparently, their negative impact on production tends to intensify over time. This situation calls for a three-pillar policy package: First, provide concessional financing and guarantees for technologies aimed at improving efficiency. Second, introduce design measures that bridge the short-term negative phase of the investment effect, such as grace periods and working capital support. Third, adopt a tariff framework that mitigates the pass-through to PPI, ensuring smoother and more predictable cost adjustments.

It should be noted that EI is the ratio of the amount of energy used to the volume of output produced. The statistical quality of energy use and the choice of deflation may create some noise in the indicator. Although the conversion of the PPI index to the "2000 = 100" format has been done correctly, a sensitivity check using a broad GDP deflator could be useful. The small sample ($T \approx 18$) and annual frequency may "smooth out" some short-term dynamics. Results could be refined if semi-annual or even quarterly series become available. There may be a risk of endogeneity. Feedback may exist in indicators such as INVEST and EMP. In future research, an IV/2SLS stage could be applied using instruments such as world energy price shocks, international interest rates/WACC, or technological import lags. Heterogeneity may exist. Therefore, in subsectors, for example in sectors C13-C15, a PMG-ARDL panel combining long-term coefficients could increase external validity. It is also possible to take electricity consumption as a separate proxy for EI and compare the results obtained.

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